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Titre :

Characterization of fabric layups by pressure print analysis and simulation of dual-scale flow based on topological skeletonization: application to composite materials processing

Résumé :

When compared to traditional materials, composites present the unique characteristic that the material microstructure and the part are created at the same time. It is only when layers of fibrous material are stacked and compacted in a mould that the complex mesoscopic architecture of the material is defined. As a consequence, the quantification of macroscale properties such as permeability can be a difficult task, as the unpredictable structure of the material is difficult to know.

In this work, the focus is put on the study of continuous fiber preforms in the context of Resin Transfer Moulding (RTM) processes. The aim of the thesis is two-fold, with the output of the first objective becoming the input to the second. The first objective is to propose a new methodology to obtain mesoscale geometrical data from preforms during processing, which would be difficult to obtain by traditional techniques. The second objective is to provide a new numerical model able to predict permeability or perform mesoscale filling simulations in a computationally efficient way and over large domains.

In the first part, the focus is on the investigation of the detailed mesoscopic features that characterize multi-layer preforms. To acquire data we propose a novel technique based on the analysis of the pressure field experienced by a dry preform under compaction. By using a commercial pressure-sensitive film, the local pressure distribution exerted by a stack of layers against mould walls is captured and analysed. Taking advantage of the periodic morphology of textiles, geometric patterns revealed by the pressure field are interpreted according to spectral Moiré analysis to recover the orientation and spatial distribution of each individual layer in the stack. This information allows one to reconstruct a digital model of the physical stack of plies.

In the second part, the focus is shifted on taking advantage of the recovered information to make predictions of the preform properties. The reconstructed digital architecture of the preform is used to carry out numerical flow simulations at the scale of the yarns, to characterize permeability of the stack or directly perform filling simulations. To avoid the huge computational cost demanded by solving a three-dimensional problem on such a small scale, the stack geometry is replaced by a skeletonized representation of the same, on which a two-dimensional flow problem can be solved numerically by adopting lubrication theory. This "medial skeleton" model is first formulated in its single scale version (flow in channels) and then extended to dual scale (flow in channels and yarns). The model potential is illustrated through several test cases.

This research establishes a pathway going from the non-destructive acquisition of data to the simulation of the dual-scale flow inside a multi-layer layup of textiles. The potential of the technique, the applicability to industrial context, as well as its limitations and future prospects are discussed.

Mots-clés:

Fabric layups, Pressure print analysis, composites processing, Topological skeletonization, Moiré theory, Dual-scale flow simulation