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

Master's Thesis

Coupled Multi-Physics Simulation of Reactive ε-Caprolactam Infusion in Porous Carbon Fiber Preforms

Thermoplastic composites offer improved impact resistance and recyclability compared to conventional thermoset systems. In the field of hydrogen pressure vessels, thermoplastic manufacturing routes such as dry winding combined with Thermoplastic Resin Transfer Molding (T-RTM) represent a promising alternative to conventional wet winding processes. In T-RTM, low-viscosity reactive ε-caprolactam is infused into dry carbon fiber preforms and polymerizes in-situ to form Polyamide 6 (PA6). The exceptionally low initial viscosity enables efficient impregnation of highly compacted fiber reinforcements, making the process attractive for lightweight structures in automotive and aerospace applications. However, reactive T-RTM is governed by several strongly coupled physical phenomena, including resin flow through porous media, heat transfer, anisotropic permeability, and temperature-dependent viscosity evolution. These interactions strongly influence impregnation quality, processing time, and overall manufacturing robustness, making process understanding and optimization essential for successful industrial implementation.

In this thesis, the focus lies on the development of a coupled transient multi-physics simulation framework for reactive ε-caprolactam infusion into porous carbon fiber preforms. The work will involve numerical modeling of Darcy-based flow, transient heat transfer, anisotropic permeability, and temperature-dependent viscosity, with the possibility of incorporating simplified reaction kinetics. Experimentally characterized material data acquired will be integrated wherever available to improve simulation accuracy. The developed framework will be used to investigate the influence of process parameters such as permeability, injection pressure, and thermal boundary conditions on resin impregnation, filling stability, and process windows for robust T-RTM manufacturing.

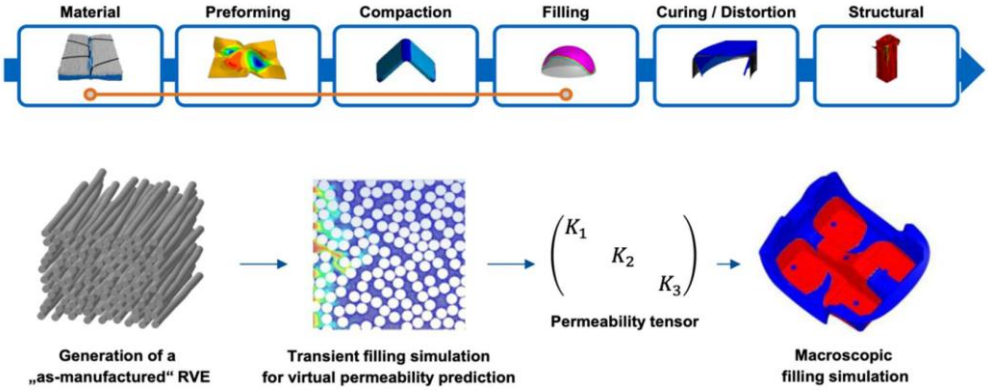

Figure 1: Virtual RTM manufacturing process (TUM-LCC)

Research focus of the thesis

- Development of a coupled multi-physics simulation model for reactive T-RTM processing.
- Integration of experimentally characterized material properties into the numerical framework.
- Investigation of key process parameters and their influence on impregnation and process stability.

Requirements

- Strong interest in numerical simulation and multi-physics modeling
- Knowledge of fluid mechanics, heat transfer, and composite materials.
- Experience with COMSOL, ANSYS, Abaqus, Python, or similar simulation software is advantageous.
- Independent working style, analytical thinking, and motivation for scientific research.

Start date: As soon as possible

For more details please contact:
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