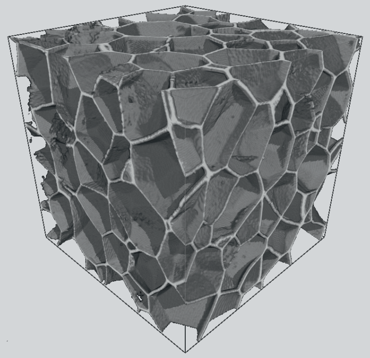

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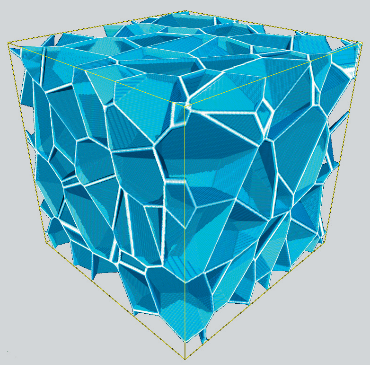

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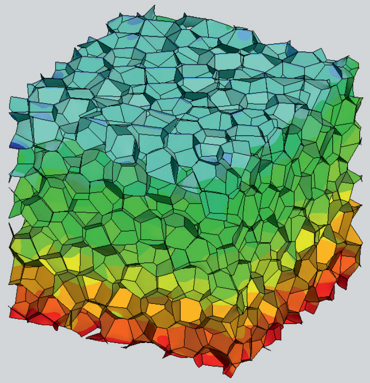

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1 *Micro-tomographic image of closed cell rigid foam (imaging Fraunhofer IWM-H)*

2 *Dilated faces of a Poisson-Voronoi tessellation*

3 *Vertical displacement field under planar load from the top*

Our competences

- 3d imaging
- 3d micro-structure analysis
- multiscale simulation of mechnical, thermal, or acoustic properties
- finding and fitting geometric models
- micro-structure optimization
- 3d print of the optimized structure

Our offer

Starting from samples of your material we image the micro-structure, analyze it geometrically in order to fit a stochastic model to it, and simulate the materials properties in both real structure and model realizations. This approach allows us to reveal optimization potentials.

Careful calibration of our processing chain using your experimental data, incorporation of your constraints, and meticulous determination of the representative volume element ensure the applicability of the results.

Software tools

At Fraunhofer ITWM, software tools for micro-structure characterization, modeling, and optimization have been developed. Interfaces to commonly used simulation frameworks are available. CAD or FEM expertise is however not required.

MAVI (Modular Algorithms for Volume Images) extracts valuable structural information like volume fractions, surface areas, size, shape, and orientation distributions from volume images. The C++-library MAVIlib offers additionally a wide variety of stochastic geometry models. MAVImesh provides input for simulation frameworks by meshing the surface of the foreground component, simplifying the mesh, and exporting it in STL format.

FeelMath (Finite Elements for Elastic Materials and Homogenization) is a fast and comfortable analysis tool for elastic micro-structures given by volume images or analytical descriptions. Precise stress analysis combined with the prediction of effective macroscopic elastic parameters by computational homogenization enable the finite element analysis of large micro-structural models having up to $5 \cdot 10^7$ voxels.

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BV_A3_Flyer_new_insight_into_microstructures_EN_nCD

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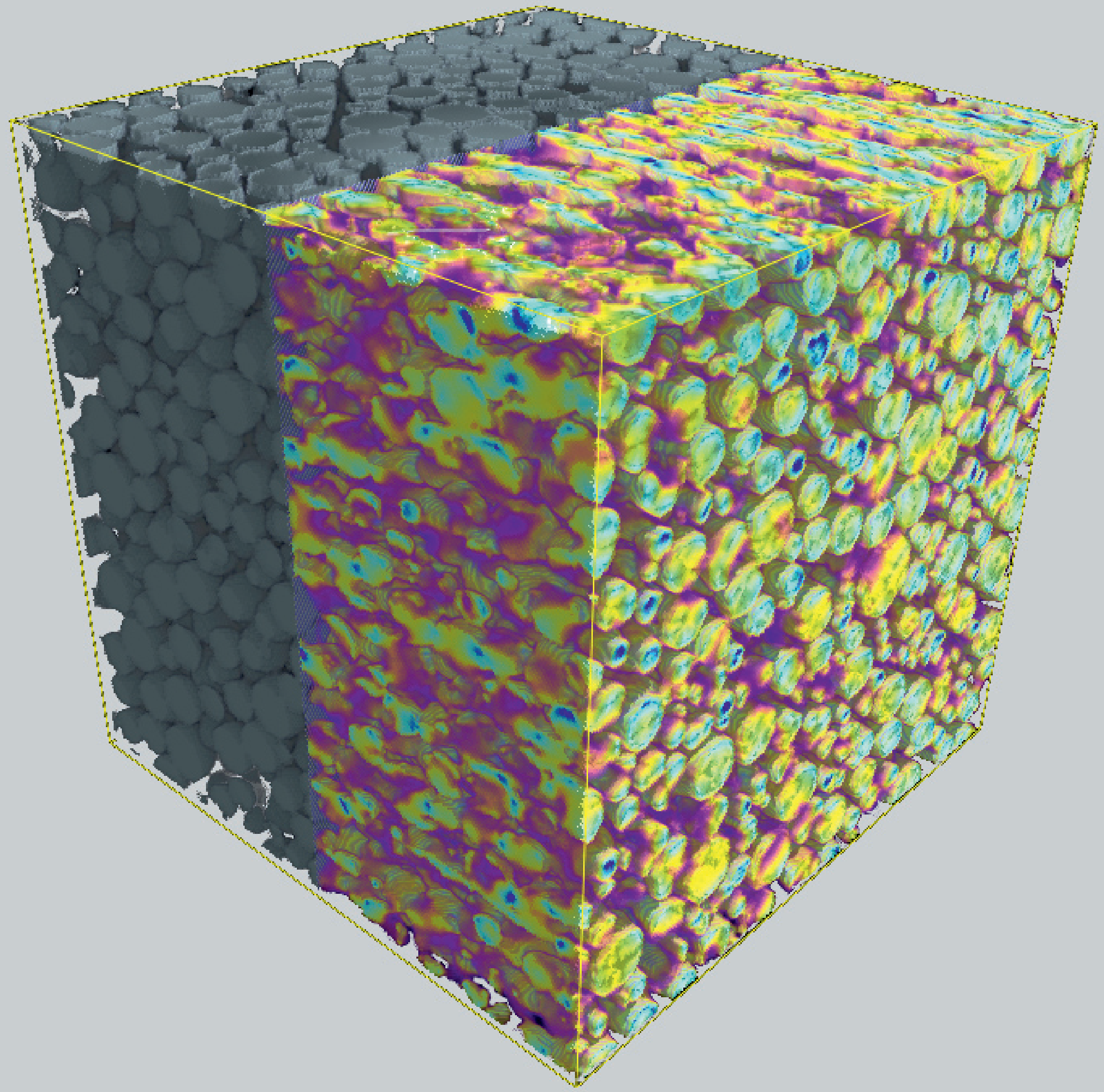
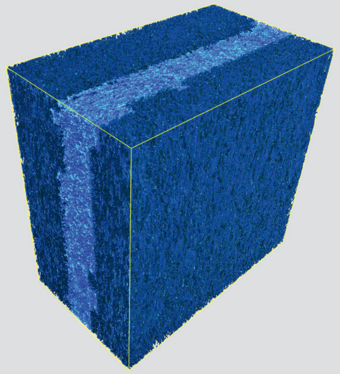
FRAUNHOFER INSTITUTE FOR INDUSTRIAL MATHEMATICS

NEW INSIGHT INTO STRUCTURE-PROPERTY-RELATIONS





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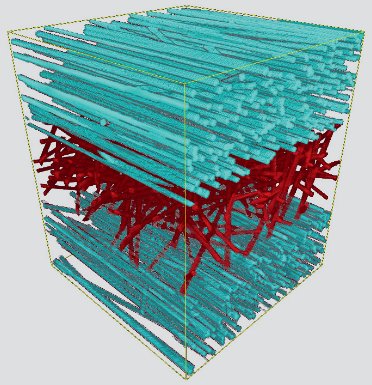

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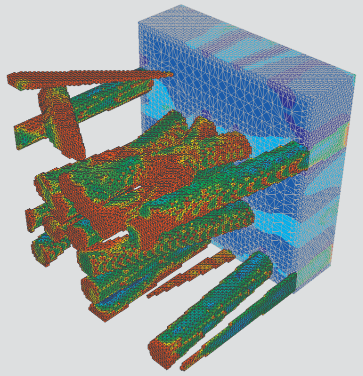

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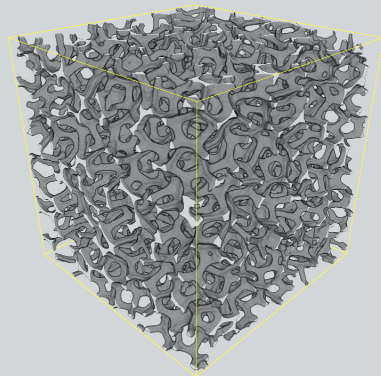

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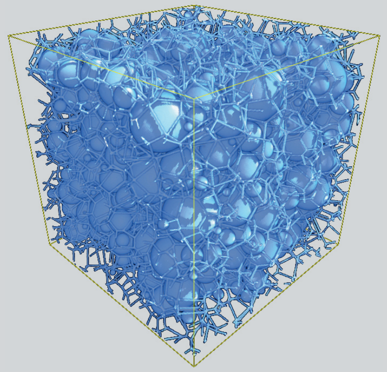

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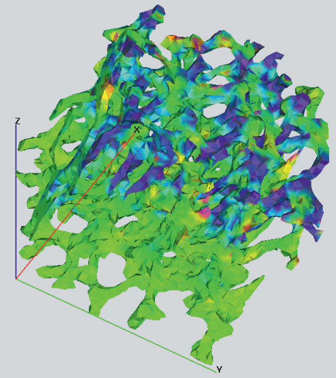

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1 *Micro-tomographic image of a glass fiber reinforced polymer*

2 *Layered Poisson cylinder model*

3 *Equivalent stress under tensile load – red high, blue low values*

The micro-structure of a material accounts strongly for its properties like thermal conductivity, elasticity, or acoustic absorption. Image analysis can provide micro-structure information needed as input for dimensioning at the macroscale, i.e. at the level of the whole part. By extracting the relevant features of the micro-structure from 3d images, phenomenological constitutive laws for the macroscale can be replaced by multiscale models, which take into account both the bulk properties of each constituent and the spatial structure of the constituents thus yielding a much more precise prediction of the material's behaviour at the macroscopic scale.

For example, the mechanical stiffness of a glass fiber reinforced polymer differs strongly depending on whether it is loaded in fiber direction or perpendicular to the fibers. In simulations, this anisotropic behaviour is captured by the fiber orientation tensor, which can be obtained by averaging local fiber directions over sub-volumes of a 3d image. Subsequently, a multiscale model is used to compute the macroscopic stiffness and strength as a function of the fiber orientation and all other essential micro-structural parameters.

Finally, the full 4th order anisotropic stiffness tensor is achieved.

3d imaging

Structural features like shape of particles, directions of fibers, and connectivity of components are crucial for actually achieving desired materials properties. State-of-the-art 3d imaging methods capture the full spatial information from the millimeter to the nanometer scale. Fraunhofer ITWM provides micro-computed tomography in-house and cooperates closely with partners offering a variety of complementary 3d imaging techniques.

3d image analysis

From the 3d image data, structural information is gained. Components are identified and their volume fractions and the area of the boundary surface between them are measured. Anisotropies are revealed and their strength is quantified. Correlations between components and the range of interaction can be judged. Local fiber or normal directions as well as local pore sizes or thickness values provide information about inhomogeneities and disruptions. For structures consisting of objects – pores or particles – size and shape distributions are determined as well as correlations between those characteristics and the spatial position.

Image based material characterization

In the pre-processed 3d image, macroscopic thermal, elastic, and acoustic material behaviour can be computed based on the respective properties of the constituents of the micro-structure. If the micro-structure varies within the considered part or component, this image based material characterization is able to determine the material parameters with high spatial resolution. For that purpose Fraunhofer ITWM developed robust and fast numerical methods, which take into account more micro-structural information than analytical methods in micro-mechanics.

Optimization of micro-structures

Macroscopic material properties can be simulated in realizations of geometric models, too. This approach enables the simulation study even if 3d image data is not available or not of sufficient quality. Moreover, simulating within a model structure allows not only to determine the size of the representative volume element but also to run the computations in sufficiently large volumes.

Finally, the modelling opens the door to so-called virtual material design and optimization of micro-structures. Simple changing of model parameters results in slightly altered geometries, in which the target property can be simulated again. This cycle can be repeated until the optimal micro-structure is found. Thus costly mechanical tests and production of samples can be reduced while the relation between micro-structure and properties is better understood.

Stochastic geometry models

This strategy relies on geometry models representing essential features of the micro-structure realistically while being controlled by a manageable set of parameters. Models from stochastic geometry are well adapted to the microscopic heterogeneity typically observed in materials structures. Random Laguerre tessellations are a versatile model family for cellular structures, germ-grain-models and random packings are suited for granular media, cylinder systems and fiber packings model non-woven and fiber reinforced materials.

4 *Micro-tomographic image of a nickel-chrome foam*

5 *Edges of a Laguerre tessellation along with the generating ball system*

6 *Vertical displacement field under planar load from the top*