FIBROUS REINFORCEMENT MICROSTRUCTURE EVOLUTION DURING THE INFUSION PROCESS: EXPERIMENTAL CHARACTERIZATION WITH CT-SCAN

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Introduction

Composites manufacturing using the infusion process (VARTM) involve a decompaction phenomenon due to the vacuum bag flexibility [1]. For structural parts, woven or non-crimp fabrics are mainly used and exhibit a double-scale flow during their impregnation by a liquid resin. Previous studies modelled and simulated both the double-scale flow and the evolution of the compaction state, assuming that the fibrous preform is a continuous medium with a varying permeability ([2], [3]). Nonetheless, a detailed knowledge of the fabric microstructural morphology is essential because it impacts intra-tow and inter-tow permeabilities [4], and then, for instance, composites part filling time.

This study proposes an experimental methodology to quantify at macro-scale (stack scale) and meso-scale (tow scale) the evolution of a same fibrous microstructure under several compaction states.

Experimental method

A controlled level of vacuum (60 mbar) is applied in a cavity where five plies of quasi-unidirectional non-crimp glass fabric are previously laid down (Figure 1a, dry state). A 1D continuous flow of glycerol is then maintained along the fibers direction, leading to a decompaction phenomenon near the fluid inlet (Figure 1a, saturated state). For each compaction state, two 3D images of the microstructure are recorded: the first one near the fluid inlet and the second one near the vacuum vent.

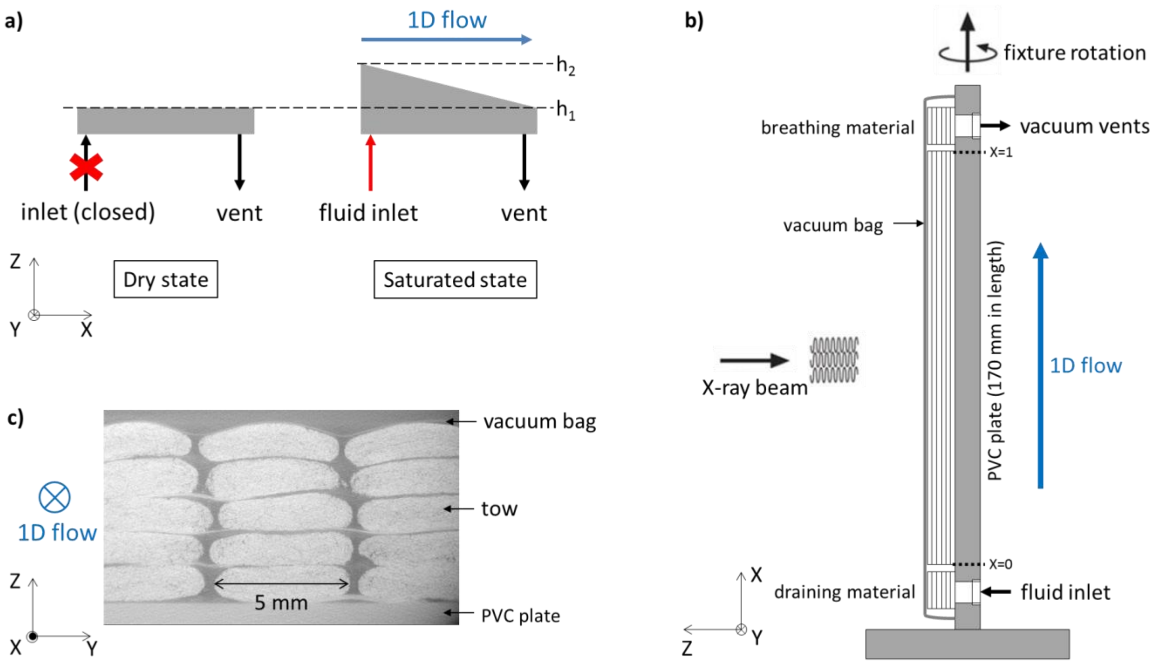

Figure 1: *a) Experimental protocol. b) Sketch of the set-up for in-situ infusion in the X-ray CT. c) A cropped slice (YZ plane) extracted from the X-ray CT 3D reconstruction at X=10 mm, near the fluid inlet, at dry state.*

To implement this experimental procedure, a set-up is developed to realize *in situ* downsized infusion inside the X-ray CT device (Figure 1b). A PVC plate is dimensioned to respect the geometric constraint imposed by the X-ray CT device. To ensure tightness, a double vacuum circuit is adopted. A bagging strategy was previously validated to limit boundary effects (not detailed here).

The obtained 3D reconstructions (Figure 1c) have a field of view (40x40x40mm^3) large enough to measure the macro-scale decompaction. For dry and saturated states, 11 slices (YZ plane, see Figure 1c) along X axis are selected. For each slice, the vacuum bag detection allows the definition of an average stack thickness. Moreover, the resolution of the obtained images (10 µm^3/voxel) is sufficient to detect precisely the boundary of each tow. A slice (YZ plane) near the fluid inlet is analyzed, and an image-processing algorithm including edge detection [5] is applied to compute tow areas.

Results and discussion

In the following section, the deformation is defined as (1):

$$\Delta H_i = \frac{{h_i}^{saturated} - {h_i}^{dry}}{{h_i}^{dry}} \tag{1}$$

where *i* stands for *macro* or *meso*, h_{macro} is the stack thickness, h_{meso} is the tow area.

At macro-scale, the fluid flow induces a thickness variation gradient along the X-axis (Figure 2a). It validates the ability of the set-up to reproduce and record the decompaction phenomenon within constrained area of the X-ray CT device. Near the fluid inlet (X=0.08), extracted microstructures at dry and saturated states (Figure 2b) highlight a decompaction gradient along the thickness (Z-axis): the tow displacement is higher near the vacuum bag. Nonetheless, the tows deformation, occurring along the Z-axis, is comparable (Figure 2c) for tows located near the vacuum bag and near the PVC plate.

The set-up, whose efficiency is validated at macro-scale, allows a novel quantification of the decompaction phenomenon at meso-scale. Tows deformations and displacements within the stack, occurring mainly along the Z-axis (negligible movements and deformations are recorded along the Y-axis), drastically reorganize the fibrous reinforcement microstructure.

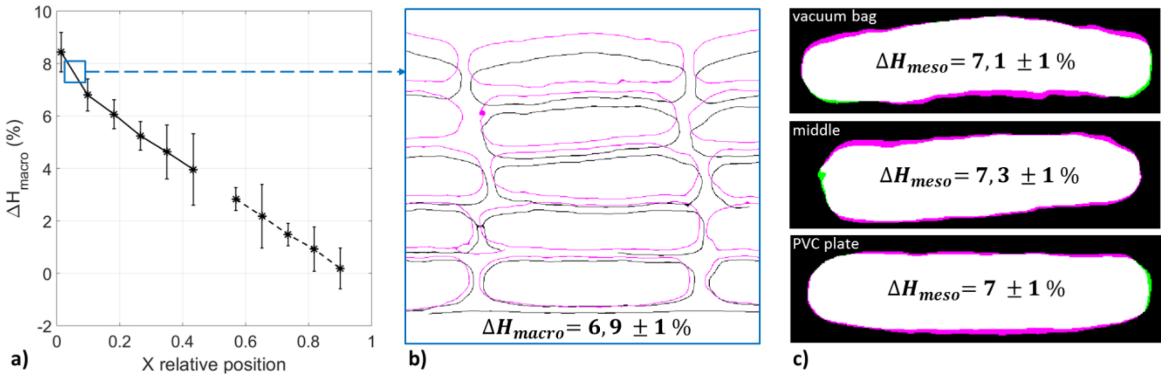

Figure 2: *a) Macro-scale decompaction along X-axis (flow direction). b) Superposition of dry (black) and saturated (pink) post-treated microstructures at X=0.08. c) Superposition of dry (white) and saturated (pink) extracted from b).*

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