STOKES-DARCY FLUID FLOW SIMULATIONS WITHIN 3D INTERLOCK FABRICS WITH CAPILLARY EFFECTS – EXPERIMENTAL INPUT INFLUENCE AND COMPARISON WITH EXPERIMENTAL OUTPUT

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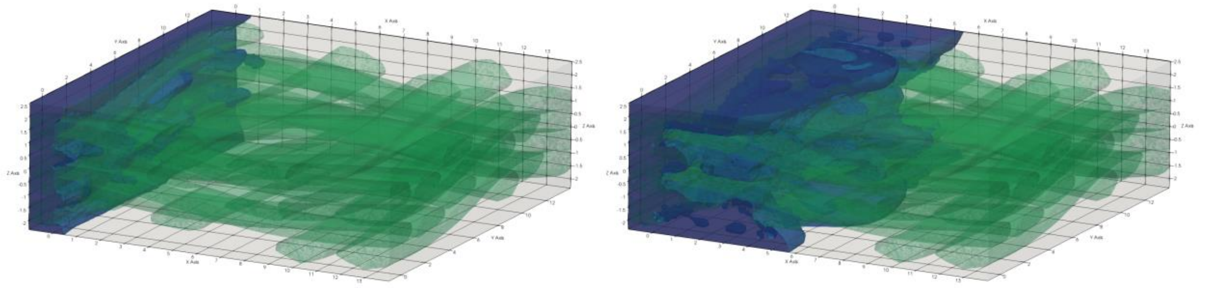
Abstract

Resin Transfer Molding (RTM) is a widely used process in composite material manufacturing, involving the compaction of a fibrous 3D interlock preform to achieve targeted Fiber Volume Fraction (FVF), followed by impregnation with liquid resin. Dual-scale flows within and between homogeneous equivalent porous yarns must be modeled for predicting impregnation schemas and defects. At the mesoscopic scale, fabric unit cells are characterized by yarn morphology and intra-yarn FVF fields. Those parameters shall be linked to a permeability tensor field for application of the Darcy law at a larger scale. The dual-scale nature significantly affects saturated and unsaturated fluid flows, especially due to capillary phenomena within yarns, which are modeled as an addition to Darcy's law via a capillary pressure. The effect on the effective value of the calculated permeability has yet to be assessed. The aim of the numerical approach is to develop a robust numerical framework for simulating fibrous media impregnation at the mesoscopic scale [1-3] and then to compare the results with experimental characterizations. Fluid flow is modeled by the Darcy equation within porous yarns and by the Stokes equation between yarns, employing a monolithic approach with a mixed velocity-pressure formulation stabilized by a Variable Multi-Scale (VMS) method. Accurate description of resin flow within porous yarns requires locally oriented intra-yarn permeability tensor fields and capillary stress tensor (the "orthotropic capillary pressure" [4]) at the resin-air interface. Additionally, pressure enrichment is introduced at the fluid front, represented by a level set function, to capture pressure discontinuity in Darcy domains. Saturated and unsaturated Stokes-Darcy fluid flow simulations are conducted to determine fabric permeability as a function of global FVF, corresponding to different compaction levels, evaluating hence the influence of capillary phenomena on the impregnation scenario (Figure 1).
Experimental estimations of permeabilities have been performed at different scales and regimes [5]. The intra-yarn permeability and capillary stresses have been estimated to be fed to simulations. At the scale of the process, permeabilities with steady and transient flows have been estimated with a set-up complying with the standard ISO 4410:2023[6] (Figure 2).

Although the order of magnitude for steady flows is rather easy to compare, a discussion is needed for these estimations on the transient flow.



(a) (b)

Figure 1. Filling simulation of the as-woven unit cell; (a) beginning and (b) middle of the simulation.

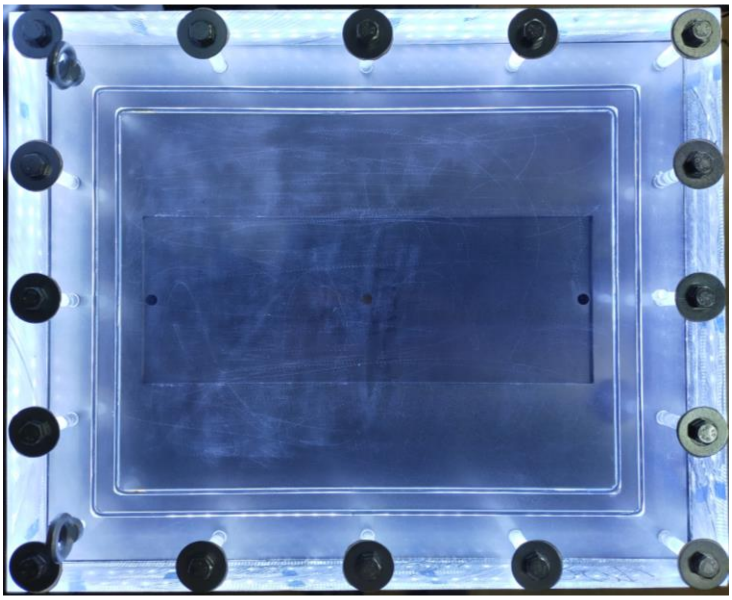


Figure 2. Setup of permeability test complying to ISO 4410:2023 [6].

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