GRADIENT - **Graded interphases** for enhanced dielectric and mechanical strength of fiber reinforced composites

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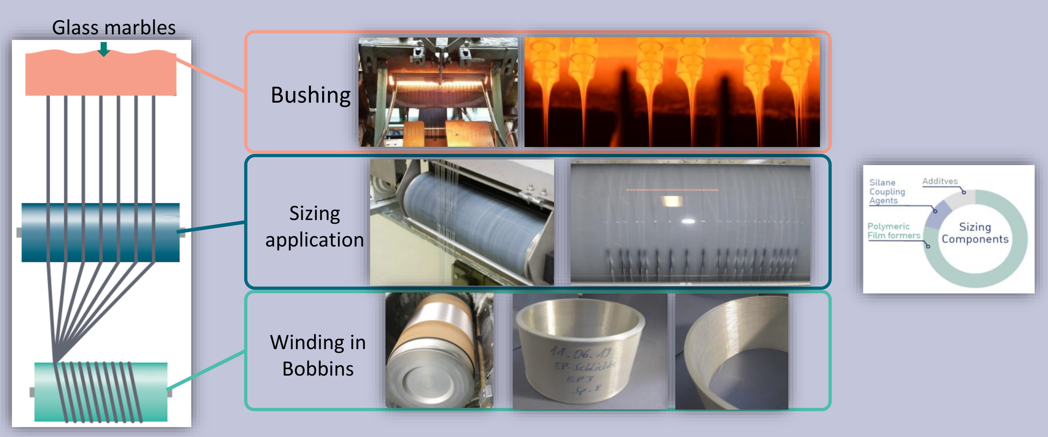
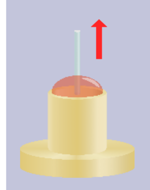
Project Aim

Power transformers and switchgears are key components made of high-performance composites used in power grids. Their availability and robustness have a decisive influence on the reliability and profitability especially for the future expansion of power grids. Their mechanical but also dielectric composite strength is strongly determined by the **fiber-matrix interphase as the origin of micro-scale damage**. The objective of the project is the development of approaches to reduce stress concentrations in the interphase in order to increase the durability of composite structures. This is achieved by fiber surface modification for a gradation of the interphase to avoid the distinct stiffness difference occurring between fiber and matrix.

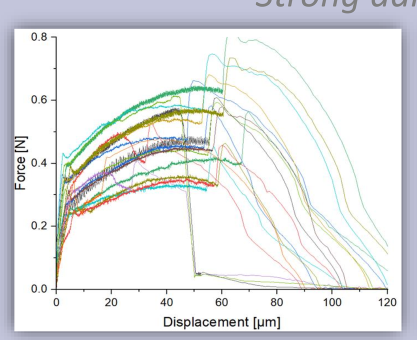
Glass fibers with modified surfaces were produced via a pilot spinning line.

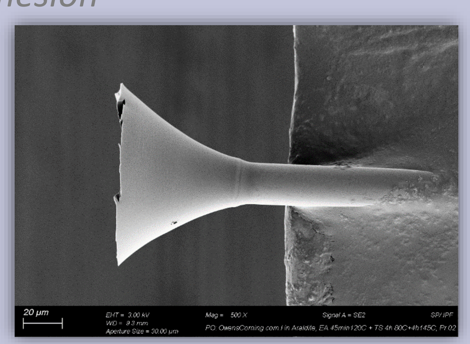




Single fiber pull-out (SFPO) studies were performed to determine interfacial shear strength and analyze the damage process, taking into account factors such as fiber diameter and embedment length.

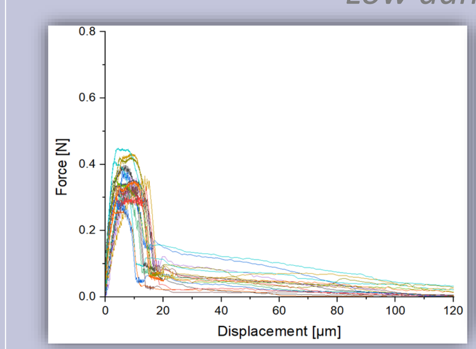
Strong adhesion

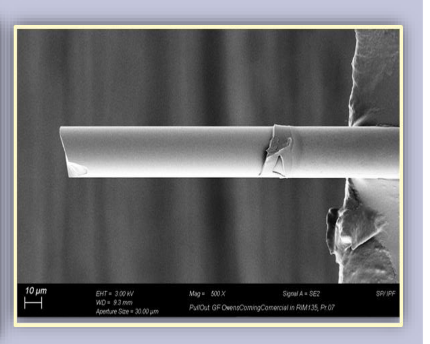




SEM image after SFPO

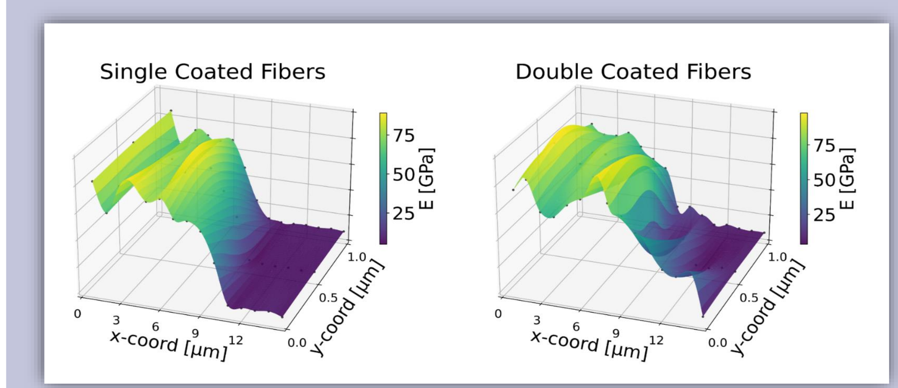
Low adhesion





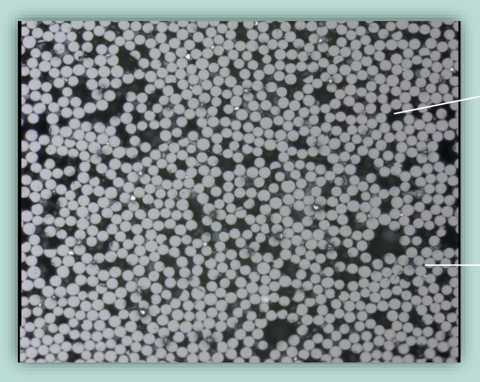
SEM image after SFPO

The characterization of the **interphase stiffness by nanoindentation** revealed the strong influence of surface treatment, sample preparation and measuring parameters on the results obtained.

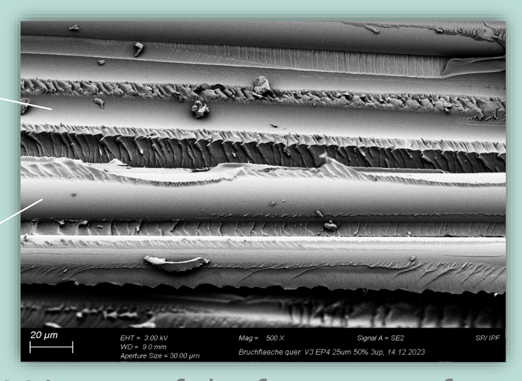


Nanoindentation using Berkovich tip

Unidirectional (UD) composite plates were made from tailored glass fibers with different fiber diameters. The longitudinal and transverse tensile strength was analyzed.

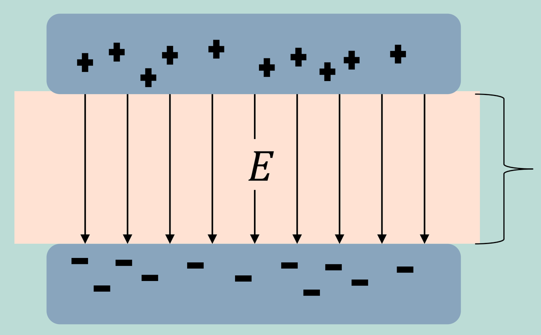


Cross-section image of a UD composites with 65% of fiber fraction



SEM image of the fracture surface after transversal tensile strength showing a strong fiber/matrix interaction

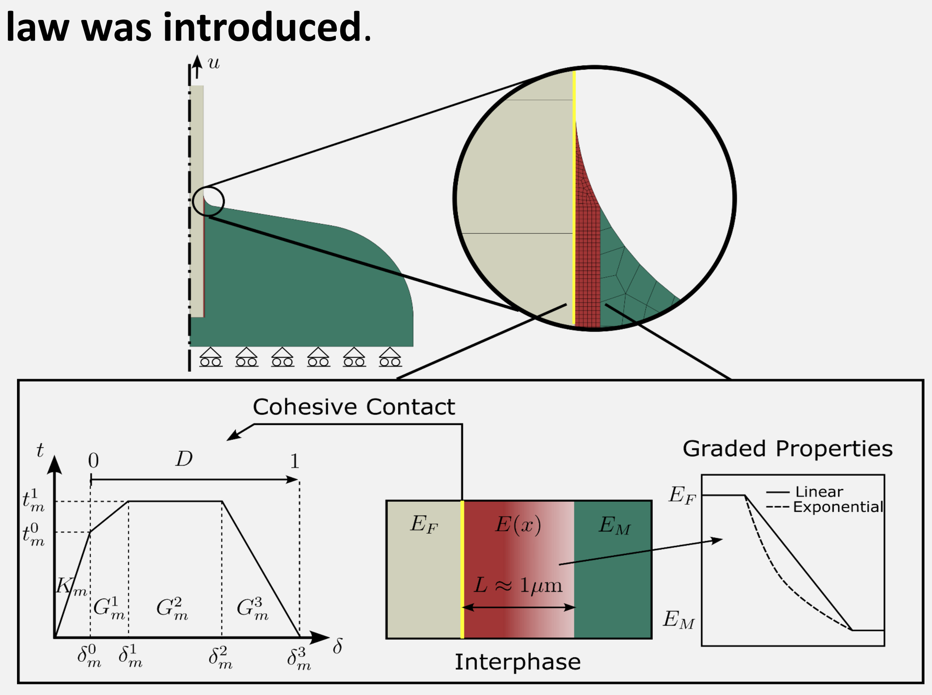
A systematic study on the **dielectrical strength of UD composites by varying material parameters as well as manufacturing processes** is carried out in order to build up fundamental knowledge about the mechanism in the interphase that could lead to dielectrical breakdown.



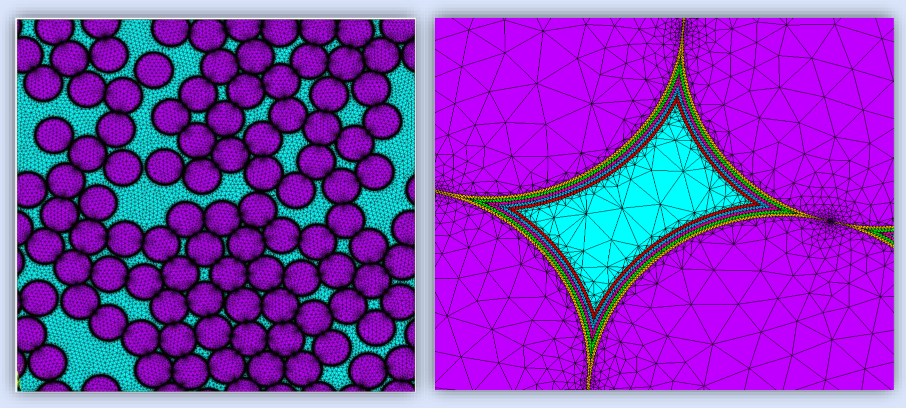
Breakdown strength $E_{\mathrm{BD}} = \frac{U_{\max}}{d}$

Breakdown of a sample in the dielectric strength test

To further understand the damage processes of the SFPO, micromechanical finite element method (FEM) simulations were conducted. **A generalized variant of a traction separation law was introduced.**

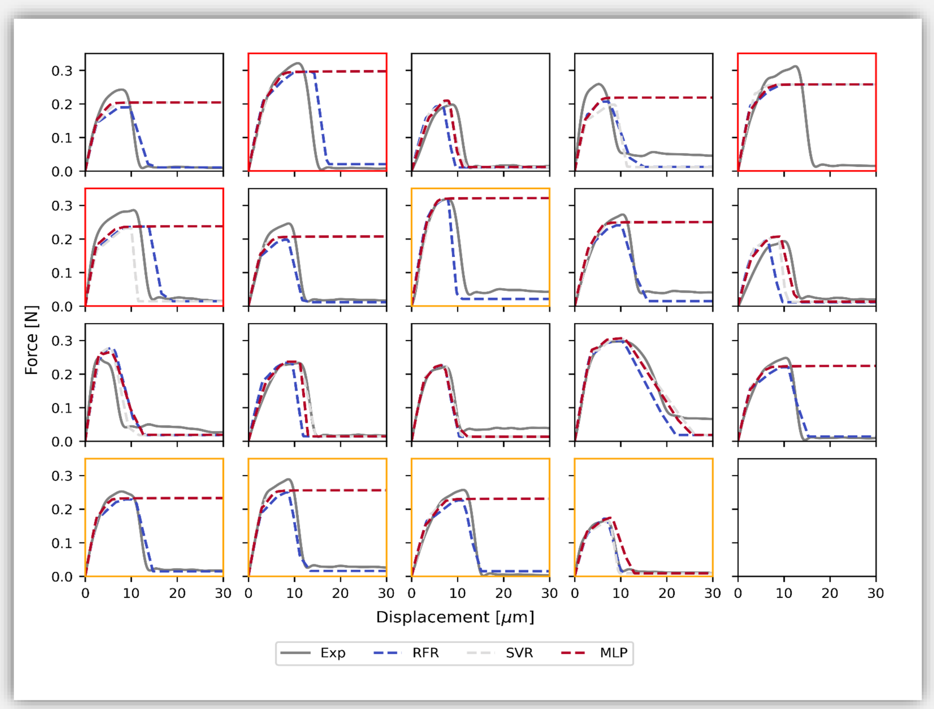


A periodic representative volume element **(RVE) with a layer-wise interphase structure** was employed in the study to examine the effect of a gradient in interphase stiffness on the effective elastic properties and stress concentrations using FEM.



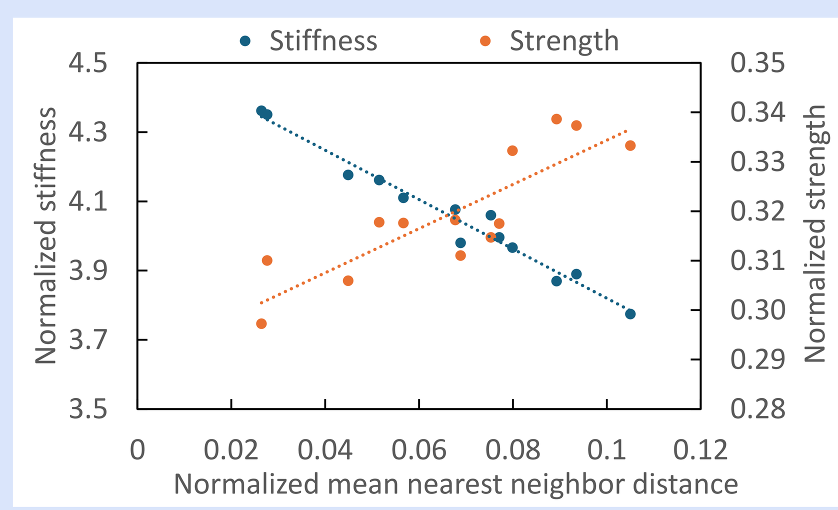
Example of FE mesh for RVE with 100 fibers (left) and mesh refinement for interphase (right)

Interphase parameters were determined from SFPO using supervised Machine Learning (ML).

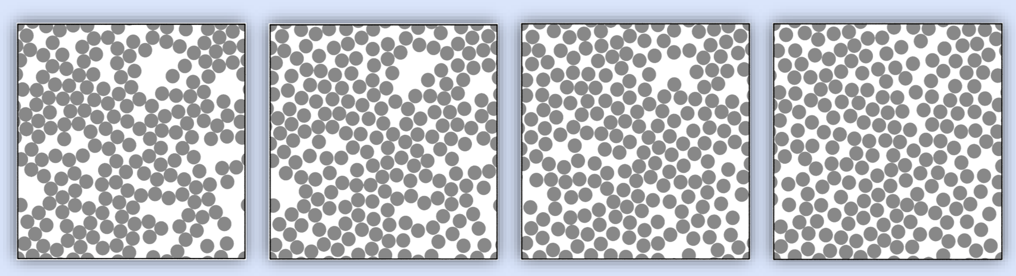


- The predictions made by various ML models were utilized as the input for FEM simulations:
  dashed lines = simulations;
  solid lines = experimental results;
  colored frames = significant plastic deformation of the matrix material;
- A ML model was trained to predict the interphase parameters from experimental force-displacement curves.
- FEM simulations revealed that interphase damage can be described by plasticity.

To investigate the impact of fiber distribution on the effective transverse stiffness and strength of UD composites, advanced RVE generation algorithms were employed in conjunction with FEM simulations.



Transition from clustered to equilibrium distribution of fibers



Clustered ⟷ **Equilibrium**

The studies were performed within the “Graded Interphases for Enhanced Dielectric and Mechanical Strength of Fiber Reinforced Composites "[GRADIENT] project carried out under the M-ERA.NET 3 scheme (European Union's Horizon 2020 research and innovation programme under grant agreement No 958174) and co-financed with tax funds on the basis of the budget passed by the Saxon state parliament), grant No. 360049.