CAPILLARY WICKING IN FABRICS; ORTHOTROPIC ISSUES, MODELING OF SWELLING AND EFFECT OF RESIN

M. F. Pucci[1*], P-J. Liotier[1], S. Drapier[1]

[1] *Department of Mechanics and Materials Processing, George Friedel Laboratory, Mines Saint-Étienne, 158 Cours Fauriel 42023 Saint-Etienne, France.*
*Corresponding author (monica.pucci@emse.fr)

Keywords: *Capillary wicking, Sustainable composites, Fibre swelling, LCM processes.*

Introduction

Liquid Composite Moulding (LCM) processes are well-known as efficient low cost processes to manufacture composite with high performances or bio-based reinforcements. Nevertheless the problem of voids formation is still common and of primary importance. Void minimization in composites manufactured by LCM calls for an improved understanding of local wetting to achieve void predictions in composite parts, development of models for fibrous preforms filling and defects location prediction. Local wetting properties depend on physico-chemical and morphological aspects that can be controlled through fibre treatment. However, caring about the sustainability of both reinforcements and resins implies to avoid some chemo-mechanical treatments that could generate unhealthy products or wastes [1].

Capillary wicking in a fibrous medium is described by the Washburn equation and can also be modelled by Darcy law under the effect of a capillary pressure P_{cap} [2]. The orientation of the fibres in those reinforcements has a significant effect on the capillary wicking kinetic. Methodologies for characterizing capillary wicking in both flax and carbon fibres reinforcements were set, for selected quasi-UD fabrics in their three main directions. Mass gain during wicking recorded by a tensiometer will be used for the characterization of both geometrical effects and wetting parameters to determine the P_{cap}. For flax reinforcements, sensitive to liquid sorption, results observed are a superposition of the mass gain due to capillary wicking and porous medium fibre volume fraction modification due to swelling. Those effects have been modelled and a modified approach of Washburn theory has been developed to predict accurately capillary wicking in fabric undergoing swelling in liquid [3].

Experimental methods

The spontaneous impregnation of fibrous reinforcements inserted in a cylindrical sample holder of radius R, by a liquid (wicking) can be described through a modified Washburn equation [2]:

$$m^2(t) = \left[\frac{(c\bar{r})\varepsilon^2 (\pi R^2)^2}{2} \right] \frac{\rho^2 \gamma_L \cos\theta_a}{\eta} t \qquad (1)$$

where c is a parameter taking into account tortuosity, $\bar{r}$ is a mean porous radius, ε the porosity = 1-V_f (the fibre volume ratio). All parameters in the square brackets concern morphology and configuration of porous medium. The other parameters express the dependence of wicking on the interactions between the medium and the liquid (through ρ, η and γ_L that are respectively the density, viscosity and surface tension of liquid, and θ_a, that is an apparent advancing contact angle). In parallel, a flow through a porous medium can be described by the well-known Darcy law, relating an equivalent fluid velocity v_D to the pressure drop, through the permeability of the considered medium K and the liquid viscosity η. From the equivalence between the Washburn equation and the Darcy law, a new definition of capillary pressure was given [2]:

$$P_{cap} = (c\bar{r})\varepsilon \frac{\gamma_L \cos\theta_a}{4K} \qquad (2)$$

Wicking tests were performed with a tensiometric procedure set to measure the geometric factors and the apparent θ_a for unidirectional fabrics in their three main directions. First quasi-UD carbon fabrics (V_f =40%) were tested with water. Then flax fabrics were submitted to a thermal treatment that modifies the wetting behaviour of fibres [1] and wicking tests were performed varying the V_f for both untreated and treated flax fabrics.

Results and discussion

Fig.1 shows wicking tests recorded for carbon fabrics (V_f =40%) in the warp direction of quasi-UD fabrics with n-Hexane and water. A linear trend of wicking was observed allowing to fit experimental curves with the Washburn equation (Eq.1) and determining both geometrical factors and θ_a for capillary pressure calculation (Eq.2). Linear trends were also found for the other main directions of fabrics [2]. For untreated and treated flax fabrics with water (V_f =40%) difference in wicking kinetics were observed (Fig.2-left). Treated fabrics present a linear trend that can be fit with Eq.1 just as for carbon fabrics. Untreated flax fabrics swell in water causing an evolution of geometrical parameters during wicking. A semi-empirical model considering this effect was then introduced [3]. Washburn equation was modified for fabrics undergoing swelling and a fit with the new law was achieved (Fig.2-right). Experimental procedure can be then applied to different fabrics and liquids, allowing to evaluate the influence of material geometry (morphology of fabrics), porosity (different V_f), but also viscosity and surface tension of liquid on the capillary impregnation phenomena. Wicking tests using resins were performed for untreated and treated flax fabrics, revealing a significant difference in impregnation kinetic due to the treatment. Including those capillary parameters in finite elements simulations, to describe more accurately LCM processes is the next asset.

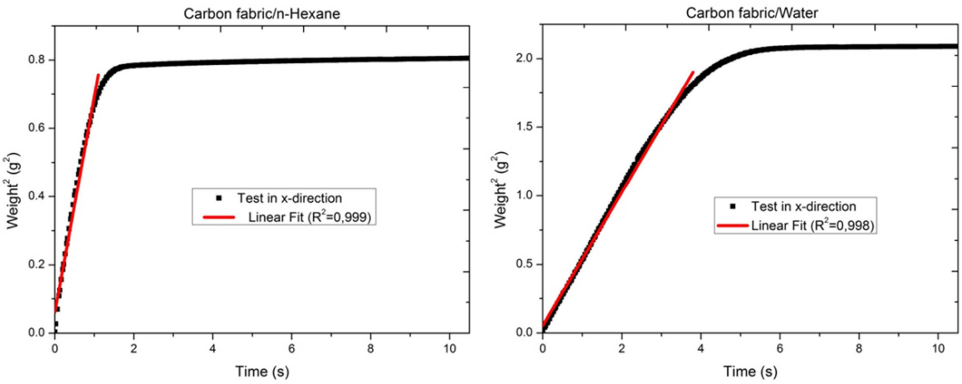

Figure 1: *Linear fits obtained for carbon fabrics (Vf =40%) in x-direction.*

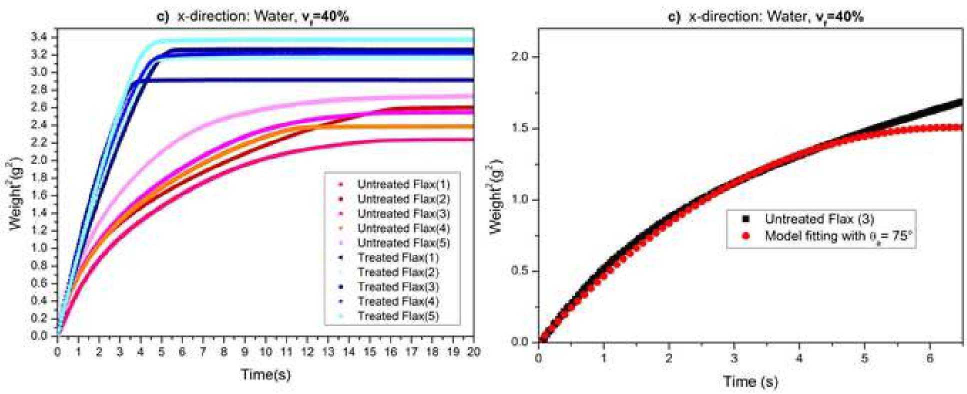

Figure 2: *Wicking curves obtained for untreated and treated flax fabrics and fitting with the semi-empirical model.*

References

[1] Pucci MF, Liotier P-J, Drapier S, Capillary effects on flax fibers-modification and characterization of the wetting dynamics, *Compos Part A: Appl Sci Manuf* 77: 257–265; 2015

[2] Pucci MF, Liotier P-J, Drapier S, Capillary wicking in a fibrous reinforcement-orthotropic issues to determine the capillary pressure components, *Compos Part A: Appl Sci Manuf* 77: 133–141; 2015

[3] Pucci MF, Liotier P-J, Drapier S, Capillary wicking in flax fabrics – effects of swelling in water, *Colloids Surf A: Physicochem Eng Aspects* 498: 176–184; 2016