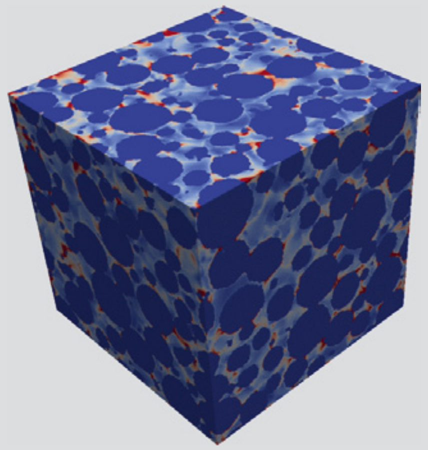

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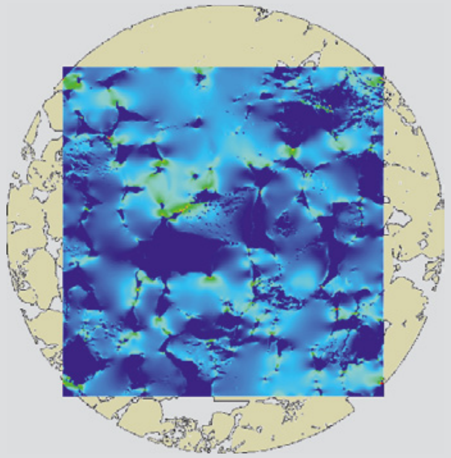

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1 *Stress field in a polymer foam*

2 *Drill core sample of Berea sandstone*

3 *Stress field in Berea sandstone*

Fast and memory efficient iterative solver

The superior performance of the method results from the reformulation of the periodic boundary value problem into the so-called Lippmann-Schwinger integral equation. Several trigonometric collocation methods are implemented as discretization for this integral equation.

- Parallel Fast Fourier Transformation
- Multi-threaded code
- Neumann series based solver
- Krylov subspace based solver

Computational costs for the laminate shown in figure 1

Resolution	Runtime	Memory usage
256 × 256 × 2096	120 min	6427 MB
64 × 64 × 524	2 min	103 MB

Precise prediction of macroscopic properties

- Direct computation of stress and strain in contrast to Finite Element Analysis (FEA) and Finite Volume Methods (FVM)
- Computation of full material tensors for anisotropic materials
- Computation of accurate lower and upper bounds of the properties
- Multiphase voxels for the higher order approximation of the interface

Features and highlights

- No mesh generation needed
- Fully resolved CT scans (after segmentation) can be used as input without clipping or downsampling
- Downsampling of the volume image possible
- User-friendly graphical user interface
- Extendable material data base
- Advanced visualization and postprocessing of the results
- FeelMath is restricted to periodic boundary conditions, but Dirichlet or Neumann conditions can be approximated using stiff or soft boundary layers.

Interfaces

- GeoDict
- MAVI
- VTK viewer, e.g. Paraview
- Finite element packages, e.g. ABAQUS, CalculiX, ANSYS®

System requirements

- Operating system: Windows or Linux
- RAM: 8–96 GB (recommended)
- CPU: Intel i5 or i7 (recommended)
- Graphics Card: 1 GB RAM or more

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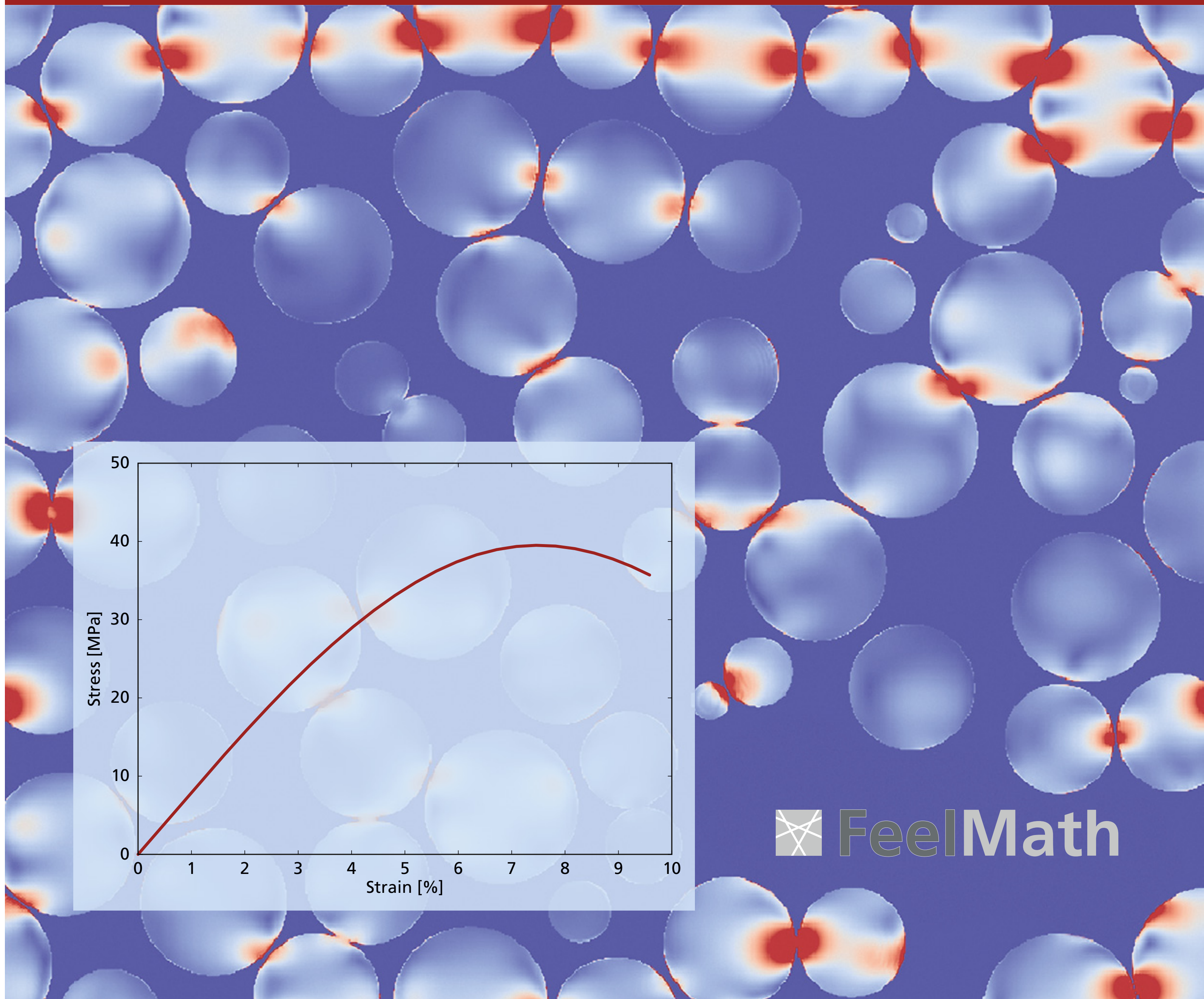
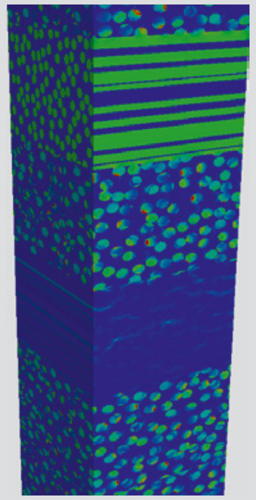
FeelMath – ENHANCED NONLINEAR MATERIAL SIMULATION TOOLKIT





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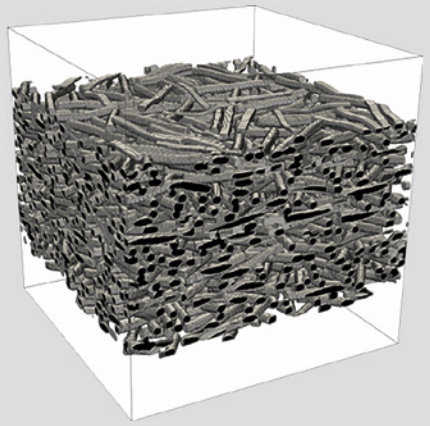

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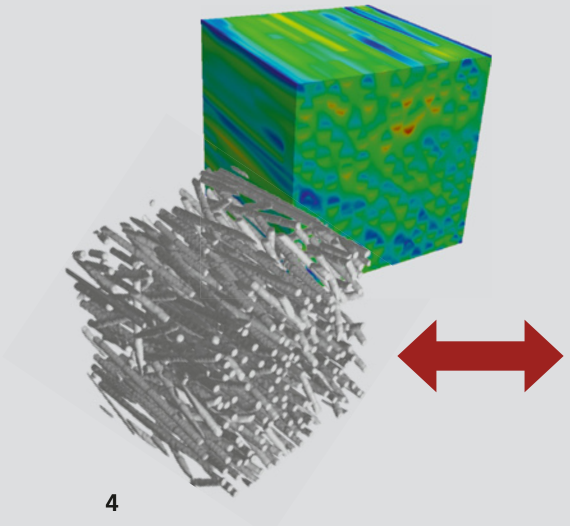

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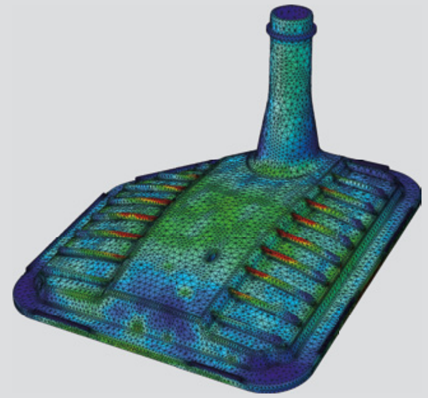

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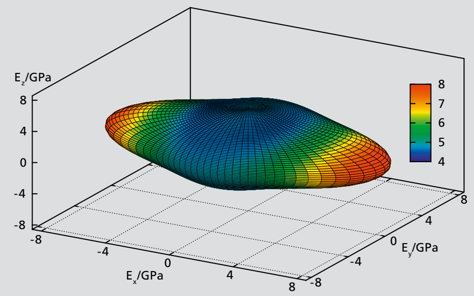

6

1 Stress field in a fiber reinforced laminate

2 Uncompressed nonwoven

3 Compressed nonwoven

From microstructure to macroscopic properties

Stiffness and strength of composite and porous materials depend on the properties of their constituents (phases) and their distribution in the microstructure. FeelMath is the universal tool to calculate the effective elastic properties on the basis of microstructure models, where these models are coming from 3D images or from structure generators (e. g. CAD software). FeelMath can be used to characterize, understand and optimize materials. In contrast to measurements, FeelMath is able to predict the full material tensors (e. g. all elasticity coefficients) of anisotropic materials. For sensitivity analysis, FeelMath allows variations of single microstructure parameters, whereby all other parameters held constant.

Homogenization

On the basis of the precisely computed local stresses and strains, averaging methods result in estimation of the macroscopic, i. e. effective, material parameters.

- Analytical formulas and numerical methods for the prediction of macroscopic material properties
- Analytical and numerical bounds for the macroscopic properties

Effective properties

- Stiffness and strength
- Thermal conductivity and expansion
- Viscoelastic creep and relaxation

Materials and database

FeelMath is the universal solver for microstructured materials. The solver is especially useful for highly complex microstructures:

- Interwoven matrices
- High contrast between constituents
- Nearly rigid inclusions and pores
- Incompressible materials

Examples of tested materials:

- Fiber reinforced polymers
- Particle reinforced elastomers
- Reinforced concrete
- Minerals and geomaterials
- Metal matrix composites (MMC)
- AlSi alloys
- Wood fiber boards and composites
- Polymer foams
- Nonwovens, felts and textiles

The material database which is included in FeelMath can be easily customized for each field of application.

Arbitrary material laws

Constitutive laws for nonlinear behavior of the constituents can be implemented in user defined functions (UDF). UDF-interface is the similar to UMAT-functions in ABAQUS or CalculiX, so that ABAQUS or CalculiX can be used to test the material law.

Examples of material laws for constituents:

- Anisotropic linear elastic
- Hyperelastic, elastoplastic, viscoplastic
- Damage of brittle and ductile phases
- Fluid phases

Process chain simulation

Modern process simulation software (e. g. for casting, injection moulding) is able to compute properties of the resulting local microstructures. On the other hand, locally varying material properties have to be taken into account to predict the mechanical behaviour of the components accurately. FeelMath is the appropriate tool to obtain from the output of the process simulation the necessary input for the structural analysis simulation. FeelMath is well suited for integration into process chains.

Multiscale model

Failure and progressive damage of fiber reinforced materials occur as a result of a variety of microstructural damage mechanisms, such as:

- Matrix damage
- Fiber pull out
- Fiber breakage

→ Consider microstructural effects to predict macroscopic damage evolution.

→ Define isotropic damage model for single phases.

The macro problem can easily be integrated in a standard finite element analysis framework which is used to solve the macroscopic boundary value problems on the component level. Furthermore, the micromechanical model is used as a kind of virtual material laboratory for complex microstructures to examine the fracture behavior in terms of the onset of macroscopic crack under different loading conditions.

Multiscale simulation

For complex shaped components and structures, nonlinear deformations involve load redistributions and non-proportional loading of the material. Therefore, the ultimate solution for the adequate prediction of failure and fatigue is the fully coupled multiscale simulation. FeelMath is ideally suited as microstructure solver, whereas a traditional finite element code can be employed as solver for the macroscopic structure. A parallel computer is recommended for real-life multiscale simulations.

Consulting work

- Find optimal microstructures w. r. t. stiffness, strength and conductivity
- Add particular features to FeelMath
- Acquire specific material parameter and fill the material data base of FeelMath
- Implement user defined material functions for specific constituents

Profit from FeelMath

- Complete characterization of anisotropic mechanical behavior
- Acceleration of composite material development
- Reduction in number of prototypes
- Gain a keen insight in structure-property-relation

4 Volume element of GFRP material: glass fibers and stress field of the volume element

5 Stress field of the component

6 Young's modulus distribution for the volume element