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Motivating the development of a virtual process chain for sheet molding compound composites

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This contribution presents a physical process chain and the corresponding virtual process chain for sheet molding compound (SMC) composites. Here, focus lies on the physical process chain as a motivation for the virtual process chain as discussed in the authors' publication [1]. The key steps of the virtual process chain are the identification of initial and boundary conditions, the compression molding simulation, the mapping of data and the structural simulation. The so established virtual process chain is validated via experimental investigations on a demonstrator structure. Both, the predicted results of the compression molding simulation, as well as the results of the structural simulation are in good accordance with the experiments.

1 Introduction

SMC composites, as representatives of fiber reinforced polymers, stand out due to their high specific stiffness and strength, comparatively low manufacturing costs, and the high freedom of design. Complex parts with, e.g., integrated ribs, beads or similar features can be manufactured [2]. SMC parts are produced via a compression molding process [3]. To simplify the development and testing of new parts a virtual process chain is of high advantage. This digital twin of the physical process chain increases the flexibility of part adjustments as well as the optimization of physical manufacturing processes. In order to establish a suitable and sophisticated virtual process chain, which is also able to correctly predict the structural behavior of the produced part, the physical process chain needs to be analyzed and understood in detail. Figure 1 (top) shows the

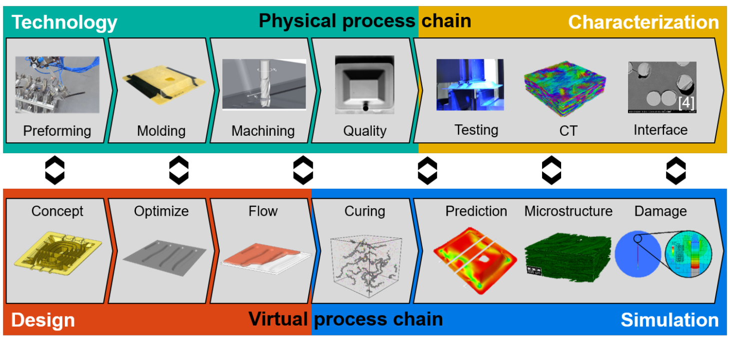

Fig. 1: Physical and virtual process chain for SMC composites. (Interface micro CT scan performed at Fraunhofer IWM [4].)

physical process chain schematically. We summarize the preforming of the initial material components, the compression molding, subsequent machining processes and the quality assurance under the research area Technology. The research area Characterization combines experimental testing, computer tomography and microscale investigations such as interface analysis. Figure 1 (bottom) shows the corresponding steps of the virtual process chain. Here, the research area Design consists of the initial concept finding of the part, as well as optimization and flow computations of the manufacturing process. The research area Simulation covers all simulative aspects from the curing to the prediction of the structural behavior, including, e.g., microstructural information and damage evolution.

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2 Key aspects

When we focus on the key aspects of the process chains, we remain with the steps as shown in Figure 2(a). The compression molding process and the resulting fiber orientation (FO) in the part strongly depend on the initial and boundary conditions. This microstructural composition influences machining processes and especially the structural performance during testing or application. The corresponding virtual process chain needs initial conditions and boundary conditions based on the initial

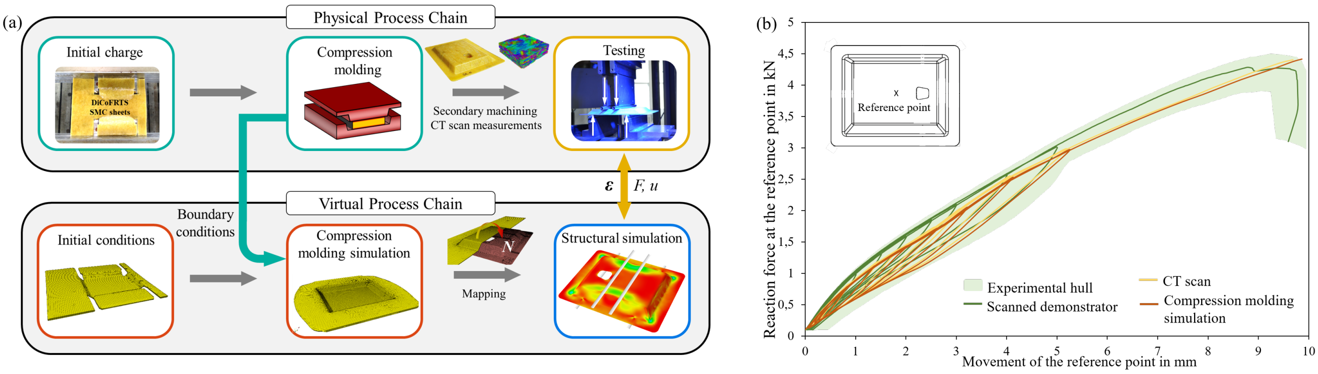

Fig. 2: (a) Key steps of the physical and virtual process chain for SMC composites, (b) measured and simulated force-displacement curves of demonstrator reference point due to cyclic four-point bending.

charge and the compression molding process as an input. The computed data, such as the FO, is subsequently mapped from the molding simulation to the stuctural simulation in order to seamlessly take the data into account in the chain. The structural simulation can then be used to predict the effective stiffness, damage and performance of the part. The predicted effective behavior can be validated via the comparison of the strain field ε, as well as force F and displacement u.

3 Application

In order to analyze the physical and virtual process chain we produced glass-fiber reinforced SMC demonstrator parts and tested the structural behavior via cyclic four-point bending tests. We measured the force-displacement curve of a reference point in the middle of the demonstrator, as indicated in Figure 2(b). We defined the virtual process chain accordingly. We use a Coupled-Eulerian-Lagrangian approach for the flow simulation based on an anisotropic non-Newtonian fluid model [5]. The FO is computed from Advani-Tucker and Jeffery's equation. We transfer the data using a neutral Visualization Toolkit format and the MPCCI MapLib library [6]. For the structural model we implemented an elastic-damageable mean-field approach [7]. The model can depict the leading SMC damage mechanisms, namely fiber-matrix interface debonding and matrix cracking. Figure 2(b) shows the force-displacement curves of the demonstrator reference point. The dark green curve is the behavior of a demonstrator that we also scanned via CT. The light green area is the experimental scatter of all conducted experiments. The result using the FO from the scanned demonstrator is shown in yellow. The red curve is the computed behavior based on the virtual process chain. These results already show that the structural behavior of the demonstrator can be predicted quite accurately based on the virtual process chain. Experimental results and results based on CT scans can be reproduced satisfactorily. A more detailed discussion on the topic can be found in [1]. An extension of the considered steps within the virtual process chain can help to improve the accuracy.

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