Chair of Carbon Composites
TUM School of Engineering and Design
Technical University of Munich

Virtual Material Characterization and Development

Numerical investigation of the material behavior on different scales

Motivation

Virtual material characterization methods aim at the derivation of material properties based on numerical descriptions. Even though experimental input parameters are still required, simulations offer the opportunity to reduce the extensive testing effort to fully characterize heterogenous materials. For example, test matrices can be reduced by virtually modelling test configurations and load combinations (which require complex test setups) with reduced effort. To characterize the material behavior correctly, the material has to be modeled at lower scales such as the microscale or mesoscale. The lowest scale is the microscale, where characteristic material structures are analyzed, e.g. the fiber-matrix interaction. On the mesoscopic scale, repeated characteristic elements are modeled, e.g. the fabric structure of ply interaction. The results from micro- and mesoscale are usually homogenized and serve as input for a macroscale simulation of the whole part.

Goals

- Reducing test effort
- Derivation and homogenization of material properties
- Improving the knowledge of materials by investigation on small scales

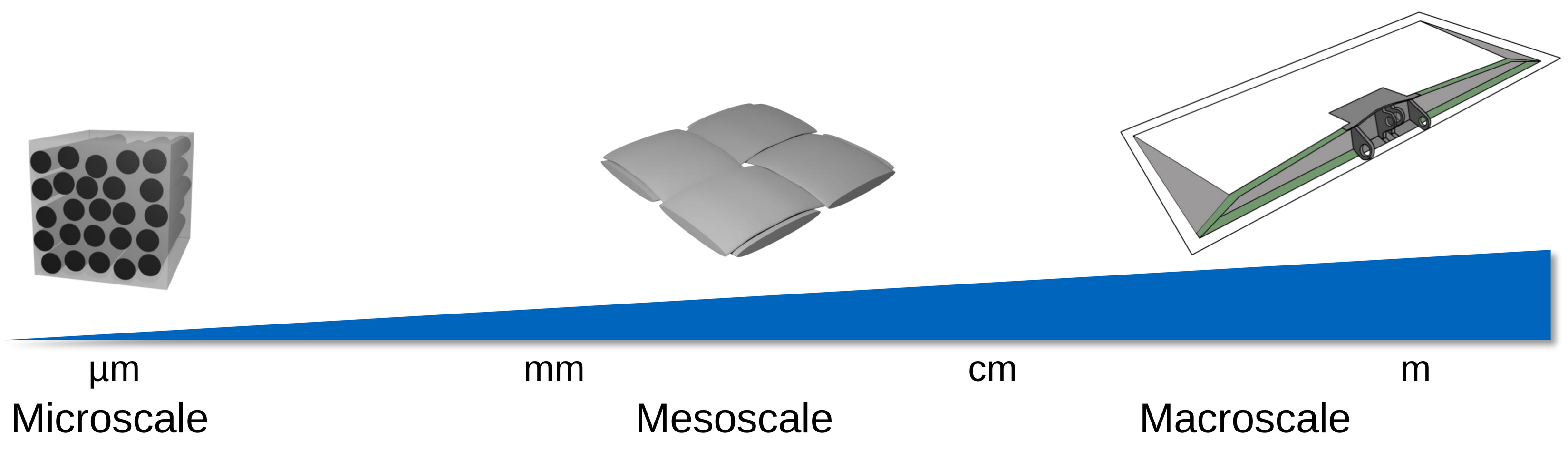

Fig. 1: Typical scales for composite material simulations

Examples

Virtual Permeability Characterization

The determination of the permeability of textiles is usually characterized by time consuming and complex experiments. To reduce the testing effort, a multiscale approach can be used to determine the permeability of a textile. Starting at the microlevel, the permeability of a fiber tow is analyzed using a representative volume element of the textile. On the mesoscale, the architecture of a textile is taken into account and the permeability tensor is calculated and used for filling simulation at a macrolevel.

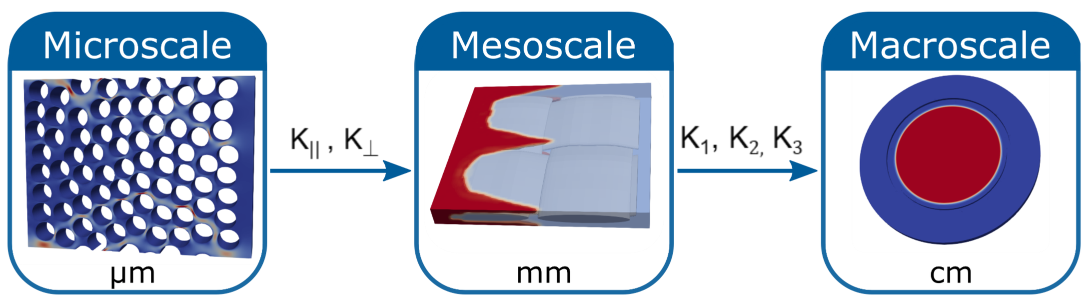

Fig. 2: Multiscale approach for permeability determination

High-fidelity Damage Modeling

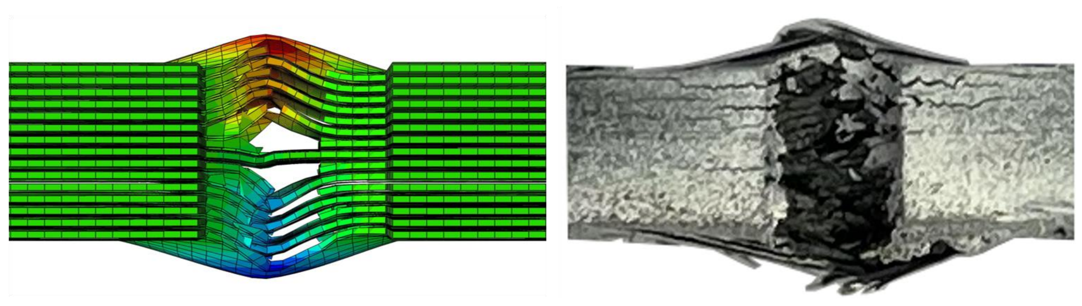

Fig. 3: Comparison of simulation results with experiments [Thesis Bach 2023]

The complex damage behavior of composite materials cannot be studied in detail on a macroscopic level. An alternative to that is ply-by-ply modeling of a laminate on the mesoscale. It enables detailed investigations of the behavior during damage events such as delamination. A special focus of the chair is the consideration of strain rate dependent effects, which are relevant for crash and impact simulation. By using input from microscale simulations and providing homogenized properties for the macroscale, the ply-by-ply model can act as a connecting element between these scales.

Modeling of Composite Structures

Endless-fiber-reinforced polymers consist of microscopic constituents. Modelling a single ply as a homogeneous material is not always sufficient, especially if microscopic effects like intra-ply crack initiation and propagation are relevant for the macroscopic failure mechanism. In this case, a simulation at the microscale can allow for a deeper understanding of the material behavior. The chair is investigating this approach by developing microscale material simulations utilizing representative volume elements (RVEs) consisting of discrete fibers, fiber-matrix interfaces and the resin matrix system. A coupling to larger scales further allows a multiscale investigation of the part.

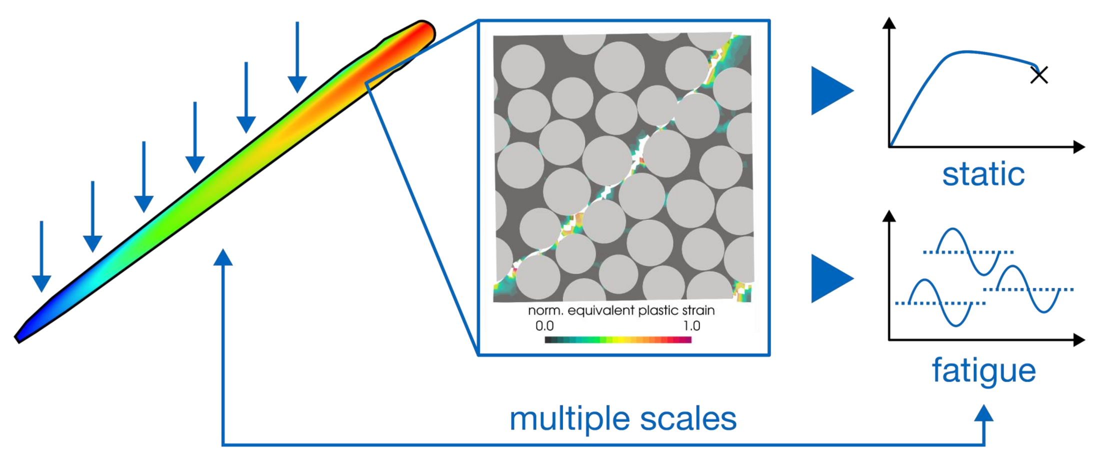

Fig. 4: Modeling of wind turbine blades

Lattice Cell Structures for Additive Manufacturing

Periodic 3D-printable lattice structures may be analyzed through multiscale virtual characterization. A unit cell, which corresponds to a mesoscale representative element, can be modelled with finite elements and the homogenized properties can be calculated through virtual characterization. The derived properties can be assigned to a metamaterial that can be applied to macroscopic lattice assembly. The periodically assembled structure can than be 3D-printed, and could be used for case-specific supporting structure or core infill of additively manufactured components.

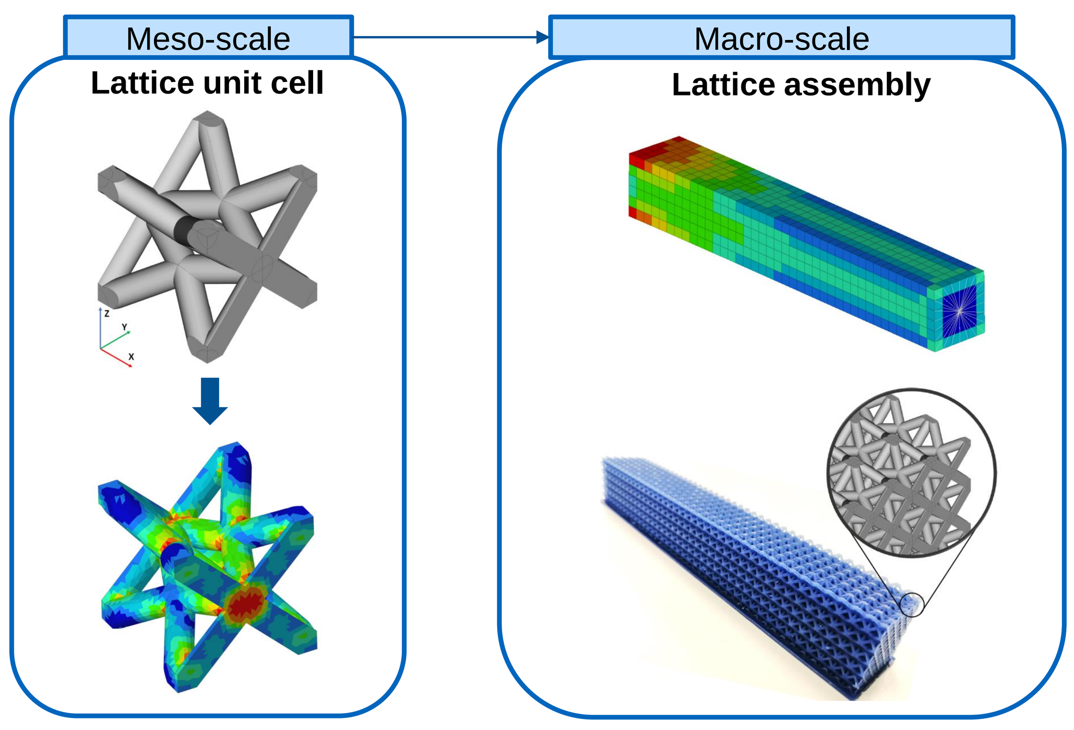

Fig. 5: Simulation of additive manufactured lattice cells

More information and contacts: