NUMERICAL ANALYSIS OF POST-FILLING FLOW IN HYBRID OOA PREPREG/LCM PROCESSES

M. Danzi[1*], D. Filipovic[1], C. Schneeberger[1], P. Ermanni[1]

[1] *Laboratory of Composite Materials and Adaptive Structures, ETH Zurich, Leonhardstrasse21, 8092 Zurich, Switzerland*
*Corresponding author (mdanzi@ethz.ch)

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Introduction

Hybrid Out-of-Autoclave (OOA) prepreg / Liquid Composite Moulding (LCM) processes are leading-edge solutions for the fabrication of highly integrated composite structures. They consist in the combination of pre-impregnated textiles and dry preforms subsequently impregnated by infusion methods. The hybrid technique affords great flexibility in design and material choice, merging the advantages of the single technologies to overtake their disadvantages [1]. The usage of OOA systems further enhances the potential for costs saving and large part manufacturing. Moreover, the process foresees the co-curing of the two resins, ensuring short processing cycles and optimal adhesion between the components.

In hybrid processes, the biggest concerns lie on the quality of the transition zones between the two resins (Figure 1). The properties of this laminate region are defined by complex fluid-structure interactions, occurring during the impregnation and consolidation of the reinforcement. The process is divided in two phases. (1) Prior to the infusion of the second resin system, the prepreg resin flows in through-thickness direction into the dry fabric. This mechanism is called bleeding and it is the consequence of the consolidation of the prepreg stack. (2) After complete impregnation, the resin pressure in trough-thickness direction tends to homogenize, resulting in a further resins relocation.

Numerical tools enable a thorough investigation of those mechanisms and permit to assess the influence of material and process parameters. To this purpose, we have established a coupled fluid-mechanical numerical simulation describing both the bleeding and the post-filling resin flow. We have put our focus on the implementation of a comprehensive material model for the description of the fibre bed compaction behaviour and in particular, for the representation of the compaction/decompaction hysteresis.

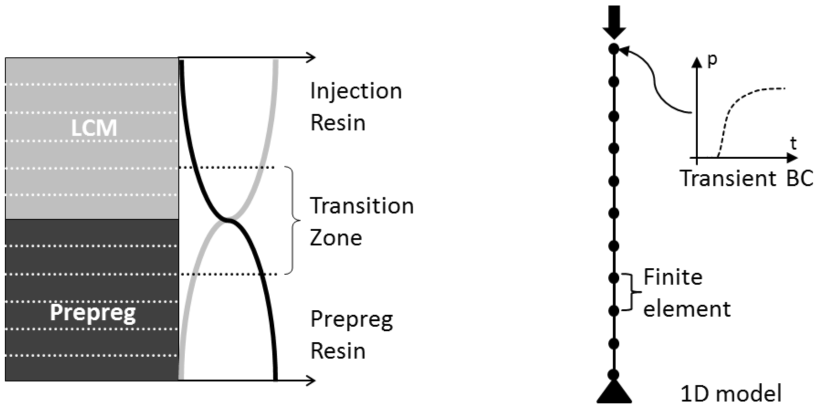

Figure 1: *Representation of the hybrid OOA prepreg / LCM laminate.*

Numerical Model

In this investigation, we consider a hybrid laminate with six plies of MTM®44-1/TC516 prepreg at the bottom and six plies of TC516 dry fabric on the top, subsequently impregnated with a MVR®444 LCM resin (Figure 1). A 1D numerical simulation is implemented in COMSOL Multiphysics, exploiting different modules for the description of the mechanical deformations (Terzaghi's law), resin flow (Darcy's law) and laminate consolidation (equation of continuity). The first process phase (prepreg resin bleeding) is defined through a full coupling of the model physics, considering homogenized single scale flow conditions and imposing a compaction load at the upper layer. Additional information on this simulation can be found in [2]. For the simulation of the second process phase, we implement transient boundary conditions at the upper laminate end, simulating the arrival of the second resin system (Figure 1).

The relevant material properties for the description of the hybrid process are the textile through-thickness permeability, the resins rheology and the fibre bed compaction stiffness. All those properties have been characterized experimentally [3]. For the description of the fibre bed compaction behaviour, an extension of the approach suggested by Comas-Cardona is used [4]. The compaction hysteresis is described by implementing in the simulation a non-linear elastic-plastic material model.

Results and Conclusions

The established simulation enables the prediction of resin pressure and laminate consolidation during the bleeding and the post-filling phases. The introduction of the fibre bed decompaction hysteresis model has a significant influence on the results. The hysteresis behaviour affects the consolidation of the laminate during and after the resin flow. Its effects are visible also at the end of the post-filling phase, when the pressure field has homogenized, resulting in a non-even fibre volume fraction distribution in the final laminate (Figure 2).

The numerical tool has been further exploited in the investigation of the process robustness, analysing the influence on the results of two process parameters: process temperature and arrival time of the second resin (holding time). Based on the simulation results, we are able to suggest tailored process strategies for the production of integrated components. The optimization process aims at obtaining laminates with overall good quality (low porosity) and a smooth transition between the prepreg and the LCM region.

This work is highlighting the importance of numerical tools for the understanding of fluid-structure interaction mechanisms in composite processing. Moreover, we show the relevance of considering the fibre bed compaction hysteresis behaviour in through-thickness resin flow simulations.

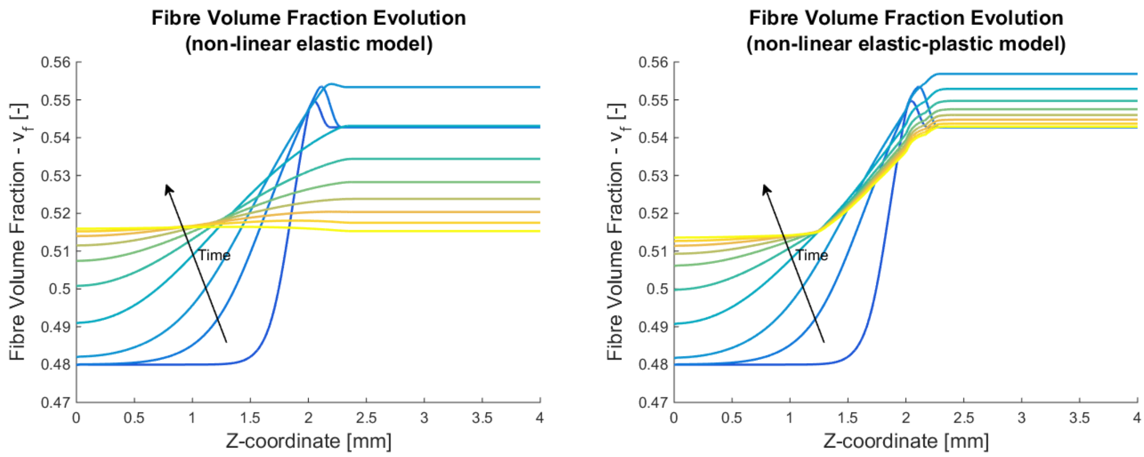

Figure 2: *Numerical solution of the fibre volume fraction evolution: visualisation of the fibre bed compaction hysteresis behaviour (resins temperature: 80°C, holding time: 120s).*

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