MOLD FILLING SIMULATION IN RTM PROCESSING OF NATURAL FIBER COMPOSITE MATERIALS. EXPERIMENTAL VALIDATION.

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Introduction

Darcy's law is widely used to model the fluid flow through a porous medium, and it is also extensively used in modelling flow processes in composite materials manufacturing. This law allows predicting the flow front position inside the mould cavity during the filling stage. Fluid viscosity and reinforcement permeability are the main properties involved in Darcy's law. In contrast to synthetic fibres, the permeability of natural fibre reinforcements does not necessarily remain constant along the wetted region of the fabrics throughout the infiltration process, because the porosity can change as the fibres absorb fluid and swell. In a previous work [1], a numerical model called "the permeability field model" (PFM), was developed to predict the mould filling stage of the RTM processing of natural fibre based composites. This model considers the fact that different regions of the wetted perform experience higher or lower fibre swelling depending on the amount of time that they have been immersed in the fluid, leading to a permeability field along the wetted fibre bed. In the present work, the validation of the PFM is presented by comparing the predicted results with those observed experimentally.

Permeability field model (PFM)

The pressure distribution along the mould cavity is solved using the finite element method (FEM). The movement of the flow front is modelled using the "Volume of Fluid" technique (VOF) with a fully convective scheme and SUPG stabilization [2]. The numerical calculation is performed in three steps. First, the pressure distribution, P(x), is calculated over the entire domain by using Darcy´s Law. Then, the fluid velocity field, V(x) is calculated from pressure field. A variable (α) that determines the filling fraction is transported (locating the flow front where $\alpha=1/2$). The material derivative is equal to zero, because neither source nor sink exist along the process domain (1).

$$\frac{d\alpha}{dt} = \frac{\partial\alpha}{\partial t} + V\ \nabla\alpha = 0 \tag{1}$$

Finally, the filling fraction, α, is advected by the local average values of the velocity field. Dirichlet boundary conditions are imposed at the injection and vent nodes. The permeability value in the wetted region of the preform depends on the instantaneous porosity of each element of the mesh. The permeability in the dry region of the preform is assumed to be 10^3-10^4 times higher than the initial permeability, K_0. This allows setting a pressure value almost null at the front flow without the need of moving boundary conditions or remeshing, thus simplifying the algorithm. Every time a new element is "filled" by the fluid ($\alpha>1/2$), a local flag is raised and a local "element wetting time" starts to be computed by the algorithm. Then, the porosity of each element in the domain is calculated using an empirical relation obtained from swelling tests (fiber diameter vs. time data) performed with the same fluid being modelled. The instantaneous permeability of each element can then be computed applying the Carman-Kozeny model (which relates the permeability with the porosity of the preform) which empirical parameters were determined with a non-swelling fluid.

Materials and methods

Flax fibre mats were used in this study. A 20%V/V water/glycerine solution was used as a swelling test fluid and SAE20 motor oil was used as the non-swelling fluid. Fibre swelling was evaluated by optical microscopy. Unidirectional permeability tests were carried out following the guidelines and recommendations provided by the 2nd Permeability Benchmark [3]. Pressure sensors were used to collect fluid pressure data along the mould and a video camera was installed to record flow progression.

Results

In the PFM, each element of the mesh has its own permeability value, which is only a function of immersion time. Despite the pressure drop is linear within each element, the global pressure distribution does not follow a linear behaviour, as expected from models that consider a constant permeability value. The PFM predicts a higher pressure drop in the zones where the fibres experienced higher swelling than in the zones where fiber swelling was less significant. Experimental data extracted from pressure sensors along the mould showed good correlation with the PFM (Figure 1). Flow progression was also more accurately predicted by the PFM than Darcy's Law, as can be seen in Figure 2. As expected, Darcy's Law predicts a faster mould filling since it does not consider the decrease in permeability caused by fibre swelling.

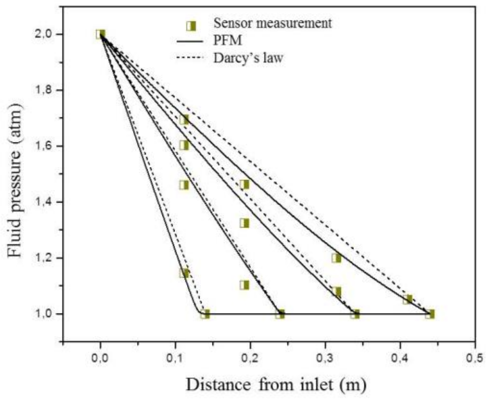

Figure 1: *Pressure gradients*

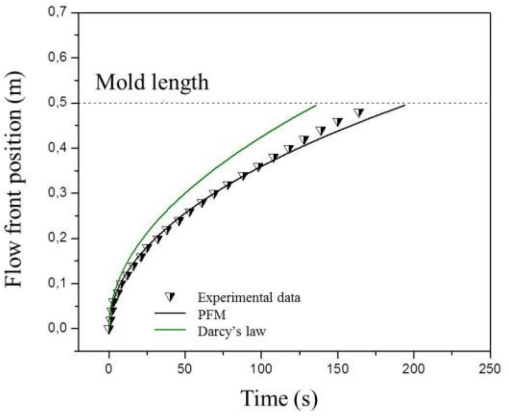

Figure 2: *Flow progression*

Conclusions

The permeability field model predicts a non-linear pressure gradient along the wetted preform, and a slower flow progression that Darcy's Law which assumes a constant permeability value. When a polar fluid was used, fibres swelling occurred causing a permeability decrease as the immersion time increased. Experimental data was more accurately fitted by the PFM that by Darcy's Law. Therefore, fibre swelling should be taken into account if polar fluids are used as tests fluids for permeability test or resins that cause significant fibre swelling are used to manufacture composite parts.

References

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