Characterization of a reinforcement fabric for high-volume production of composite components via melt thermoplastic Resin Transfer Molding (RTM)

Long-Fiber Reinforced Thermoplastics (FRTP) are potential candidate materials for light structural components in vehicles, thanks to an interesting combination of low weight and high mechanical strength. FRTP can be produce by RTM, a type of process which involves the direct injection of a resin in a mold where the reinforcement (in form of fabric) is placed. Critical parameters affecting process rate are resin viscosity and fabric permeability, which is a measure of how easily the fabric is impregnated by the resin. In this study, a fabric with a particular structure which confers to it a high permeability is studied and characterized. Permeability is measured in flow experiments with model fluids. Fabric architecture is observed by x-ray microtomography and used to develop a simple numerical model for permeability, which is found in good agreement with experimental results. The presence of capillary effects during fabric impregnation is also investigated.

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Introduction

Thermoplastics in the melt state have very high viscosity (>100 Pa.s), and therefore require high injection pressure in order to flow in a mold, which could cause destruction or movement of the fibers during RTM. In this project, we use thermoplastics (polyamides) specifically formulated to have reduced viscosity (between 10 and 100 Pa.s) without losing mechanical properties, which are suitable for RTM. Darcy's law [1] for in-plane unidirectional flow at constant fluid pressure leads to an impregnation time dependent on resin viscosity (η) and fabric permeability (K) of

$$t \propto \frac{\eta}{K}.$$

Therefore it is necessary to increase fabric permeability in order to obtain reasonable process time. In this work we study the permeability of a fabric whose permeability is increased by the presence of large channels in the flow direction.

Glass Fabrics

A non-crimp fabric (NCF) and a twill 2/2 (woven) are studied (Fig. 1). Contrarily to wovens, in NCF fiber bundles are simply overlapped and stitched. The NCF under study has a special architecture, with bundles denser and thinner in one direction than the other. The meso-structure of this fabric observed at x-ray tomography (Fig. 1) shows the presence of longitudinal channels between the bundles and aligned in one direction, which is not observed for the woven.

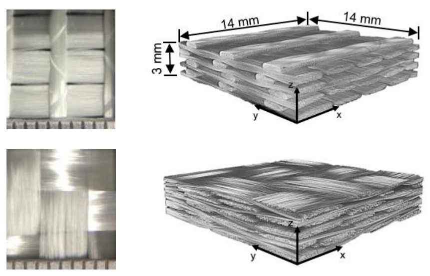

Fig. 1: Top view and 3D reconstruction from x-ray tomography for a 4-layers NCF (top) and 5-layers woven (bottom)

Permeability Measurements

Fabric permeability is measured in a setup (Fig. 2) which allows both unsaturated (from flow front evolution *L(t)*) and saturated (from fluid flow rate *Q* at outlet) measurement, for impregnations performed at constant applied pressure (-Δ*P*) at the inlet. Therefore, for each experiment two permeability values are obtained, i.e.

$$K_{unsat} = -\frac{(1-V_f)\,\eta\,L(t)^2}{2\,\Delta P\,t} \qquad (1)$$

$$K_{sat} = -\frac{Q\eta L_{tot}}{A\Delta P} \qquad (2)$$

and their ratio $R_S = \frac{K_{unsat}}{K_{sat}}$ is used to evaluate the presence of capillary effects [2] during unsaturated flow.

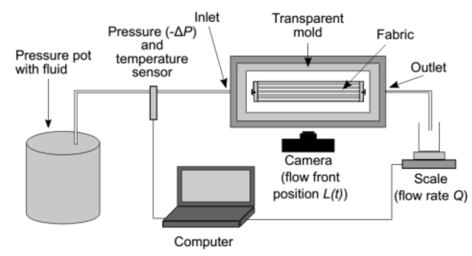

Fig. 2: Setup for permeability measurements

Numerical model

A model was developed to estimate (saturated) permeability of the NCF based on its micro/meso-structure (Fig. 1) and on hydraulic circuit analysis, assuming that flow is predominant in the channels and non-relevant within fiber bundles. Pressure drop in a channel of arbitrary shape is defined as[3]

$$-\Delta P = R_{hyd} Q_{out} \qquad (3)$$

where R_{hyd} is the hydraulic resistance, equal to

$$R_{hyd} = 2\eta L P_c^2 / A_c^3, \qquad (4)$$

P_c, A_c and L being perimeter, area and length of channel. Combining Eqs. 2 and 4, permeability of a channel is:

$$K_{channel} = A_c^3 / 2 P_c^2 A \qquad (5)$$

and A is the cross-sectional area of a unit cell. Eq. 5 is valid in the case of. Eq. 5 needs to be adapted depending on the shape and connectivity of channels, which changes with the number of layers under compaction.

Results

- Permeability of the NCF is almost one order of magnitude higher than the woven for comparable fiber content (Fig. 3)
- Estimation of permeability based on channels is in agreement with experiments, meaning that micro-flow is not relevant (Fig. 3).
- For the woven, capillary effects decrease with capillary number as expected[2], but they do not play a significant role in the NCF (Fig. 4).

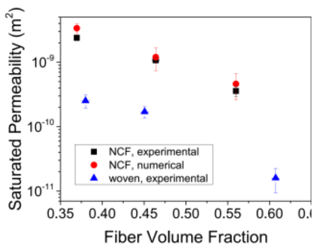

Fig. 3: Saturated permeability varying with fiber volume fraction

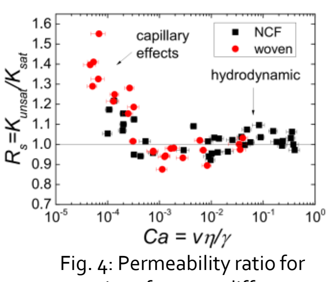

Fig. 4: Permeability ratio for a series of tests at different capillary numbers. V=fluid velocity, γ=surface tension

Expected impact

The present work focuses on the characterization of glass fabric reinforcements for production via RTM process of FRTP components, which are at the same time light and strong, and could therefore replace steel in vehicles in order to reduce their overall weight. RTM has the advantage of allowing production of components with high degree of complexity at low-cost of equipment. However, production rate with melt thermoplastics is low due to their high viscosity. To ease the production process, a fabric with higher permeability has been identified and characterized, in order to gain a deeper understanding of the flow mechanisms. We found that the presence of gaps, or channels, is the key to permeability enhancement. For instance, this can be done by introducing a third phase in the fabric preform[4]. Moreover, we developed a simple yet effective model to predict permeability in the case of longitudinal channels, which allows to easily predict filling time

References

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