A MICROMECHANICAL MODEL TO SIMULATE CAPILLARY FLOWS IN DUAL SCALE POROUS MEDIA

Claudia Thurnherr, Christophe Ravey and François Trochu*

Department of Mechanical Engineering, Chair on Composites of High Performance (CCHP),
Centre de Recherche en Plasturgie et Composites (CREPEC),
École Polytechnique de Montréal, P.O. Box 6079, Station « Centre-Ville »,
Montréal (Quebec), Canada, H3C 3A7

ABSTRACT

In Liquid Composite Molding (LCM), the resin flow in the mold cavity is usually modeled by a macroscopic model based on Darcy's law. However, most engineering textiles are porous media of two scale porosity, inside which capillary effects play a significant role at slow impregnation velocity. As studied by Ruiz et al. [1], part quality is connected to capillary flows because mesoscopic voids can be entrapped at low capillary numbers. Based on the description of dual scale effects provided by Pillai & Advani [2], a new algorithm was devised to predict dual scale flows through unidirectional fibrous reinforcements. A comparison with capillary rise experiments provided a good prediction of the initial flow velocity and, when saturation is taken into account, of the evolution of the capillary front. This opens up the possibility of predicting the optimal flow velocity in LCM without using complex experimental setups and conducting lengthy experiments.

The first step consists of providing a detailed description of the local "fiber volume content" of the fibrous reinforcement. Figure 1 shows the pixel-based description of porosity in the Tissa uni-directional fibrous reinforcement investigated here. The numerical algorithm devised to predict the dual scale flow through the fiber bed is based on the methodology proposed by Trochu et al. [3] to solve Darcy flows, in which the analytical formulas of Gebart [4] are used to model the longitudinal and transverse permeability of the fiber tows. The capillary pressure in the fiber bed was evaluated from the average diameter of its porous equivalent set of capillary tubes. A series of capillary rise experiments were carried out using the experimental setup described by LeBel et al. [5]. As such the model provided a good prediction of the initial velocity of the capillary front. However, afterwards the numerical flow front was much faster than in the experiments. For this reason, saturation of the fiber bed was considered.

In a second stage, the local saturation of the fiber bed was estimated as a function of pressure by Van Genuchten equation [6]. Following Wolfrath et al. [7], a model of relative permeability $k_r = S^m$ with $m = 2$ was considered. As shown in Figure 2, not only the calculated initial flow velocity provides a good agreement with a series of capillary rise experiments, but also the full evolution of the capillary front is very well predicted in time. Note that the model reproduces also the fingering effect observed in capillary flows.

This excellent comparison with experiments clearly demonstrates the key role played by saturation in the filling of dual scale porous media. In addition to providing a novel way of modelling dual scale flows, this first result opens up the possibility of predicting by numerical simulation the optimal flow velocity in LCM. The same approach can be generalized to model 3D capillary flows through complex woven reinforcements. By adding a boundary condition of specified injection pressure or flow rate at the inlet gate, the algorithm can also be used to predict dual scale flows through fibrous reinforcements.

KEY WORDS: Darcy's law, dual scale flow, capillarity, saturation

(a)

(b)

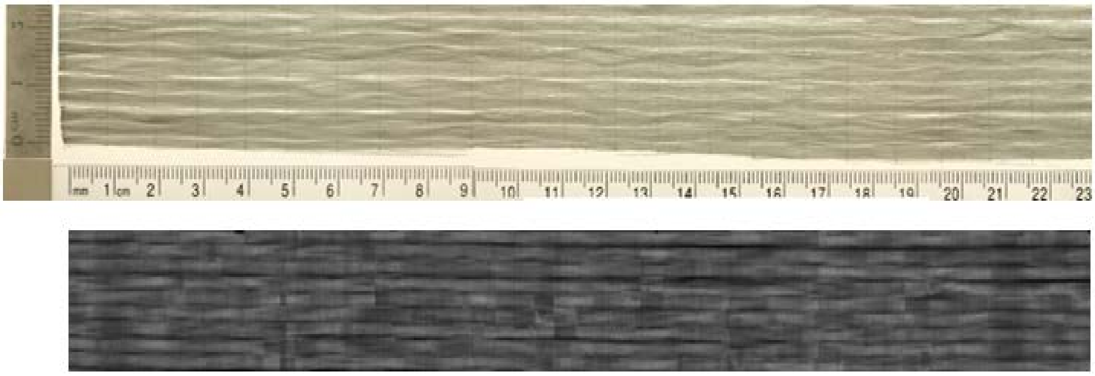

Figure 1: Image (a) is an original picture of the fibrous reinforcement. Image (b) shows the grey level mapping obtained after processing in order to evaluate the local fiber volume content.

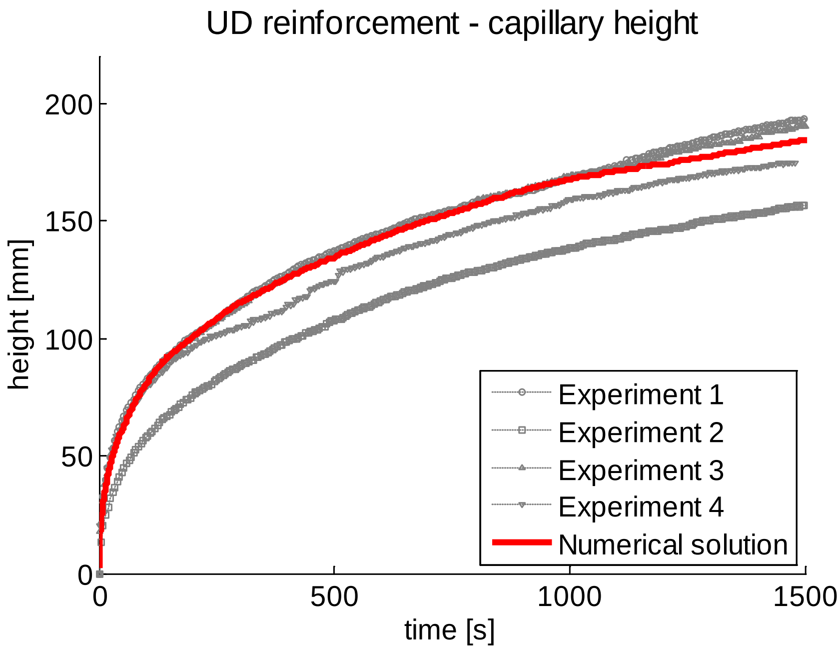

Figure 1: Capillary height as a function of time modelled with a saturation model

REFERENCES

1. Ruiz, E., V. Achim, S. Soukane, F. Trochu and J. Breard, *Optimization of injection flow rate to minimize micro/macro-voids formation in resin transfer molded composites.* Composites Science and Technology, 2006. **66**(3-4): p. 475-486
2. Pillai, K.M. and S.G. Advani, *A model for unsaturated flow in woven fiber preforms during mold filling in resin transfer molding.* J. of Comp. Mat., 1998. **32**(19): p. 1753-1783.
3. Trochu, F., R. Gauvin and D.M. Gao, *Numerical analysis of the resin transfer molding process by the finite element method.* Advances in Polymer Technology, 1993. **12**(4): p. 329-342.
4. Gebart, B.R., *Permeability of Unidirectional Reinforcements for RTM.* Journal of Composite Materials, 1992. **26**(8): p. 1100-1133.
5. LeBel, F., A.E. Fanaei, E. Ruiz and F. Trochu, *Experimental Characterization by Fluorescence of Capillary Flows in the Fiber Tows of Engineering Fabrics.* Open Journal of Inorganic Non-metallic Materials, 2012. **2**: p. 25-45.
6. Van Genuchten, M.T., *A Closed-form Equation for Predicting the Hydraulic Conductivity of Unsaturated Soils1.* Soil Sci. Soc. Am. J., 1980. **44**(5): p. 892-898.
7. Wolfrath, J., V. Michaud, A. Modaressi and J.A.E. Manson, *Unsaturated flow in compressible fibre preforms.* Composites Part A-Appl. Sci. & Man., 2006. **37**(6): p. 881-889.