Chair of Carbon Composites
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Virtual Modelling and Chaining of Manufacturing Processes

Optimiziation of Process Development with Numerical Endorsement

Process Optimization

Process optimization is one of the main applications of process simulation. In manufacturing composite structures, the selection of process parameters significantly affects the fiber orientation, interlayer adhesion, defects, warpage and etc. With the process simulation, the critical conditions and crucial process parameters can be found and optimized.

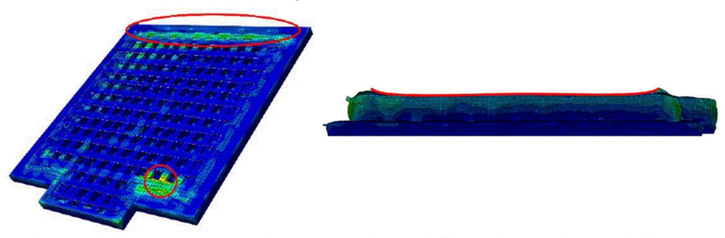

Fig. 1: Simulated warpage of extrusion 3D printed molding tool

For instance, the process simulation of composites extrusion 3D printing, based on the thermal-mechanical model, the influences of various process parameters on the mechanical properties and final geometrical shape of the printed part can be quantitatively determined, as shown in Fig. 1. With optimized process parameters obtained by the process simulation, the cost of trial and error in the praxis can be greatly reduced.

In other manufacturing processes, such as SMC, and RTM, by utilization of filling process simulation, the flow of the material in the mold can be predicted. Furthermore, the filling time, possible dry spots and the variation in fiber orientation can be forecasted as seen in Fig. 2. By variation of the process parameters and conditions in the simulation model, cost and time intensive adaption of the manufactured tool can be reduced.

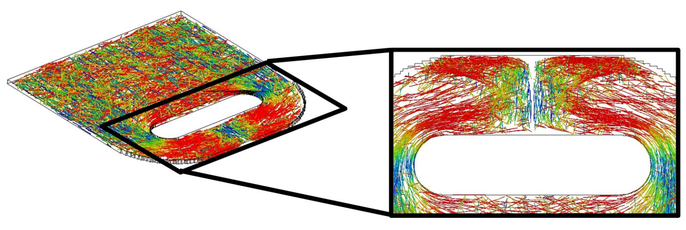

Fig. 2: Fiber orientation in SMC filling simulation

Motivation

For the definition of the best process parameters to obtain ideal material and part characteristics, several trials have to be run with actual material, machines and employees.

Substituting these trials with numerical replicas allows a significant reduction in development costs and time.

The LCC has been developing and optimizing specific simulation tools for many different manufacturing processes, with a main focus on avoiding process induced defects and the development of in-house approaches to chain different manufacturing steps.

Chaining of Production Steps

The manufacturing quality of composite parts depends on different process steps, most commonly draping, compaction, filling and curing. Simulation analysis systems are available for each process step to predict the behavior of the fibers.

Every simulation analysis system has its own numerical methods to calculate their results. Most of the time generated results are specifically related to the analysis system and can not be passed directly between process steps. Hence, an efficient chaining of the process steps is required.

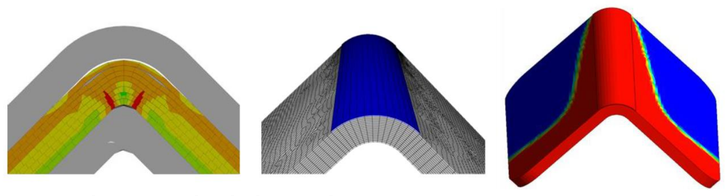

Fig. 4: Chaining of RTM process steps

The chaining of the process steps for the Resin Transfer Molding (RTM)-process can be seen in Fig. 4. The Fiber Volume Content and the contact status between preform and tool can be exported from the compaction simulations and imported into the filling simulations. This makes the visualization of a faster flow in the gap, more precisely the edge race tracking channel, possible [Bub22].

Avoidance of Process-induced Defects

Carbon composites are high-performance materials that are widely used in various applications such as aerospace, automotive, and sports equipment due to their superior strength, stiffness, and light weight. However, the manufacturing process of carbon composites can induce defects that can compromise their mechanical properties and reduce their overall performance.

One of the most common defects are **voids**, which caused by trapped air or incomplete filling (Fig. 5). One approach to avoid the formation of voids is to carefully control the temperature, pressure and flow front progression. A process simulation helps to set the correct parameters.

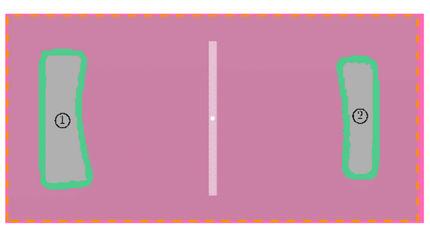

Fig. 5: Simulated void formation during an infusion process with a line inlet in the center of the plate part and a line outlet at its right edge [Zar18]

Warpage is a defect where the composite material bends or distorts out of shape (Fig. 3). It can occur due to uneven temperature distribution, shrinkage or due to residual stresses within the material. The use of simulations can predict and mitigate potential warping issues before they occur.

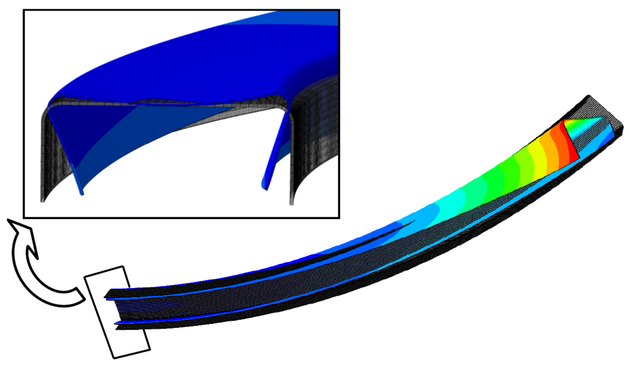

Fig. 3: Spring-In and twist after curing on a generic fuselage frame [Har16]

Other interesting fields to consider chaining of process steps are among others braiding and Automated Fiber Placement (AFP). Here, the compaction during the process has a huge influence on defects. With chaining the compaction simulation to the curing and/or mechanical simulations these defects can be visualized and prevented.

More information and contacts: