COUPLING BETWEEN HEAT TRANSFER AND SATURATION: EXPERIMENTAL INVESTIGATION

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Introduction

Prediction of the residual porosity is crucial for composite industry. In LCM processes creation of porosities during impregnation results from the architecture of fabrics that causes two-scale flows: one within the tows and one between the tows. Literature showed that a minimum porosity is obtained when both flows have the same velocity what can be related to the capillary number. Numerous experimental measurements were performed after consolidation of the composite part to confirm this assumption. Other experiments aimed to determine the saturation curve during impregnation. They are based on the study of variations of optical [1], [2], acoustic or electrical [3] properties of the material according to saturation. As thermal properties also depend on saturation, heat transfer analysis can be used. Reciprocally if saturation impacts heat transfer, it must be integrated in the modeling, especially for rapid LCM processes like C-RTM for which a strong coupling between flow, heat transfer and chemistry appears. In this work heat transfers in the composite during filling are modeled by convection-diffusion equation (1) for which thermophysical properties evolve as function of saturation. A first identification of the saturation curve is performed considering a constant velocity for the resin. A second identification is carried out using a two-phase model for the fluid. The saturation curve is anew determined as well as the relative permeabilities of the fabric to air and resin.

Experimental set-up and heat transfer modeling

Unidirectional injections at constant flow rate (2.1mL.min-1) of a model fluid into a UD textile preform of size 400*100*2.74mm were performed on an experimental bench (Fig.1). Heat is dissipated into the preform by the means of thin heaters glued on the underside of the upper part of the mold. Three heat flux sensors, mentioned as HFS1 to HFS3 in Fig.1, integrated in the bottom steel plate at different locations, record the thermal response of the porous material. In equation (1) thermal properties depend on the saturation.

$$\left(\rho C_p(S(x,t)\right)\frac{\partial T}{\partial t} + \left(\rho C_p(S(x,t)\right)\vec{u}.\overrightarrow{\nabla T} = \vec{\nabla}\cdot\left(\overline{\overline{\lambda(S(x,t)}}\overrightarrow{\nabla T}\right) \tag{1}$$

Effective thermophysical properties of the dry and fully-saturated porous medium in transverse and longitudinal directions have been measured by several methods. A straightforward law of mixtures for the longitudinal conductivity as well as for the volumetric heat capacity (ϱCp) is used. Because of the large sensitivity of transverse thermal conductivity on heat transfer a homogenization method based on asymptotic expansion was used sequentially at the two scales of the reinforcement to determine the evolution of the thermal conductivity. The results show that the conductivity is not linear according to saturation and depends on the ratio of micro and macro voids.

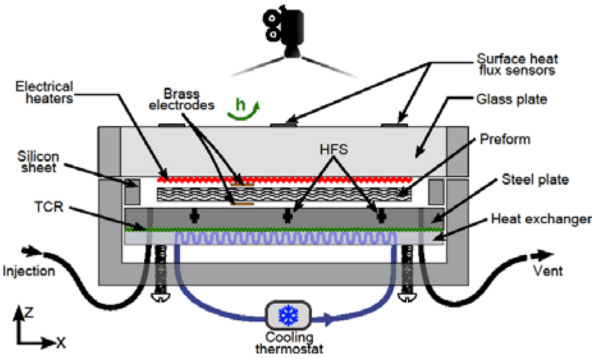

Figure 1: *Schematic view of the bench*

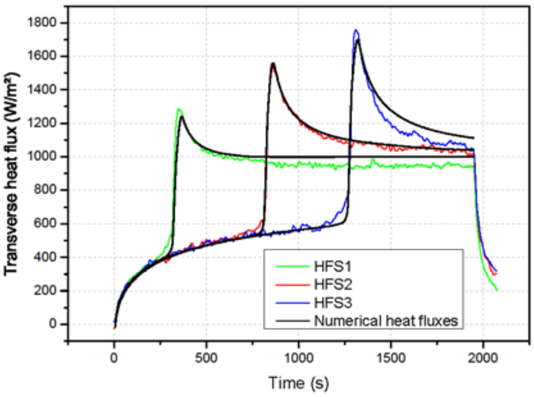

Figure 2: *Experimental and numerical heat fluxes*

Results

In a first approach, a constant velocity is considered in equation (1). The numerical heat fluxes obtained after identification of the parameters of the saturation curve are plotted in Fig.2 and the saturation curve in Fig.3. In the second approach a two-phase flow between the resin and the air present in the preform is used. For each α phase the velocity is given by:

$$u_\alpha = -\frac{K k_{r\alpha}}{\mu_\alpha \phi} \nabla P_\alpha \tag{2}$$

The relative permeability is described with a model of Corey which gives $\mathrm{k}_{\mathrm{r}_\mathrm{w}} = \mathrm{b}_\mathrm{w}\, \mathrm{S}_w{}^{\mathrm{n}}$ for the wetting phase and for the non-wetting fluid $\mathrm{k}_{\mathrm{r}_{\mathrm{nw}}} = \mathrm{b}_{\mathrm{nw}}\,(1 - S_w)^n$. Van Genuchten model is chosen to describe the capillary pressure. The identification of the coefficients of the Corey model leads to the relative permeabilities plotted in Fig.4.

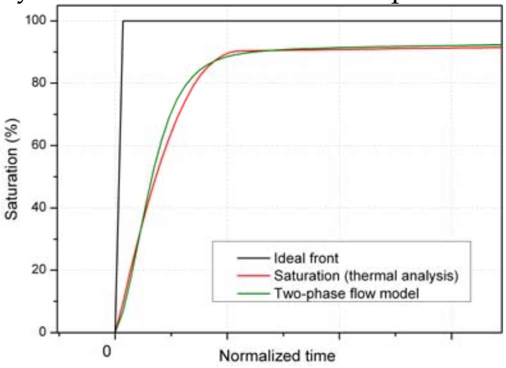

Figure 3: *Saturation curve*

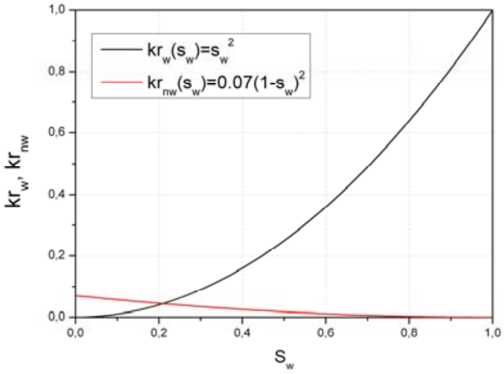

Figure 4: *Identified relative permeabilities*

The saturation curve obtained in this case is added in Fig. 3. For both methods the results are consistent. The weak value for the air permeability can be explained by the model which considers only incompressible phase. Further work should take this into account.

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