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Development and validation of a CAE chain for unidirectional fibre reinforced composite components

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ABSTRACT

Current development of composite components made by Resin Transfer Moulding (RTM) requires numerous manual iteration steps to find the optimal design in conjunction with optimal process control. Still, such components are often highly oversized since the real material behaviour is influenced by the processing history and cannot be sufficiently predicted by simulations. The draping process is the predominating process for the fibre alignments, resulting in varying fibre orientations and local draping effects. These material characteristics influence the moulding process as well as the mechanical performance and need to be considered for sizing and virtual validation of RTM structures. Therefore, a continuous virtual process chain (CAE chain) is developed in this work, where geometry and material data are transferred between the finite element models by using a neutral exchange format and mapping algorithms. The CAE chain is applied and validated by a complexly curved RTM part. To demonstrate the benefit of the CAE chain, a reference model is used, where the fibre orientations are simply projected to the component's surface. For experimental validation, the simulation results are compared to pressure and temperature measurements in the case of moulding simulation, and to tension and bending tests in the case of structural simulation.

1. Introduction

The excellent mass-specific properties of carbon-fibre reinforced plastics (CFRP) can be tailored to the actual requirements and make CFRP well qualified for use in lightweight constructions. However, the economical exploitation of these theoretical potentials is currently limited by insufficiencies of manufacturing processes, by lack of knowledge of the material behaviour and by insufficient prediction of the structural performance. These weaknesses can only be solved by establishing a close collaboration between the three disciplines of methods, materials and processes [1]. Another important precondition for improving CFRP applications is an integrated simulation of the entire CFRP process chain, where all significant process parameters and process results are transferred between the single simulation steps. Such a continuous virtual process chain (CAE chain) ensures a reliable consideration of manufacturing effects, which may extensively influence the material behaviour. Furthermore, a continuous CAE chain offers the potential to accelerate the large number of development loops and, thus, reduces the overall development costs.

For metal processing, several holistic simulation platforms with FE-based data exchange have already been established (e.g. FEDES [2], MpCCI [3], ICME [4]). Also in the field of injection moulding, software packages are available, which enable the transformation of process simulation results to the FE models of structural simulation (e.g. DIGIMAT, SIGMA SOFT). While CAE chains for metal processing and injection moulding are already established and applicable for commercial process development, the development of CAE chains for high-performance FRPs like RTM is just at the beginning. Due to the complexity of the multi-step and multi-physical RTM process, simulation methods for the single process steps are mostly implemented in highly sophisticated, stand-alone finite element (FE) or finite volume (FV) software. A time-efficient kinematic draping analysis, which disregards

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material properties and boundary conditions, is not sufficient to reliably predict the preformed fibre architecture [5]. Consequently, kinematic draping analysis and simple curvature models are just conditionally suitable for continuous CAE chains, as shown by Bickerton et al. [6,7] for mould filling. For woven fabrics, reliable homogeneous FE models are available [8] and have successfully been applied by Louis and Huber [9] to model draping effects on mould filling. Non-crimp fabrics like unidirectional (UD) fabrics, on the other hand, show a far different forming behaviour than woven fabrics and local draping effects cannot be predicted as precisely by homogenised material models [10]. To overcome such discrepancies between "as-built" and "as-planned" in structural validation, so-called feedback methods have been developed in the past, which transfer the actual manufactured fibre orientations into structural simulation models [11]. Brauner et al. [12] have applied online process monitoring methods to measure ply position, thickness and fibre orientation and use those data as input for thermo-chemical curing and structural simulation.

Just in the last few years, larger consortia have spent effort to holistically combine multi-step process and structural simulation methods for UD non-crimp fabrics, presented so far only at conferences [13–18]. While previous and current work on CAE chains mostly concentrates on the transfer of fibre orientations, further local effects like fibre volume content, fibre waviness, overlaps and gaps have hardly been considered. However, they may have considerable effect on the resin flow [19] and the structural behaviour [20]. Moreover, there is a shortage of continuous experimental validation of the CAE chain throughout the entire process from draping over moulding up to structural performance, particularly for complexly curved parts. The current work presents a CAE chain, where intermediate development stages (presented at conferences [15,18]) have been extended by a transformation method for fibre volume contents. Furthermore, a comprehensive experimental test program has been conducted to validate the proposed CAE chain throughout the RTM manufacturing process, from draping, over moulding up to the final structural behaviour.

2. Virtual process chain

2.1. Structure of the CAE chain

The virtual process chain proposed in this work is illustrated in Fig. 1. The CAE chain consists of four simulation domains: draping, moulding, curing and structural simulation. The simulation steps are connected by information flows, which comprise the transfer of relevant process parameters and material data. The focus of the present work is the reliable prediction of process results and the reliable flow of information from left to right. Therefore, the CAE chain is applied to a complex 3D-curved structure: Draping, moulding and structural simulations are performed and draping simulation results are mapped to the subsequent simulation steps. Curing is not yet included, but subject of ongoing investigations. To evaluate the benefit of the CAE chain, the simulation results of the mapped models are compared to experimental tests and to reference simulation models, in which fibre orientations are simply projected to the component's surface.

For transfer of information from draping to moulding and structural simulation, the simulation results have to be converted between the different types of FE meshes. Therefore, two intermediate steps are necessary, cf. [15]. First, a neutral exchange format is established to be independent of the applied simulation software. Second, a uniform mapping software is used to suitably convert the data from one FE mesh to another. As interchange format the vtk ASCII format has been selected. In order to conduct the mapping, the mapping library MpCCI MapLib is applied [21]. The transformation process between two adjacent simulation domains is illustrated in Fig. 2.

2.2. Neutral exchange format

The requirements for a neutral file format are based on the needs for data mapping, particularly on the used data types of the FE software and on the mapping software. Hence, all possible element types from various FE programs need to be reflected. Additionally, all relevant composite parameter have to be considered, like fibre orientations as vectors or fibre volume content and thicknesses as scalars. To fulfil these requirements, the vtk file-format from the Visualisation Toolkit project had been selected. All elements and value types are supported, and the mapping library MpCCI MapLib has a native reader/writer for this format. Additionally, the open source scientific visualization program ParaView is available in order to visualise, compare and assess the data of the neutral vtk format. More information on the used features of the vtk file-format can be found in [15].

To generate and to translate the vtk files, software-specific transformation scripts have been developed, each dedicated to the applied software package (e.g. LS-DYNA, PAM-Form, PAM-RTM, OpenFoam, Abaqus and others) used for a certain simulation domain. In Table 1 all command line scripts are listed which have been implemented in the ongoing project to build up the CAE chain. While the transformation of the mesh and the composite information into the vtk format is relatively simple, the transformation of the mapping results from vtk format into the respective input deck of the FE software is much more complex. For example, the handling of gaps and overlaps has to be performed in this step. The transformation script is responsible to solve these issues adequately and to generate a correct FE input deck which is processable by the FE software.

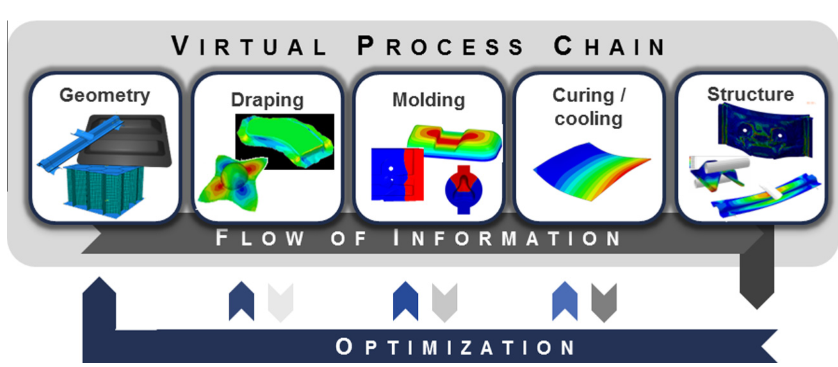

Fig. 1. Virtual process chain combining design, process and structural simulation.