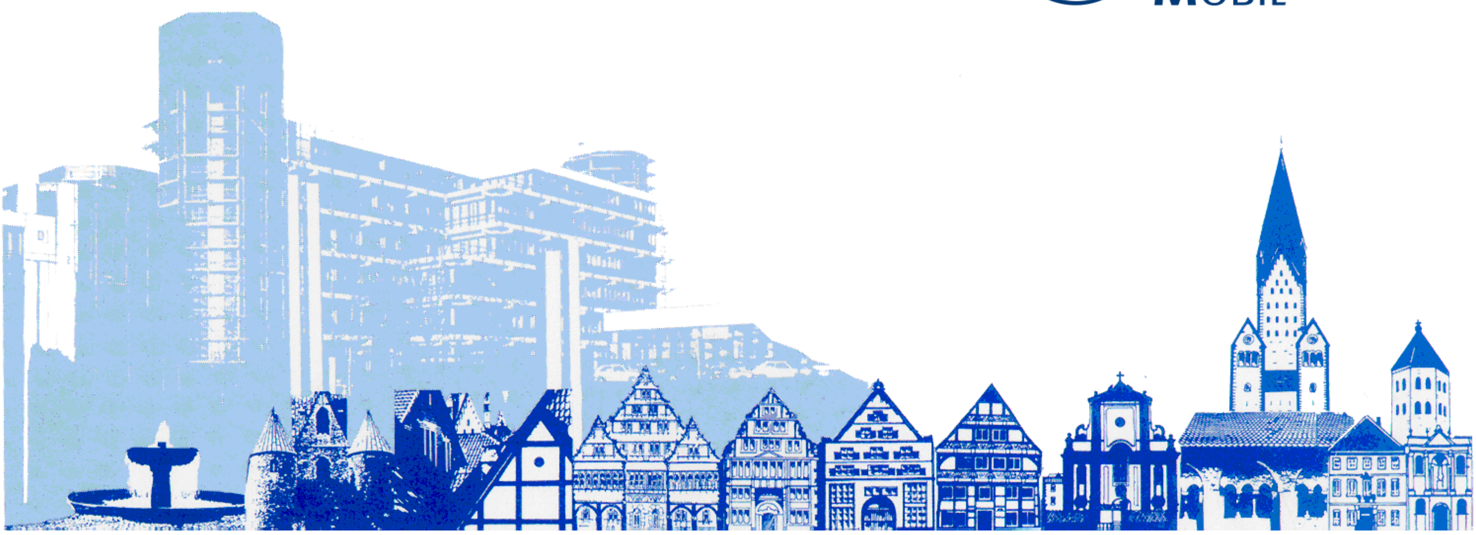
28. Workshop
Composite Forschung in der Mechanik

Schwerpunktthema:
Simulation im Leichtbau

09. und 10. Dezember 2015
Paderborn, Liborianum

Prof. Dr.-Ing. R. Mahnken, M.Sc.
LTM, Universität Paderborn

Prof. Dr.-Ing. T. Böhlke
ITM, Karlsruher Institut für Technologie (KIT)



28. Workshop Composite Forschung /

Simulation im Leichtbau

Vorwort

Die Arbeitsgemeinschaft Composite, das Internationale Graduiertenkolleg Integrierte Entwicklung kontinuierlich-diskontinuierlich lang-faserverstärkter Polymerstrukturen (DFG GRK 2078) und das NRW Fortschrittskolleg Leicht-Effizient-Mobil (LEM) laden herzlich zur Veranstaltung 28. Workshop "Composite Forschung in der Mechanik" ein. Mit der gemeinsamen Veranstaltung sollen Verfahren zur Werkstoff- und Prozessmodellierung verschiedener Materialklassen vergleichend diskutiert werden, wobei in diesem Jahr Anwendungen aus dem Leichtbau im Fokus stehen werden. Dazu sind wie in den Vorjahren Sektionen zu Kunststoffen aber auch zu metallischen Werkstoffen im Leichtbaubereich geplant. Die zweitägige Veranstaltung ist offen für Mitarbeiter von Industrieunternehmen, Forschungsinstituten und Universitäten.

In dem Workshop sollen aktuelle Fragestellungen zu Leichtbauwerkstoffen unter Berücksichtigung der Herstellungsprozesse, der Mikro- und Makroheterogenität der Werkstoffe und thermo-mechanischer Kopplungen interdisziplinär diskutiert werden. Charakterisierungs- und Simulationsmethoden zur Beschreibung, Bewertung und Optimierung von Bauteilzuständen in verketteten Fertigungsprozessen stehen ebenso im Vordergrund wie Aspekte der Fertigungstechnik und Qualitätssicherung.

Gemeinsame Workshops mit Wissenschaftlern verschiedener Fachrichtungen haben in der Vergangenheit in Paderborn zu spannenden und aufschlussreichen Diskussionen geführt, auf die wir uns auf Grund der interessanten eingereichten Beiträge auch in diesem Jahr freuen dürfen.

R. Mahnken, T. Böhlke

28. Workshop Composite Forschung

Ein gemeinsamer Workshop von:

1. *Arbeitsgemeinschaft Composite*
2. *Internationales Graduiertenkolleg Integrierte Entwicklung kontinuierlich-diskontinuierlich lang-faserverstärkter Polymerstrukturen (DFG GRK 2078)*
3. *NRW Fortschrittskollegs Leicht-Effizient-Mobil (LEM)*

Programm

Mittwoch, 09. Dezember 2015

9:00 Eröffnung

Experimentelle Methoden
Chairman: R. Mahnken

09:05-09:30 C. Zinn, Z. Wang, M.Schaper: Laser-based interface-structuring of in-strinsic manufactured hybrid structures

09:30-09:55 Mohammad Reza Khosravani, Kerstin Weinberg
Experimental Investigation on Strength of Composite Sandwich Plates and Joints

09:55-10:20 Peter Blaschke, C. Dreyer, R. Paeschke, M. Bauer, Y. Chowdhury, T. Schneider:
Experimetal vibroacoustic aproaches for validation of numerical simulations, Process control and quality assurance of composites

10:20-10:45 Kaffeepause

Mikromechanik in Kompositen
Chairman B. Eidel

10:45-11:10 Ch. Dammann, Rolf Mahnken:
Three Scale Modeling of Fibre-Reinforced Composites

11:10-11:35 Matti Schneider, Dennis Merkert, Matthias Kabel:
FFT-Based Finite Element solvers for Micromechanics

11:35-12:00 Marc Schöneich, S. Berbenni, F. Dinzart, H. Sabar, M. Strommel:
Micromechanical Modeling of Viscoelastic Three-Phase Polymer Composites Following a New Double Inclusion Approach

12:00-12:25 Bernhard Eidel:
Mechanical analysis of hollow-tube microlattices: towards ultralight composite materials

12:25 Gruppenfoto

12:35-13:45 Mittagessen

Wellen und Schädigung in faserverstärkten Kunststoffen
Chairman: Th. Böhlke

14:00-14:25 Nguyen Vu Ngoc, Rolf Lammering:
Numerical investigation of guided waves in layered composite structures

14:25-14:50 Christian Marotzke, T. Feldmann:
Fracture processes in composites under off axis loading

14:50-15:15 Jaan-Willem Simon, Bertram Stier, Brett Bedmarcyk, Stefanie Reese, Jacob Fish:
Modelling damage in undirectional and textile CFRP composites

15:10-15:45 Kaffeepause

Modellierung faserverstärkter Kunststoffe
Chairman: Ch. Marotzke

15:45-16:10 Matthias Kabel, Matti Schneider:
Finite Strain Computational Analysis of Stacked Unidirectional Prepreg Materials

16:10-16:35 Niels Goldberg, Jörn Ihlemann:
On the Fast and Accurate Stress Calculation for Distributed Fibre Directions

16:35-17:00 Robert Kießling, Jörn Ihlemann:
Large strain viscoplasticity for a undirectional fibre-matrix composite

17:00-17:25 Felix Heinrich, Rolf Lammering:
An Approach to Model Printed electronics on Fiber Reinforced Composites

18.30 Abendessen im Liborianum

Donnerstag, 10. Dezember 2015

Integrierte Entwicklung kontinuierlich-diskontinuierlich langfaserverstärkter Polymerstrukturen (DFG GRK 2078)

Chairman: M. Stommel

9.00-9.25 Pascal Pinter, Kay André Weidenmann:
Quantitative description of long fiber reinforced polymers based on µCT data

9.25-9.50 Róbert Bertóti, Thomas Böhlke:
Flow-induced anisotropic viscosity in short fiber reinforced polymers

9.50-10.15 Felix Schwab, D. Schneider, O. Tschukin, M. Selzer, B. Nestler:
A quantitative thermo-mechanical phase-field model for the solidification and curing of FRPs

10.15-10.45 Kaffeepause

Chairman: J. Ihlemann

10.45-11.10 Loredana Kehrer, V. Müller, T. Böhlke:
Thermoelastic homogenization of short fiber reinforced Polymers and Application to long fiber reinforced thermosets

11.10-11.35 Lukas Schulenberg, Thomas Seelig, Dong-Zhi Sun:
Modeling damage and failure of long fiber reinforced considering effects of microstructure

11.35-12.00 Markus Spadinger, Albert Albers:
Iterative coupling of flow simulation and topology optimization for long-fiber-reinforced plastics

12:00 Abschlussworte

12:15-13:15 Mittagessen

ABSTRACTS

FLOW-INDUCED ANISOTROPIC VISCOSITY IN SHORT FIBER REINFORCED COMPOSITES

R. Bertóti, T. Böhlke

**Chair for Continuum Mechanics, Institute of Engineering Mechanics,
Karlsruhe Institute of Technology (KIT), Germany**

Abstract

Within the research project “Integrated engineering of continuous-discontinuous long fiber reinforced polymer structures” (GRK 2078) the development of a material model for the flow process of discontinuous long-flexible fiber reinforced composites is required. To understand the motion and the overall effect of the mentioned fibers, first the flow of short-rigid fiber reinforced composites is investigated.

The motion of a short-rigid fiber immersed in a Navier-Stokes flow is described by Jeffery’s equation [1] and by its improved variants. The orientation state of the fibers and its evolution is depicted by orientation vectors and orientation tensors [2].

Based on the actual orientation state of the fibers, an anisotropic effective viscosity tensor is calculated by a mean field model.

The effective anisotropic viscosity tensor is used to calculate the Cauchy stress in the fluid.

Four flow cases are investigated: simple shear, isochoric elongation, isochoric compression and plain strain. A comparison between numerical results and literature values [3] is discussed.

Literature

[1] Jeffery, G. B, “The Motion of Ellipsoidal Particles Immersed in a Viscous Fluid”, Proceedings of the Royal Society of London, Series A 102(715), 161-179, 1922

[2] Advani, S. G, and Tucker III, C.L, “The Use of Tensors to Describe and Predict Fiber Orientation in Short Fiber Composites”, Journal of Rheology, 31(8), 751-784, 1987

[3] Latz, A, Strautins, U, and Niedziela, D, “Comparative numerical study of two concentrated fiber suspension models”, Journal of Non-Newtonian fluid mechanics, 165(13-14), 764-781, 2010

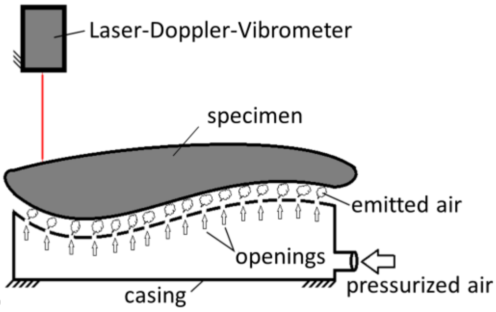
EXPERIMENTAL VIBROACOUSTIC APROACHES FOR VALIDATION OF NUMERICAL SIMULATIONS, PROCESS CONTROL AND QUALITY ASSURANCE OF COMPOSITES

P. Blaschke[1], C. Dreyer[2], R. Paeschke[1], M. Bauer[2], Y.Chowdhury[3], T. Schneider[1]

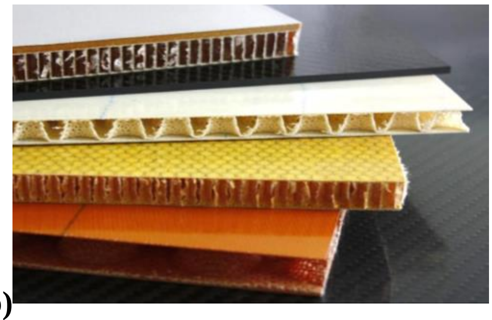
[1]Machine Dynamics and Acoustics, University of Applied Sciences Wildau, Hochschulring 1, 15745 Wildau, Germany
[2]Fraunhofer Research Institution for Polymeric Materials and Composites PYCO, Kantstrasse 55, 14513 Teltow, Germany
[3]InnoMat GmbH, Kantstrasse 55, 14513 Teltow, Germany

Abstract

Experimental data is a key element for validation and verification of numerical simulations. Optimization, process control, quality assurance, and damage analysis of light weight structures require experiments which take material properties and geometrical design into account. This article presents new vibroacoustic approaches for composite testing based on modal analysis, i.e. analysis of eigenfrequencies, mode shapes and modal damping [1]. Figure 1a exemplifies the setup of the *Levitation and Excitation* (LEx) method [2]. This method is nondestructive, adaptable, and completely contactless in terms of suspension, excitation, and measurement.



(a)



(b)

Fig. 1: (a) Experimental setup of the Levitation and Excitation (LEx) method. (b) Composite specimen developed amongst others at PYCO.

This contribution introduces the measurement concepts developed in our collaboration including enhanced model updating techniques, presents preliminary results, and discusses possibilities and limits.

Literature

[1] Blaschke, P., and Schneider, T., “Reactionless Test to Identify Dynamic Young's Modulus and Damping of Isotropic Plastic Materials”, IMAC-XXXI Conference and Exposition on Structural Dynamics, Los Angeles, Ca, Feb. 2013

[2] Blaschke, P., Paeschke, R., and Schneider, T., “Vorrichtung und Verfahren zur Schwingungsprüfung von Objekten,” German Patent Application DE 10 2015 106 603.3, Apr. 2015

A THREE-SCALE FRAMEWORK FOR FIBRE-REINFORCED-POLYMER CURING COUPLED TO VISCO-ELASTICITY

C. Dammann, R. Mahnken

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Abstract

Our work presents a three-scale model for temperature-dependent visco-elastic effects accompanied by curing, which are important phenomena in a resin transfer molding (RTM) process. The effective bulk quantities in dependence on the degree of cure are obtained by homogenization for a representative unit cell (micro-RVE) on the heterogeneous microscale. To this end, an analytic solution is derived by extension of the composite spheres model [1]. Voigt and Reuss bounds resulting from the assumption of a homogeneous matrix poposed in [2] are compared to the effective quantities. During curing and subsequent mechanical loading, the periodic mesostructure defined by a visco-elastic polymeric matrix and linear-thermo-elastic carbon fibres is taken into account as a representative unit cell (meso-RVE) subjected to thermo-mechanical loading on the mesoscale. Homogenization of the mesoscale by volume averaging is applied to obtain the effective properties for the fully cured composite on the macroscale, e.g. the macroscopic anisotropic thermal expansion coefficient in [3]. In the examples we use DSC-measurements for parameter identification and simulate the curing process as well as mechanical loading of the cured part with the finite-element-method.

Literature

[1] Christensen, R. M, “Mechanics of Composite Materials”, John Wiley and Sons, New York, 1979.

[2] Mahnken, R., “Thermodynamic consistent modeling of polymer curing coupled to visco-elasticity at large strains”, International Journal of Solids and Structures, no. 50(13), 2003-2021, 2013

[2] Dammann, C., “Mesoscopic modeling of the RTM process for homogenization”, Coupled Problems in Science and Engineering, no. VI, 713-724, 2015

MECHANICAL ANALYSIS OF HOLLOW-TUBE MICROLATTICES – TOWARDS ULTRALIGHT COMPOSITE MATERIALS

B. Eidel

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Abstract

Recent experimental work on the fabrication and mechanical testing of hollow-tutmbe microlattices [1,2] has attracted considerable interest in industry and academia. This is due to several outstanding mechanical properties of these structural materials such as being (i) ultralight, (ii) very tight, (iii) showing considerable energy dissipation and, depending on the geometry, (iv) almost full recovery of the initial lattice shape even after compressions of 50%. Moreover, thin-walled microlattices are a novel class of cellular materials, which (v) allow by their periodic, quasi-deterministic composition for a highly effective topology optimization in contrast to foams, which are stochastic in nature.

The objective of the present work is a thorough understanding of the mechanics of microlattices made of thin-walled tubes by finite element modeling and simulation. For that aim, we establish a thin-shell model along with an isotropic material law of elasto-plasticity. Our results indicate, that already the reduced unit-cell model replacing the total lattice captures significant characteristics of experiments surprisingly well and reveals the intimate interplay of geometrical features such as buckling/wrinkling/folding with the inelasticity of deformations. We show, that the simulation results for various unit cells follow universal scaling laws for effective stiffness as well as strength as a function of density (Ashby-diagrams) in very good agreement with the experiments. We propose a lattice type made of octet unit cells which shows an increase of stiffness and strength by almost two orders of magnitude compared to the original bcc lattice of the experiments in [1,2].

Literature

[1] Schaedler, T.A., Jacobsen, A.J., Torrents, A., Sorensen, A.E., Lian, J., Greer, J., Valdevit, L., and Carter, W.B., "Ultralight metallic microlattices", *Science,* **334**, 962-965 (2011).

[2] Torrents, A., Schaedler, T.A., Jacobsen, A.J., Carter, W.B., Valdevit, L., „Characterization of nickel-based microlattice materials with structural hierarchy from the nanometer to the millimeter scale", *Acta Mater.,* **60**, 3511-3522 (2012).

ON THE FAST AND ACCURATE STRESS CALCULATION FOR DISTRIBUTED FIBRE DIRECTIONS

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Abstract

The main contribution of this work lies in the introduction of an alternative approach for the fast and accurate modelling of distributed fibre directions. This method employs a quadrature rule, which uses the sample vectors of the fibre distribution function as quadrature points. Thus, the computation time is drastically reduced compared to the classic Angular Integration (AI) method whereas the accuracy remains the same. As the sample vectors are the representing directions of the fibre distribution, the new approach is named accordingly, i.e. Representing Directions (RD).

By means of two example deformations with two different free energy densities the stresses at the end of the deformations are compared for AI, RD and GST method. The latter poses an even faster alternative to the RD method as it requires only a one-time integration before the deformation. Fig. 1 demonstrates the new method's accuracy compared to the AI method for a simple shear deformation. The grey triangle depicts the set of all unique fibre distributions. The results of the GST method not only differ quantitatively but also qualitatively. It is worth mentioning, that the RD method is not restricted to rotationally symmetric distributions.

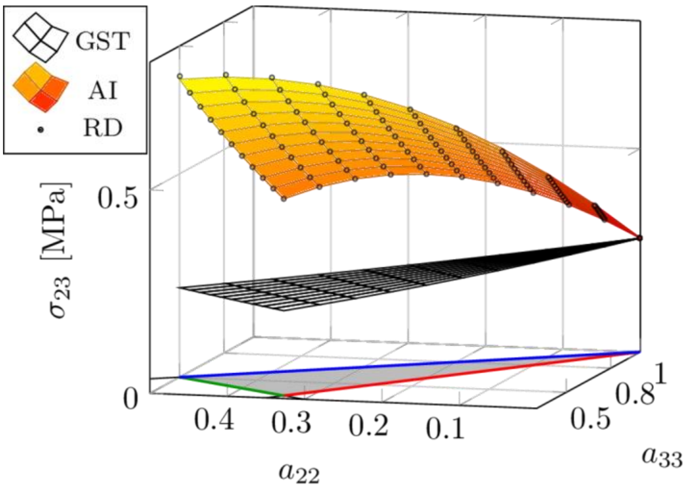

Fig. 1: Shear stress over complete range of fibre distributions computed with different methods.

AN APPROACH TO MODEL PRINTED ELECTRONICS ON FIBER REINFORCED COMPOSITES

Felix Heinrich, Rolf Lammering

Institute of Mechanics,
Helmut-Schmidt-University / University of the Federal Armed Forces Hamburg

Abstract

Printed conductive paths on fiber reinforced composites (FRC) (see Figure 1) promi: the employment of entire printed sensor networks. In the future, these printed sens networks could be integrated within load-carrying structures to monitor the structure state of health and to detect damages.

As the integrated sensors are foreign objects in the FRC structure, it must be ensur that they do not initiate damage formation. For that reason, the mechanical behavior printed metals on FRC has to be investigated. In particular, the interface between tl printed electronics and the composite surface shall be examined.

A simple numerical approach is being presented that describes the metal-FRC interfa solely in terms of a maximum normal- and a maximum shear stress. The thickness of tl printed electronics is typically of order O(3) smaller than the thickness of the FF structures. Hence, the thickness of the printed electronics is neglected in a first step. needed, the numerical approach can be extended in a second step to model the senso with a finite thickness. Advantages and disadvantages of this approach are discussed

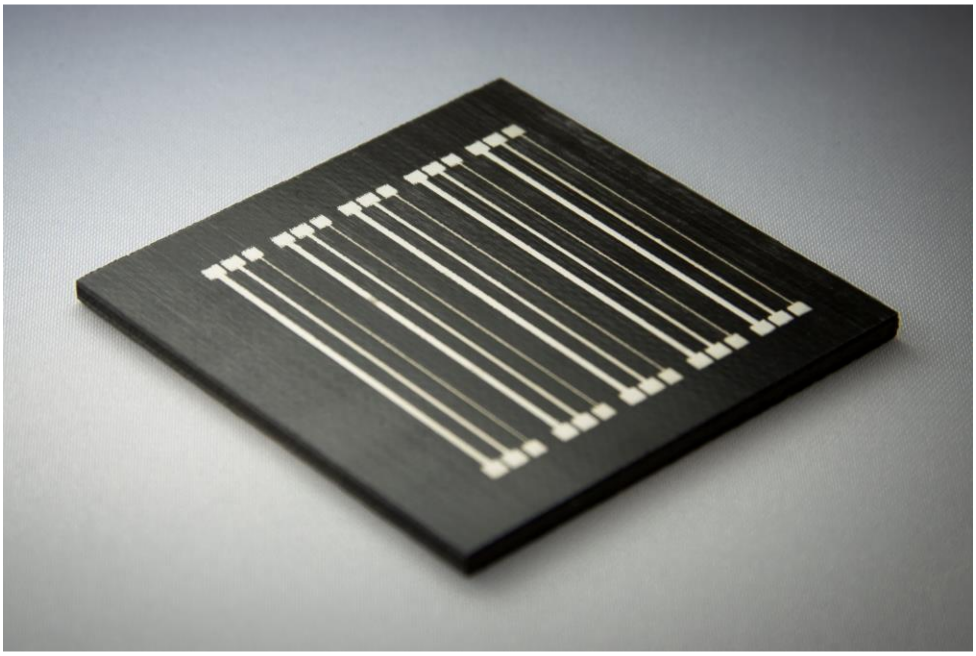

Figure 1: Printed electronics on a fiber reinforced composite

FINITE STRAIN COMPUTATIONAL ANALYSIS OF STACKED UNIDIRECTIONAL PREPREG MATERIALS

Matthias Kabel, Matti Schneider

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Abstract

Laminates of continuous fiber reinforced plastics exhibit a complex elastic and inelastic behavior. For instance, subjected to tensile loading, fibers partially reorient in loading direction, significantly enhancing the material's stiffness and strength. To take full advantage of the material's lightweight capabilities these phenomena need to be taken into account. Unfortunately, the classical theory of laminates fails to predict these effects accurately. In contrast, full-field simulations for RVEs of the microstructure (see Fig. 1) enable exploiting the material's entire lightweight potential, avoiding overly large safety factors.

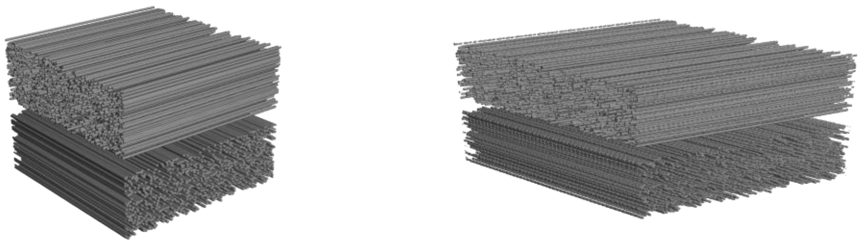

Fig. 1 Fiber reorientation of a 0°/90°-Laminate for a tensile test in 45° direction

In our talk we will discuss an efficient and fast version of the FFT-based method of Moulinec and Suquet [3], introduced in Kabel et al. [1]. To validate computational results with tensile tests and arbitrary angles of applied loading, a Lippmann-Schwinger formulation for the unit cell problem of periodic homogenization of elasticity at finite strains incorporating arbitrary mixed boundary conditions is proposed [2]. Furthermore, we recommend an alternative discretization technique [4], bypassing convergence problems of Moulinec-Suquet's [3] method in the presence of defects. Thus, imperfections introduced in the manufacturing process and degradation under external load can be incorporated into our simulations.

Literatur

[1] Kabel, M., T. Böhlke and M. Schneider. „Efficient fixed point and Newton-Krylov solvers for FFT-based homogenization of elasticity at large deformations”, Computational Mechanics 54 (6), 1497–1514, 2014

[2] Kabel M., S. Fliegener and M. Schneider. „Mixed boundary conditions for FFT-based homogenization at finite strains”, Computational Mechanics, Submitted

[3] Moulinec, H., and P. Suquet. “A numerical method for computing the overall response of nonlinear composites with complex microstructure”, Computer Methods in Applied Mechanics and Engineering, 157(1-2), 69–94, 1998

[4] Schneider, M., F. Ospald and M. Kabel. “Computational homogenization of elasticity on a staggered grid”, Submitted

THERMOELASTIC HOMOGENIZATION OF SHORT FIBER REINFORCED POLYMERS AND APPLICATION TO LONG FIBER REINFORCED THERMOSETS

L. Kehrer, V. Müller, T. Böhlke
Chair for Continuum Mechanics, Institute of Engineering Mechanics, Karlsruhe Institute of Technology (KIT), Germany

Abstract

Within the research project "Integrated engineering of continuous-discontinuous long fiber reinforced polymer structures" (GRK 2078), interdisciplinary research work focuses on a new class of lightweight materials. This class of materials consists of a combination of continuous and discontinuous fiber reinforced thermoset-based materials, aiming at, e.g., good formability, high stiffness and strength. In order to gain a basic understanding of the material and structural behavior, integrated engineering strategies need to be developed, based on the fields of material characterization, simulation techniques, process and structure optimization as well as product development. The material considered in this work is manufactured by sheet molding compound (SMC). The matrix material is based on a Vinylester resin and reinforced by discontinuous long glass fibers with a fiber volume fraction of 23%. The microstructure of the composite contains curved and randomly orientated long fibers. To gain a valid mechanical understanding of the composite, the microstructure is modeled in a first approach by means of short fibers. Regarding a short fiber reinforced composite, injection molded PPGF30, i.e. Polypropylene reinforced with 30wt.% of short glass fibers, is considered. Due to the injection molding process, an anisotropic material behavior of the composite material is induced. This is caused by a local fiber orientation distribution, spatial distribution and fiber length distribution, leading to an inhomogeneous microstructure. Furthermore, the material properties of the composite depend on the temperature and the strain rate. In order to model the effective thermoelastic material behavior on the mesoscale, a modified homogenization method is used. The discrete orientation and the length distribution of the fibers are obtained by computed tomography scans [1]. Based on the estimation of effective stiffness proposed by Willis in [2], the reference stiffness is chosen variably in the range between matrix and fiber stiffness. The influence of the variable reference stiffness on the approximation of the effective material parameters as well as on the level of the stiffnesses is investigated. Moreover, the corresponding impact on the anisotropy of the effective stiffness is determined. Further, simulation results are compared to experimental data, obtained by dynamic mechanical analysis performed with the GABO Eplexor 500 N. The application of homogenization approaches developed for short fiber reinforced composites in the context of long fiber reinforced composites is discussed. The generalization of the method is based on considering the orientation distribution of the fiber tangential directions of the long fibers as approximation for the microstructure of the composite.

Literatur

[1] Müller, V., Brylka, B., Dillenberger, F., Glöckner, R., Kolling, S., Böhlke, T., "Homogenization of elastic properties of short-fiber reinforced composites based on measured microstructure data", Journal of Composite Materials, 1-16, 2015

[2] Willis, J.R., "Variational and related methods for the overall properties of composites", Advances in Applied Mechanics, 21, 1981

EXPERIMENTAL INVESTIGATION ON STRENGTH OF COMPOSITE SANDWICH PLATES AND JOINTS

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Abstract

Currently there is increasing interest of using composite sandwich parts in aviation industry. Unique stiffness to weight ratio, corrosion resistance and high strength and durability make them very attractive for airline industry. However**,** a shortage of technical and up to date knowledge about the dynamical behavior of composite sandwich parts and joints leads to high cost for replacing damaged parts in aircraft interior. In this project, honeycomb sandwich plates and joints specimens are studied which are used in aircraft interior parts. Series of tensile tests are performed on sandwich T-joint specimens at different rate of loading to study their static and dynamic response. Accelerated ageing tests on composite structures, are performed by some researchers [1,2]. In this project, to simulate real usage condition of the honeycomb sandwich T-joint, a thermal ageing process is considered and behaviors of the specimens under different conditions are investigated. For the accelerated aging process, different temperatures are selected with various exposure times. The stability and strength of aged and non-aged adhesively sandwich joints are compared. In parallel to the experimental part, modelling and simulation analysis were carried out. The obtained results could provide time and cost saving knowledge for future material design, computational models and load carrying capabilities of honeycomb sandwich plates and joints under dynamic loading condition. It is planned to study dynamic behavior and properties of the plate specimens by Split-Hopkinson Bar test (SHB) which is most common technique to investigate the dynamic properties of wide range of materials in different strain rates. It should be noted that, the sandwich specimens are made by Diehl Service Modules GmbH which is a certified company specializing in the design, production and maintenance of aircraft interiors.

Literature

[1] Zinno, A. Prota, A. Di Maio, E. Bakis, C.E. “Experimental characterization of phenolic-impregnated honeycomb sandwich structures for transportation vehicles”. Composite Structures, 2011, 93: 2910-2924

[2] Boualem, N. and Sereir, Z. “Accelerated aging of unidirectional hybrid composites under the long-term elevated temperature and moisture concentration”. Theoretical and Applied Fracture Mechanics, 2011, 55: 68-75

LARGE STRAIN VISCOPLASTICITY FOR A UNIDIRECTIONAL FIBRE-MATRIX COMPOSITE

R. Kießling, J. Ihlemann

Professorship of Solid Mechanics, Faculty of Mechanical Engineering, Technische Universität Chemnitz, Germany

Abstract

The crash analysis of intrinsic hybrid composite structures requires a precise mechanical description and characterisation of the deployed components such as a polymer matrix with unidirectional fibre-reinforcement. In this contribution, the development of a transversely isotropic viscoplastic material model at large strains is presented.

Starting from a phenomenological description of the unreinforced polymer, a rheological model of the matrix material is deduced. The corresponding isotropic viscoplastic material model is formulated applying an innovative concept by Ihlemann [1]. As demonstrated by Kießling et al. [2], this concept enables material modelling at large strains based on the direct connection of rheological elements. The polymer's material model is utilised in a FEM simulation of a representative volume element (RVE) consisting of a polymer matrix and a fibre constituent. Based on the results of typical deformation tests, a homogenised viscoplastic material model of the unidirectional fibre-matrix composite is evolved by an anisotropic extension of the matrix material model.

Finally, a simulative crash analysis of a demonstrator utilising the developed transversal-isotropic viscoplastic material model is performed.

References

[1] Ihlemann J., "Beobachterkonzepte und Darstellungsformen der nichtlinearen Kontinuumsmechanik", VDI-Verlag, 2014.

[2] Kießling, R., Landgraf, R. and Ihlemann J., "Direct connection of rheological elements at large strains: Application to multiplicative viscoplasticity", Proceedings in Applied Mathematics and Mechanics, 15, p. 313-314.

FRACTURE PROCESSES IN COMPOSITES UNDER OFF AXIS LOADING

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Abstract

Composites are very sensible against the loading angle because of their highly anisotrop mechanical properties. Especially the resistance against failure strongly depends on the ang between the loading axis and the fiber direction since the fracture resistance in fiber direction several times higher than transverse to the fibers. In unidirectional plies even small angles le to a significant reduction of the strength. The failure processes taking place in unidirection plies under off-axis loading are the key factors dominating the failure of laminates.

Off-axis tests offer the chance to observe the failure processes taking place in unidirection plies. Two highly different principal failure modes occur in unidirectional plies exposed to o axis loading depending on the length to width ratio of the specimens as well as on the off-a angle, this is, inter fiber failure and fiber breakage. Inter fiber failure with almost no fib breakage occurs if a fracture surface can develop from one longitudinal edge of the specim to the other, that is, without touching the clamped regions on either side. If, however, sufficient number of fibers are clamped on both ends fiber breakage necessarily has to occ accompanied with a more or less intensive inter fiber failure. With growing fraction of fibe matching the clamped zones the damage of the specimen increases. Since the question inter fiber failure or fiber fracture is no intrinsic material property but depends on the specim geometry the data of different failure modes must not put together (fig. 1).

A number of off-axis tests was performed under quasistatic loading for a carbon fiber rei forced epoxy resin with a fiber volume fraction of 55%. The two different failure modes a discriminated. It is shown that a strong decrease of the failure load occurs even for small axis angles in the fiber fracture mode. For the 0° specimens only minor load drops a observable before final failure (fig. 2). The splitting of the specimens occurs during final failu For small off axis angles several load drops occur before final failure. It is shown that these a related to initial inter fiber failure in the vicinity of the longitudinal edges.

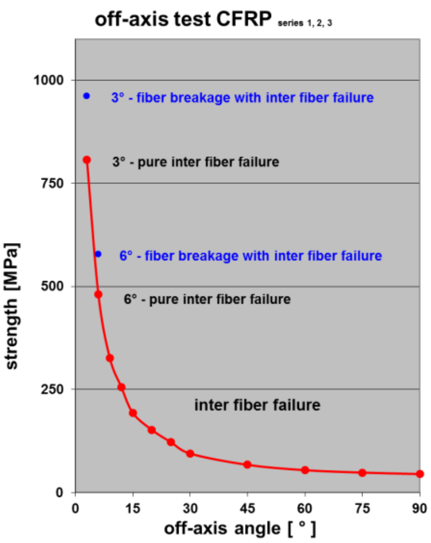

Fig. 1 strength vs off axis angle of unidirectional carbon fiber ply

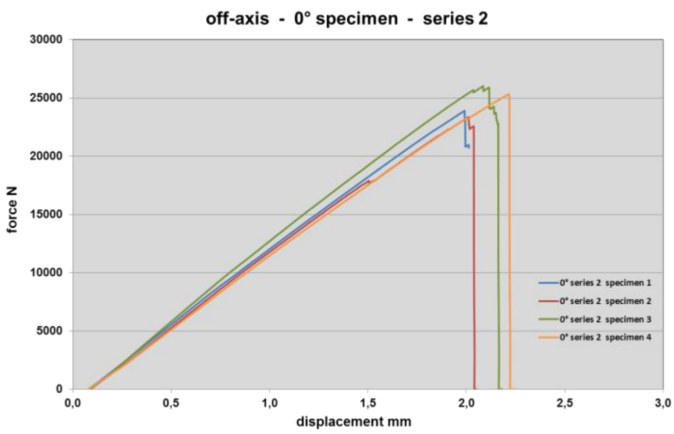

Fig. 2 force/displacement curve of 0° off axis specimen

QUANTITATIVE DESCRIPTION OF LONG FIBER REINFORCED POLYMERS BASED ON µCT DATA

Pascal Pinter, Benjamin Bertram, Kay André Weidenmann

Karlsruhe Institute of Technology (KIT), Institute for Applied Materials (IAM)

Abstract

Describing fiber reinforced polymers microstructure by non-destructive methods is a relevant topic material science serving both for validation of mechanical models and for microstructure characterizati itself. Different characteristics from µCT-images can be used for that purpose. Common descriptors a e.g. orientation tensors, local curvature or volumetric fraction of one phase in another.

For the evaluation of such descriptors, the open source toolkit "Composight" was developed at IAM. It based on the Insight Toolkit (ITK) [1] and the Visualization Toolkit (VTK) [2] and offers many use operators for post processing of CT-datasets from segmentation to data extraction. It contains se developed as well as reimplemented algorithms and uses some additional open-source projects li elastix [3,4] and Advanced Normalization Tools (ANTs) [5]. Additionally, this toolkit offers the opportun to reduce the amount of working memory needed by partitioning the images automatically in subregio that are processed subsequently.

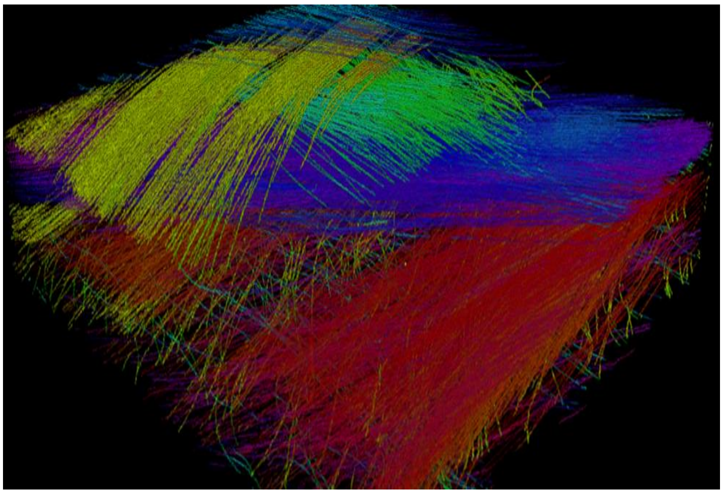

Fig. 1 Visualization of fiber orientation in glass fiber reinforced SMC

In the present contribution, common methods for orientation and curvature analysis are compared concerning accuracy and efficiency. This is done on real images (Fig. 1) as well as on artificial images with known curvature and orientation of microstructural features to calculate an absolute error. With respect to the results of the presented study, the algorithms used and parameters selected are evaluated.

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FFT-BASED FINITE ELEMENT SOLVERS FOR MICROMECHANICS

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Abstract

For computing the effective elastic and inelastic properties of composite materials the FFT-based homogenization technique of Moulinec-Suquet [1] has recently received widespread attention. Exploiting the benefits of a regular grid the method enables incorporating CT image directly, and handles a large number of degrees of freedom with a small memory footprint.

Recently, approaches have been introduced to alleviate the shortcomings of Moulinec-Suquet's method, e.g. [2], where convergence for materials including defects like pores or damaged regions is ensured.

In this talk we extend the FFT-based framework to incorporate finite element methods on a regular grid, with the following consequences.

1. Large scale finite element systems can be handled with modest hardware requirements (approx. of the same size as the original FFT-based homogenization systems).
2. The FE solutions are devoid of local defects like oscillations and checkerboard patterns. Moreover, convergence for infinite contrast is ensured.
3. Fixing the geometry and the solver assessing the respective benefits and drawbacks of FFT-, finite difference and FE discretizations is possible.

We demonstrate the potential of our findings with elastoplastic simulations on a large LFT sample with 172×10^6 displacement unknowns.

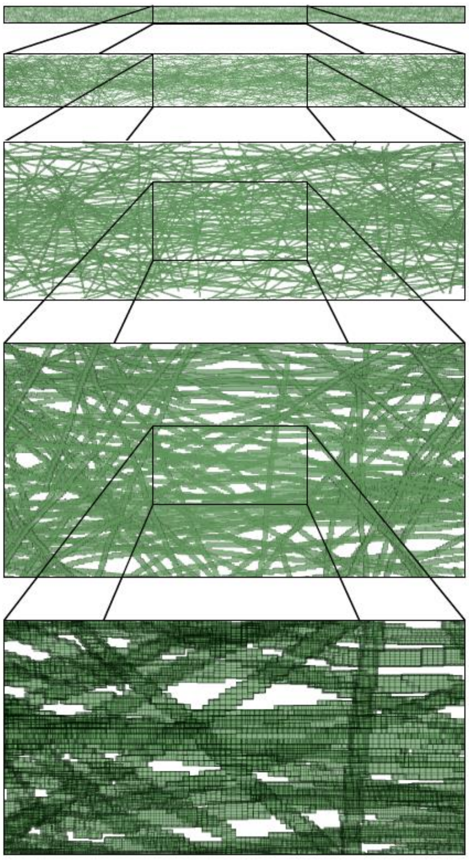

Fig. 1 LFT sample, multiply zoomed

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MICROMECHANICAL MODELING OF VISCOELASTIC THREE-PHASE POLYMER COMPOSITES FOLLOWING A NEW DOUBLE INCLUSION APPROACH

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Abstract

The realistic prediction of the mechanical material behavior in multi-phase composit by micromechanical approaches is essential for expedient FE simulations in industri applications. In recent literature, it has been discussed that composites consisting of stiff inclusion phase embedded in a soft polymer matrix show the presence of a thi phase [1]. This interphase is defined as the intersection region between the matrix a the inclusion and shows modified bulk material properties [2]. Especially for F simulations of composites and the validation of multi-scale material modeli approaches, this third phase has to be included in the micromechanical modeli procedure.

This contribution is focused on the development of a micromechanical moc describing the material behavior of a linear elastic spherical inclusion surrounded by viscoelastic interphase, embedded in a viscoelastic matrix. Thereby, the original doub inclusion model by Hori and Nemat-Nasser [3] is extended to the application on thre phase composites using a two-step homogenization scheme based on Mori a Tanaka [4]. The developed model is compared to other existing approaches and fina evaluated with experimental dynamic mechanical analysis data.

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MODELING DAMAGE AND FAILURE OF LONG FIBER REINFORCED THERMOPLASTICS CONSIDERING EFFECTS OF MICROSTRUCTURE

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Abstract

Long fiber reinforced thermoplastics (LFT) replace more and more convention materials like non-reinforced plastics or even aluminum and steel. Because of its hi strength and failure strain LFT has a high priority in industrial applications. Therefo predicting a precise material behavior of LFT in numerical simulations is tru necessary for component engineering and design. When crash loading comes in focus, it is even more important to correctly predict damage and failure. This can be challenging task when process induced local varying fiber length, fiber orientations ar fiber volume fractions need to be taken into account, e.g. from mold filling simulations

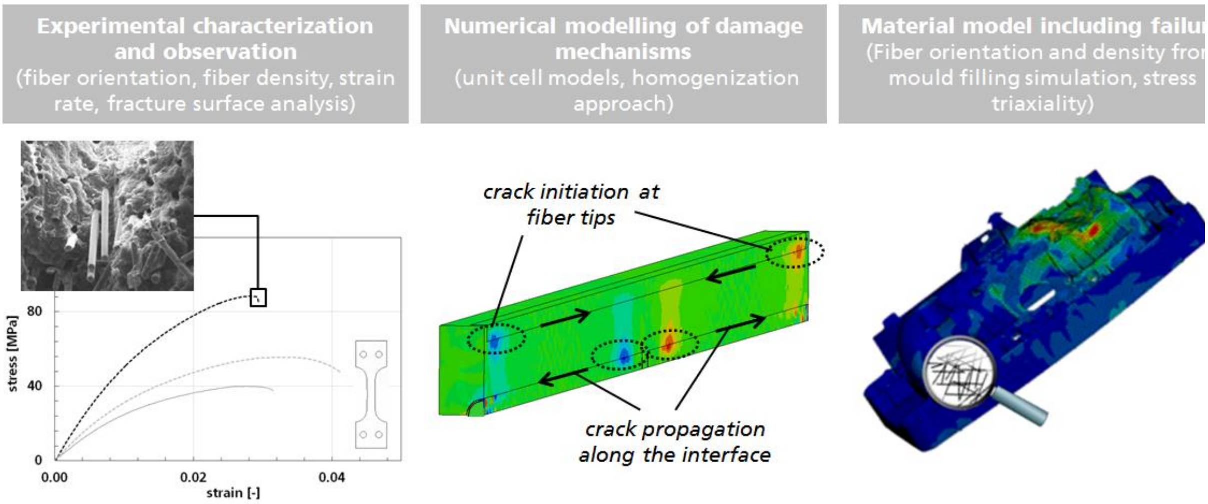

Fig. 1 Different steps of development for a complex material characterization of LFT respecting damage and failure on a micro-scale and macro-scale level.

To describe the macroscopic behavior a realistic understanding of micromechanical mechanisms is important. In this study, an injection molded LFT has been analyzed experimentally for different stress triaxialilities showing significant variations of measured strength and failure strains. An incremental homogenization approach belonging to the class of mean-field-methods using a modified Eshelby-Tensor [1] describing partially debonded fibers is evaluated for an appropriate description of damage. Focusing on the fiber-matrix Interface where damage initiation occurs, this approach is also compared to numerical unit cell calculations of predetermined fiber constellations and load cases.

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A QUANTITATIVE THERMO-MECHANICAL PHASE-FIELD MODEL FOR THE SOLIDIFICATION AND CURING OF FRPs

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Abstract

The increasing use of fibre-reinforced polymers (FRP) demands for computational models to gain a better understanding of this material class. One of the research fields in this topic is the formation of production induced eigenstrains/-stresses occuring due to different material properties of the fibre and the matrix and as a result of the solidification and curing process of the FRP. Since our aim is to model these processes via phase transitions, we choose a thermo-mechanical phase-field model [1, 2, 3] included in the PACE3D software package.
As a first step we show a thermo-mechanical model with quantitative characteristics, which is capable of mapping typical temperature changes during the solidification and curing process in presence of the phase-field diffuse interface. For the mechanical part the recently published work of [2] is chosen, a model based on force balance and Hadamard jump condition at the interface. To deal with the interface within the transient heat equation, a tensorial mobility approach introduced by [3] is used.
The heat equation model is evaluated due to its suitability for typical temperature changes during solidification and curing, whereas the mechanical model is reviewed with emphases on elasticity and then weak-coupled by implementation of thermal strains and temperature-dependent material properties. Based on the single model results the extended model is validated via a series of thermo-mechanical simulations to show the potential of this work.

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MODELING DAMAGE IN UNIDIRECTIONAL AND TEXTILE CFRP COMPOSITES

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Abstract

Carbon fiber reinforced composites (CFRP) have become very popular in numerou applications in aerospace, automotive, and maritime industry. They are typica composed of either unidirectional carbon fibers or textiles, in which the reinforcin fibers are woven or braided, embedded in an epoxy matrix material. These composit are advantageous due to their ease of manufacture, damage tolerance, and relative low cost.

However, physics-based modeling of their mechanical behavior is challenging. While the unidirectional case all fibers are considered as perfectly aligned in one particul direction, textile composites introduce additional geometric complexities, which caus significant local stress and strain concentrations. Since these internal concentration are primary drivers of nonlinearity, damage, and failure within textile composites, the must be taken into account in order for the models to be predictive.

The macro-scale approach to modeling fiber-reinforced composites treats the who composite as an effective, homogenized material. This approach is ve computationally efficient but it cannot be considered predictive beyond the elas regime, because the complex microstructural geometry is not considered. Further, th approach can, at best, offer a phenomenological treatment of nonlinear deformatio and failure.

In contrast, the lower scale approach to modeling CFRP explicitly considers the intern geometry of the reinforcement. Hence, for the UD material the statistically distribute fibers are considered on the micro-scale, whereas for textile composites the reinforcin tows, and thus their interaction, and the effects of their curved paths are accounted f on the meso-scale. The tows are treated as effective (homogenized) materia requiring use of anisotropic material models to capture their behavior.

In this paper both micro- and meso-scale approaches to modeling the deformation an damage propagation of CFRP are investigated. On the micro-scale, the influence different representative volume elements is shown. On the meso-scale, two differe approaches to model the anisotropic behaviour of the tows are compared.

ITERATIVE COUPLING OF FLOW SIMULATION AND TOPOLOGY OPTIMIZATION FOR LONG-FIBER-REINFORCED PLASTICS

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Abstract

Composite materials made of fiber-reinforced plastics enable light and stiff structures. Their mechanical behavior strongly depends on the distribution and orientation of the reinforcing fibers in the polymer matrix. Both of them are influenced by the parameters of the manufacturing process, e.g. injection or compression molding, and the components geometry. Therefore it is necessary to integrate the resulting fiber orientation and distribution of the manufacturing process into the design process. A common used method to gain initial design proposals is the topology optimization. This work proposes to integrate the results of a mold filling simulation with Moldflow iteratively into the topology optimization process in TOSCA.

First, several optimizations with different fiber orientations are presented to determine the impact of different fiber orientations on the optimization result. The investigated specimen are a tensile specimen.

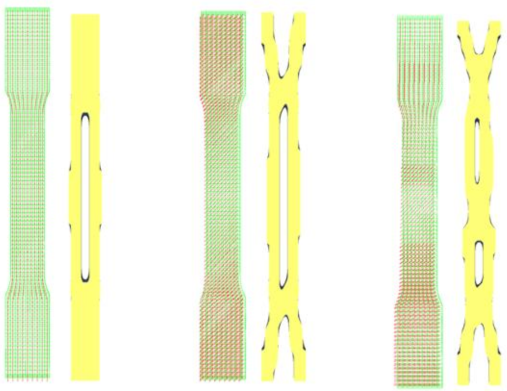

Fig. 1 Optimization Results with different fiber orientations (0°, 45°, 0° - 90°)

Based on this, a second, plate-shaped specimen under bending load is used to simulate the fiber orientation resulting from the form filling process. This initial orientation is mapped to the ABAQUS model of the specimen and the first iteration of the optimization with TOSCA starts. When the first iteration is completed, a script, written in Python, is used to transfer the results of the topology optimization back to the mold filling simulation and the first coupled iteration is completed. These steps are reiterated until a stop criterion is reached.

The result of this process is an optimized design proposal which considers the expected fiber orientation of the component caused by the manufacturing process. A final comparison evaluates the mechanical behavior of the coupled-optimized specimen with the conservatively optimized specimen.

NUMERICAL INVESTIGATIONS OF GUIDED WAVES IN LAYERED COMPOSITE STRUCTURES

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Abstract

Due to improved mechanical properties like higher stiffness and strength with comparable weight against traditional materials carbon fiber-reinforced plastics (CFRP) are deployed more and more frequently in lightweight structures. Structural health monitoring presents a challenge, since the current inspection methods such as X-ray and ultrasound examinations are only usable with restriction or no longer appropriate. Therefore there is a need for an improved inspection method. Lamb waves present themselves as a suitable alternative. They propagate over a large surface area and over long distances and interact with defects and stiffness jumps as with other wave types. When the behavior of the waves with respect to damages is studied more details about the nature, location and size of the damage can be found. However, Lamb waves also show a complex propagation behavior in anisotropic materials such as fiber composites, which is apparent in dispersion curves. First the calculation of dispersions curves for Lamb waves in thin shell structures consisting of layered transversely isotropic layers will be introduced. Based on the obtained dispersion curves the conditions for excitation of cumulative higher harmonic modes are investigated. These findings can be utilized in the next step in order to detect the degradation of fiber composites numerically.

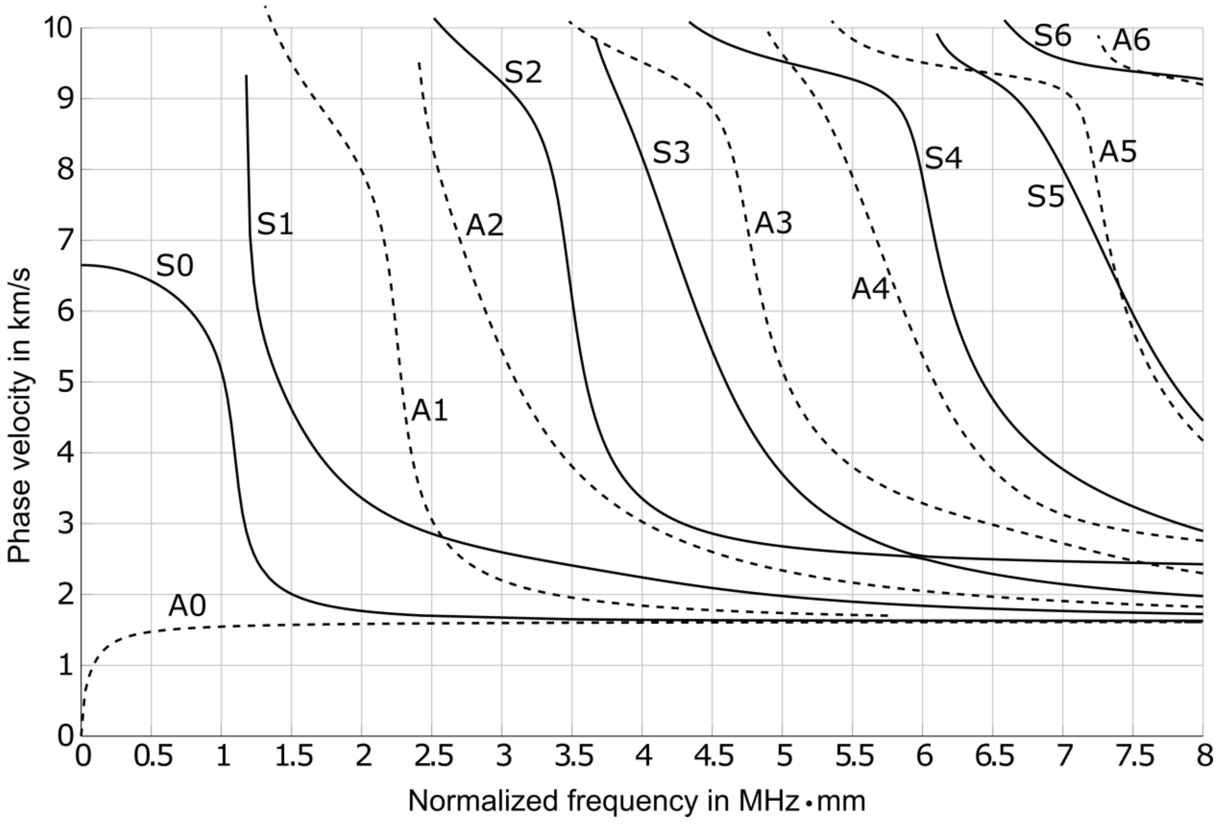

Abb. 1: Dispersion curves for a symmetric cross-ply laminate

LASER-BASED INTERFACE-STRUCTURING OF INTRINSIC MANUFACTURED HYBRID STRUCTURES

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The project's main objective is the development of a modified resin-transfer-molding (RTM) process to realize an intrinsic manufacturing of hybrid lightweight structures. The utilized procedure is based on a simultaneous insertion of a metal and a dry fiber component in the tool cavity. Subsequently, an injection of high reactive resin is performed, in which the fiber component is cured and combined to the metal component at the same time. Based on this manufacturing technique, a very resource and time efficient production of hybrid structures is feasible. In this study, hybrid structures out of carbon fiber reinforced plastics (CFRP) and micro-alloyed steels are employed to analyze the mechanical as well as corrosion properties.

For a sufficient joint strength, the interface design between the two components is essential. In addition to a good adhesion, the contact corrosion, which is a serious problem between steel and CFRP, has to be avoided by suitable constructive enhancements.

Nevertheless, the focal point is the modification of the steel surface, which possesses satisfying adhesion properties for the resin. In this case, a surface treatment by laser-nanostructuring provides a highly promising possibility. Due to the latter procedure, an increased and open-pored surface, which is characterized by various undercuts, can be achieved (fig. 1).

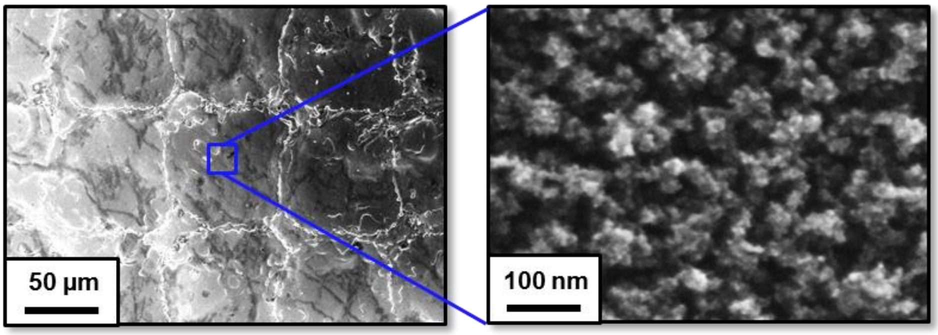

Figure 1: Example of a laser-nanostructured steel surface

Shear tension tests reveal, that in comparison to hybrid structures with non-structured metal sheets, laser-nanostructured metal sheets display an increased shear strength of approximately 30 % as its non-structured counterpart.

The second aim is to generate a highly durable connection. Therefore, several intermediate layers e.g., glass fiber fleeces or adhesive films are applied to avoid contact corrosion.

This presentation will shed light on the modified RTM process, the laser-nanostructuring, and the results of the shear tension tests depending on different structured surfaces as well as various intermediate layers. Moreover, the influence of the different intermediate layers on the corrosion behavior will be presented.

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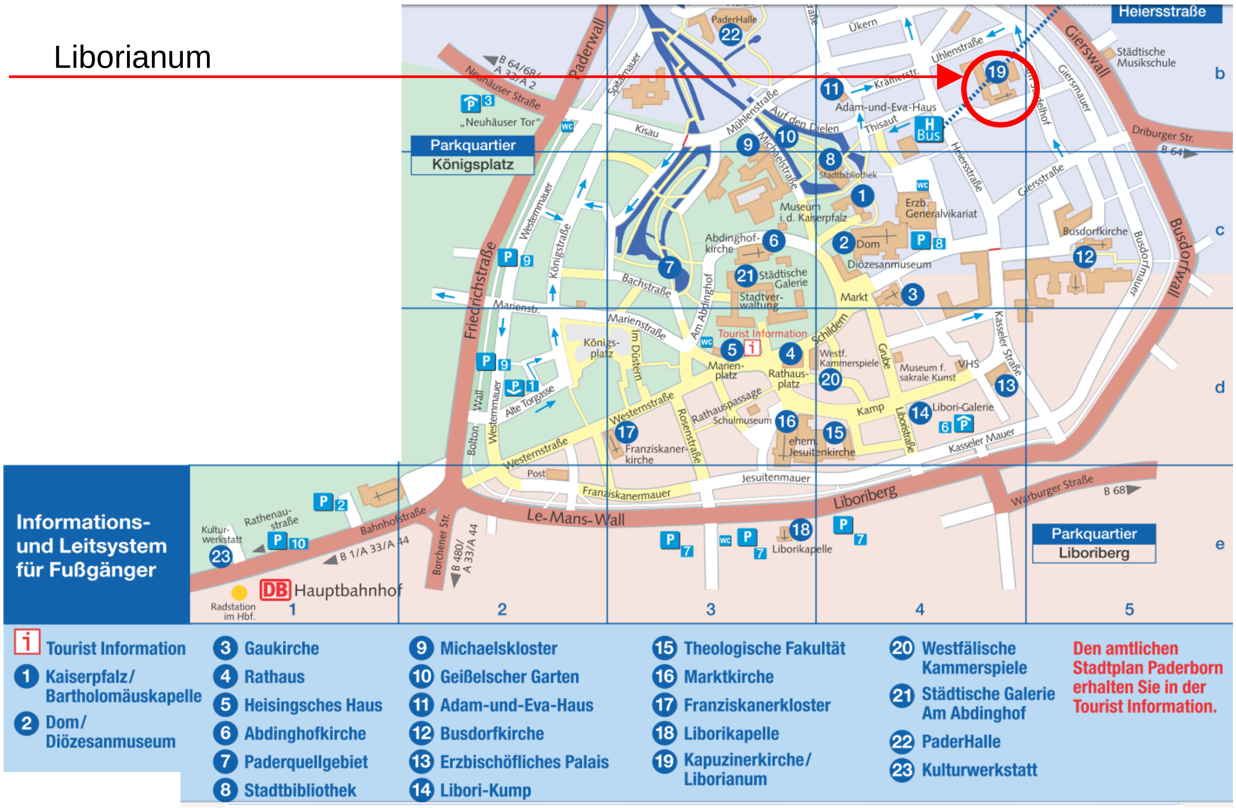
INFORMATION



(Quelle: Stadt Paderborn)

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