ANALYSIS OF MULTI-SCALE EFFECTS ON THE PERMEABILITY OF TEXTILE REINFORCEMENTS FOR LIQUID COMPOSITE MOLDING

L. Bergamasco, S. Izquierdo*, M. Laspalas, M. Lizaranzu, M.A. Jiménez

Instituto Tecnológico de Aragón (ITA) - María de Luna 8, 50018 Zaragoza, Spain
**Corresponding author's e-mail: sizquierdo@ita.es*

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Introduction

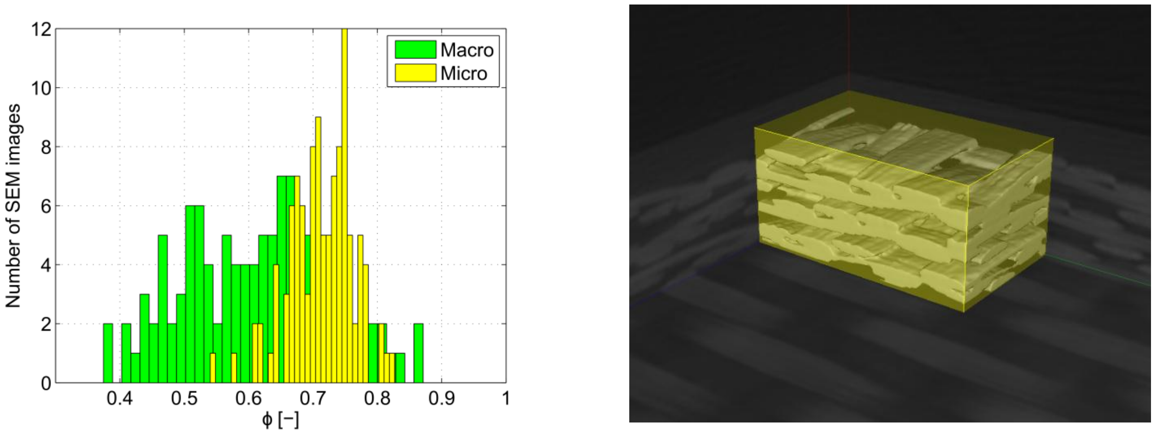
Accurate permeability prediction of fibrous textiles for Liquid Composite Molding (LCM) is a cumbersome task, due to the hierarchical structure of the preforms and thus to the multi-scale nature of the problem. For fully saturated textiles, the uncertainty primarily lies in the modification of the structure of the textile during the manufacturing process, which is due to the compression in the mold and to the injection of the resin. In this contribution we analyze these two stages separately for an 8H Satin Weave. We show that by means of standard numerical methods, the experimental data on permeability cannot be recovered over the whole range of effective-fiber-volume fractions. Therefore, we investigate the causes of this discrepancy. The effect of the textile compression is analyzed at yarn scale by an analogy with micro-structured viscoplastic soft solids. The effect of deformation due to resin flow is addressed by analyzing the fluid-structure interaction at fiber scale using a mesoscopic model, which yields the local change in permeability through a topological invariant (the Euler characteristic). Finally, we propose a unified framework based on Computational Fluid Dynamics (CFD) for the analysis of these effects.

Experimental data

A complete experimental analysis of the textile object of study is firstly presented, namely: effective permeability, compression curve of the textile, analysis by Scanning Electron Microscopy (SEM) and Computed X-ray Micro-Tomography (CMT). The micrographies are processed using image analysis techniques, which allow extracting informations on micro- and macroscopic volume fractions. Similarly, the microtomographic data is also processed in order to extract the real geometry of the textile.

Standard CFD approach

We adopt the standard approach used for the numerical evaluation of the permeability in textile preforms. A simplified geometry of a Representative Elementary Volume (REV) of the textile is modeled by Computer Aided Design (CAD). Two cases are considered: impermeable and permeable yarns. The governing equations are numerically solved using the commercial code ANSYS Fluent®, where in the permeable case the microscopic permeability is given by well-established empirical laws [1]. It is shown that by means of this simplified approach, the effective (experimental) permeability and the anisotropy of the permeability tensor cannot be recovered over the full range of volume fractions. The uncertainties underlying the errors are investigated and discussed.



(a) (b)

Figure 1: *Distributions of micro- and macroscopic volume fractions in the textile specimen yield by the image analysis of scanning electron microscopic data (a). Microtomographic data treatment for the geometrical reconstruction (b).*

Phenomenological model for textile compression

A phenomenological model is proposed for the analysis of the compression of the textile in the mold. The behavior of the yarns under compaction is described by an analogy with viscoplastic soft solids. A simplified geometrical model for the evolution of the shape of the yarns under compression yields the reciprocal contact areas, which allows the rheological model to be fitted with the experimental data using a generalized solution for compressive forces of viscoplastic materials [1].

Mesoscopic kinetic model for fiber dynamics

We address the problem of the fluid-structure interaction occurring between the fibers and the fluid flow during the injection of the resin. A mesoscopic model for the fiber dynamics is derived by analogy with suspensions of interacting particles subject to movement restrictions (caused by the textile geometry). The model provides information about the local topology (through the local Euler characteristic) of the fibers at the microscopic scale, which affects the percolating paths and thus the overall permeability [3].

Conclusions and proposed CFD approach

The work is concluded with a critical discussion of the multiscale-based uncertainties found to affect the numerical evaluation of the permeability of textiles. On the basis of the presented models, we propose a unified framework for the simulation of the compression of the textile in the mold and the injection of the resin. The proposed model is fully based on CFD and for its implementation we propose the commercial solver ANSYS Fluent®. The model is intended to be a useful tool for an improved evaluation of the permeability of textiles for LCM.

References

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