Talk: DEVELOPMENT OF CHARACTERIZATION AND SIMULATION METHODS FOR CARBON FIBER SHEET MOLDING COMPOUNDS

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Introduction

The resulting mechanical properties of parts made from fiber reinforced polymers composites (FRPCs) are highly influenced by their manufacturing process. It is therefore important to gather as much knowledge as possible about both the material and the process itself in order to be able to predict correctly the behavior of the component in final use. Over the last few years, the research teams at the Leibniz-Institut für Verbundwerkstoffe and Fraunhofer Institute for Industrial Mathematics have developed accurate and efficient methods for the characterization of carbon fiber Sheet Molding Compounds (C-SMC) processed via compression molding. The output information of the characterization tests and measurements are used to directly generate the required input parameters for compression molding simulations. The simulation is based on a user-defined material model developed specifically for modelling C-SMC materials and has been implemented for general usage within the FEA software LS-DYNA®. The purpose of this paper is to provide an overview of the entire work and to show how the individual results are combined to form a more complete digital process simulation chain. The workflow begins with the constituent materials of the C-SMC and follows on to experimental and simulative considerations to a first simplified digital representation of a final component, and can be extended in the future as required.

Material and Process Characterization of C-SMC Materials

The aim of material and process characterization is to gain an understanding of the material behavior during the process as a function of the process parameters. For C-SMC, the fiber orientation distribution is the most important material parameter that defines its behavior in processing and the final part. Therefore, the process begins with the measurement of fiber orientations on the surface of the semi-finished product during continuous production. By utilizing the polarizing effect of carbon fibers, the polarization camera allows in-situ and accurate detection of fiber orientation (Figure 1a). The polarization images taken by the camera can be used to create a digital representation of the entire semi-finished material product roll. Fiber orientation information can then be extracted for virtual cutting and stacking plans for subsequent process simulations or experimental compression molding runs. [1][2]

The next step is the characterization of the compression molding forces and flow using the so-called press rheometry. Press rheometry allows material characterization close to the real process by using the same equipment and process parameters. Depending on the tool geometry, a 1D or 2D flow is induced in the material. The goal of the experiment is to record the stress response and analyze the flow front behavior of the C-SMC using different process parameters (Figure 1b). It is also possible to analyze the resulting fiber orientation distribution after compression again using the polarization imaging. [3][4][5]

Process Simulation of C-SMC Materials

The results of the material and process characterization experiments serve as input information for compression molding process simulations. A user-defined material model considers both the compaction and flow behavior of the C-SMC during compression molding using the multi-physics FEA solver LS-DYNA®. Based on the results of the characterization tests, the most important material parameters were identified and implemented into the material model. To allow separate consideration of the individual effects, the material model is designed using a building block approach with each block connected by individual parameters (Figure 2a). The advantage of such an approach is the possibility to change the individual mathematical descriptions of the complete model without having to redevelop the model and provides the possibility to add new model extensions as required. While the measurement of the fiber orientation on the surface of the C-SMC semi-finished product provides the initial fiber orientation for the simulation, the verification and calibration of the material model is carried out via a simulation of the press rheometer tests (Figure 2b). In this process, the input parameters are adjusted to such an extent that the most realistic possible material behavior is captured. By analyzing the differences to the real material behavior, necessary future improvements and extensions of the model are identified. Finally, the calibrated material model is used to perform a process simulation at the component level where the fiber orientation, the quality of filling and formation of weld-lines and warpage can all be predicted and analyzed (Figure 2c). [4][6]

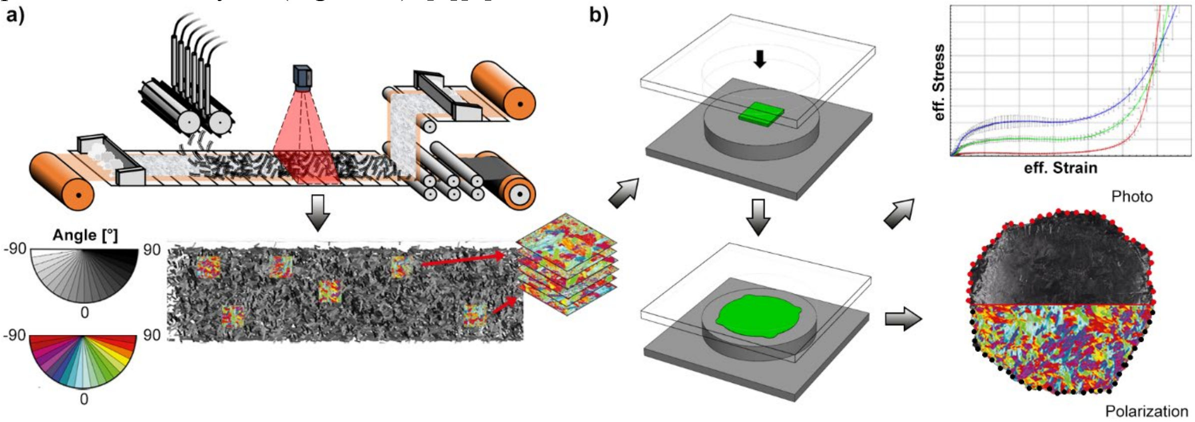

Figure 1: *Overview of material characterization methods and results. a) Measurement of fiber orientation in-situ during continuous production. b) Press rheometry with an open tool geometry and resulting stress response and flow behavior*

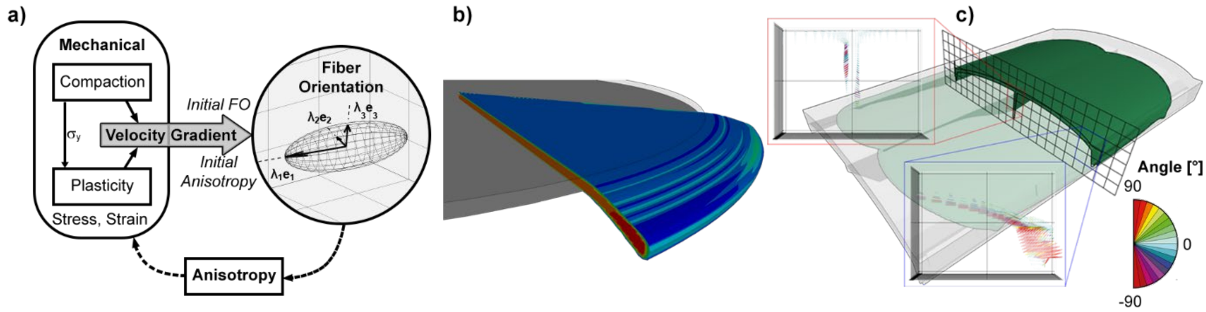

Figure 2: *Workflow used to create a material model for C-SMC compression molding. a) Concept of a building block approach user-defined material model, b) Simulation of characterization (one-eighth) press rheometry model and c) Full component simulation.*

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