INTEGRATION OF CAPILLARY EFFECTS IN THE 3D ORTHOTROPIC SIMULATION OF LIQUID RESIN INFUSION (LRI) PROCESS

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Introduction

The Liquid Resin Infusion (LRI) process consists in impregnating fibrous reinforcements with a liquid resin flowing in the thickness direction, by pulling vaccum in the system. Thus, at macroscopic scale, the resin flow is mainly driven by the pressure gradient generated by vaccum assistance. However, it has been experimentally demonstrated that capillary effects resulting from carbon reinforcements and epoxy resin or water interaction at a lower scale, can reach a value of 0.32-0.4bar [4,5] which represents a third of the process driving force. Consequently, the aim of this paper is to establish a 3D numerical model that takes into account these capillary effects in the macroscopic simulation of orthotropic composite material manufacturing processes such as LRI process [3].

Mathematical and numerical setting

At macroscopic scale, the resin flow through fibrous reinforcements is assumed to be described by Darcy’s equation, which relates the flow velocity to the pressure gradient and three parameters: the fluid viscosity, the preform permeability and its porosity. The fibrous reinforcement high orthotropy results in an orthotropy of both the permeability and the capillary effects. Therefore, as the permeability, the capillary effects are represented by a second-order diagonal tensor which contains the capillary pressure values in the 3 eigen-directions.

The model is implemented in a mixed finite element framework with a continuous piecewise linear approximation for the velocity and pressure variables. A variational multiscale method [2] ensures the numerical consistency of the fluid problem. Capillary pressure is applied at the flow front described by a level set function, as a natural interface condition of Darcy problem. This strategy generates a pressure discontinuity at the flow front. Moreover, spurious velocity appears around the fluid interface because the standard pressure space does not allow a sharp variation of the variable. In order to circumvent those oscillations, a local pressure enrichment [1] is used. This consists in adding pressure degrees of freedom with discontinuous shape functions in the elements crossed by the interface. Note that this technique does not increase the size of the algebraic system, since these new degrees of freedom can be condensed prior to the global assembly. Thereafter, the model is validated with the method of manufactured solution [6] in order to calculate the convergence rates. Good convergence rates are obtained for both velocity and pressure fields.

Numerical results

In this section, a numerical simulation of the filling stage of highly orthotropic stiffeners during the LRI process is performed in an industrial and realistic context. The effects of capillary action on the resin flow through preforms are assessed. The in-plan permeability is a hundred times higher than the transverse permeability. As capillary forces are more significant in less permeable medium, the capillary pressure in the transverse direction is higher than in the plan. The input paramaters are detailed in **Table 1**.

Table 1: *The input paramater for the LRI process simulation*

Orthotropic axes	Permeability (m^2)	Capillary pressure (Pa)	Other parameters
x	$3 \cdot 10^{-11}$	$0.5 \cdot 10^{3}$	Resin viscosity = $1 \cdot 10^{-1}$ Pa.s
y	$1 \cdot 10^{-11}$	$1 \cdot 10^{3}$	Air viscosity = $1 \cdot 10^{-5}$ Pa.s
z	$3 \cdot 10^{-13}$	$32 \cdot 10^{3}$	Porosity = $4 \cdot 10^{-1}$

The fluid front position at various time (t =1000s, 3000s, 4000s, 6000s) is presented in Fig. 1. The capillary effects may have significant impact on the filling scenario during the LRI process simulation. In fact, when taking into account the capillary effects, the filling stage lasts about 1h30min whereas it lasts twice this time whithout any capillary effects. In this case, the capillary effects favor the macro-filling speed. More experimental studies still need to be carried out in order to validate and to calibrate the numerical model.

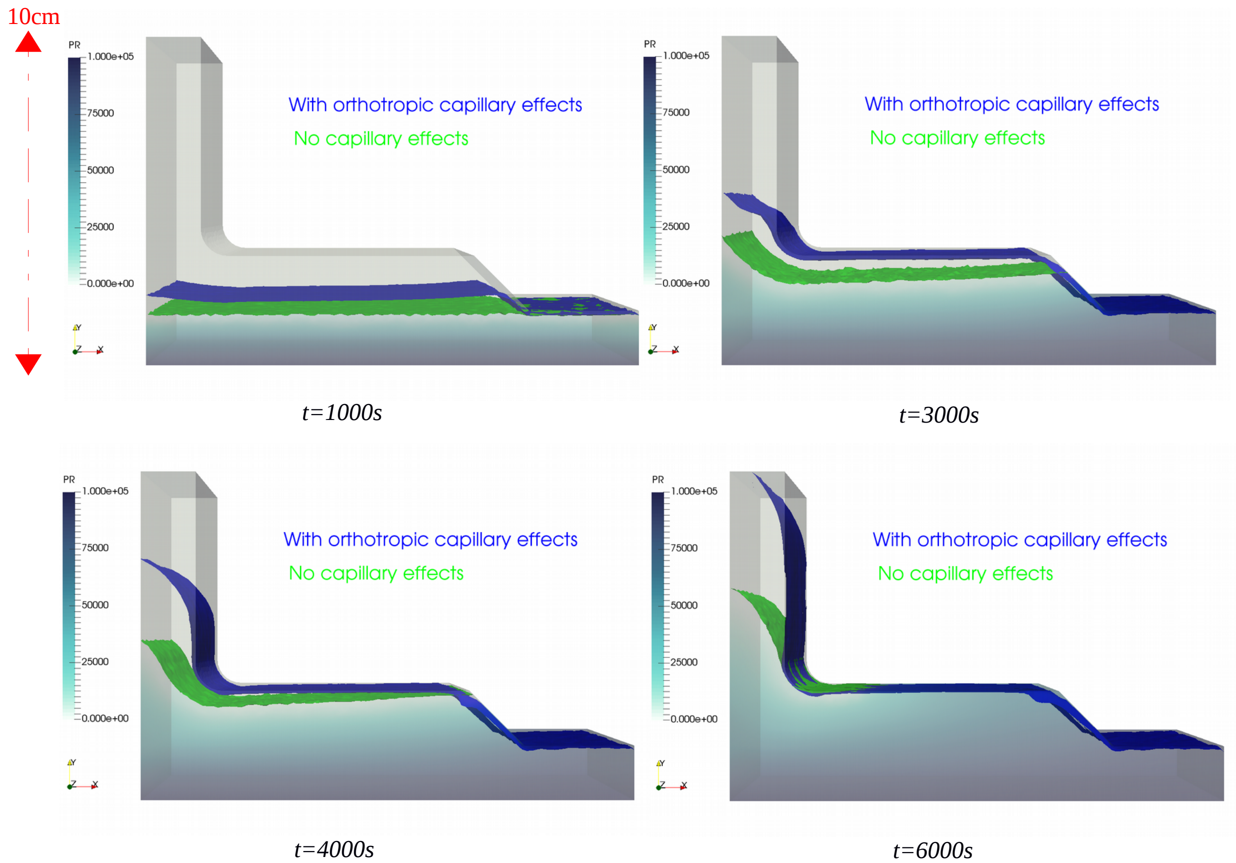

Figure 1: *The LRI filling stage with (blue) and without (green) taking into account the capillary effects, at various time.*

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