MODELLING THE RESIN FLOW THROUGH FIBRES DURING RESIN TRANSFER MOULDING

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Abstract
Fibre Reinforced Polymers (FRP) have become a staple in modern engineering due to their high strength-to-weight ratio. Resin Transfer Moulding (RTM) is a popular method of manufacturing FRP at high production rates. The process parameters of RTM need to be optimised to ensure the efficiency of the process and that the FRP parts are free of significant defects. The reinforcement fabric is a dual-scale porous medium, resulting in an unsaturated liquid resin flow [1]. This complex flow behaviour needs to be accurately captured in Computational Fluid Dynamics (CFD) simulations, which can then be used for process optimisation. In this work, 2-dimensional resin flow simulations were implemented in OpenFOAM. The unsaturated resin flow is modelled based on the advective-diffusive transport of a saturation variable. A new solver, *rtmFoam*, was introduced by modifying an existing library with the inclusion of a scalar transport equation. Simulation results showed that the unsaturated nature of the resin flow can be successfully replicated using this approach.

Method
The resin flow through reinforcement fabric can be modelled as a flow through a porous medium. Therefore, the mass conservation equation for an incompressible liquid (Eq. 1) is solved alongside the momentum conservation equation where the porous medium effects are included using a momentum sink term. The resin is assumed to be Newtonian, and the flow is in the creeping flow regime (Reynolds Number << 1), which reflects the realistic processing conditions present during RTM [2]. This reduces the momentum equation to the Stokes equation given by Eq. 2. Here, $\mathbf{u}$ is the velocity, p is the pressure, μ is the viscosity, ρ is the density, and $\mathbf{K}$ is the permeability tensor.

$$\nabla \cdot \mathbf{u} = 0 \tag{1}$$

$$\rho \frac{\partial \mathbf{u}}{\partial t} + \nabla p = \mu \nabla^2 \mathbf{u} - \mu \mathbf{K}^{-1} \mathbf{u} \tag{2}$$

The existing transport equation of the *interFoam* OpenFOAM library was modified with a diffusion term to account for the advective-diffusive transport of a saturation variable α (0 when unsaturated, 1 when saturated), as given by Eq. 3 [3][4]. Here $\mathbf{D}$ is the coefficient of diffusion.

$$\frac{\partial \alpha}{\partial t} + \nabla \cdot \alpha \mathbf{u} - \nabla \cdot (\mathbf{D} \nabla \alpha) = 0 \tag{3}$$

To minimise the numerical diffusion at the flow front and emphasise the effects of physical diffusion, the higher-order Superbee flux limiting scheme was used to discretise the advective term of Eq. 3.

Results

Fig. 1 shows the filling of a $500mm \times 250mm$ mould under a constant resin flow rate of $1 \times 10^{-7}\ m^3/s$. Isotropic permeability and diffusivity are assumed, and the values of **K** and **D** are taken to be $1 \times 10^{-9}\ m^2$ and $2 \times 10^{-7}\ m^2/s$, respectively. The temporal evolution of the saturation indicates the distribution of the resin within the mould. The partially saturated region arising due to the dual-scale nature of the porous medium can also be observed, as shown in Fig. 2. The inlet pressure variation for a linear mould resin injection under a constant flow rate is given in Fig. 3. Here, the initial non-linear variation of pressure is due to the partial saturation of resin at the inlet, which eventually becomes a linear variation reflecting the Darcy law after the inlet becomes fully saturated.

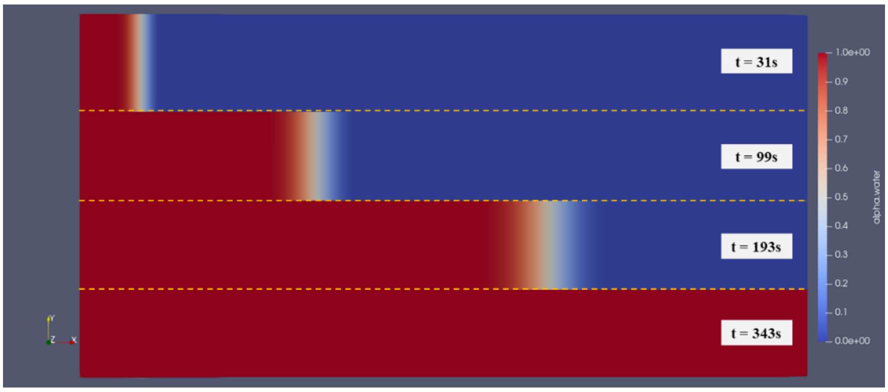

Figure 1: Evolution of the resin flow within the flow domain with a partially saturated front

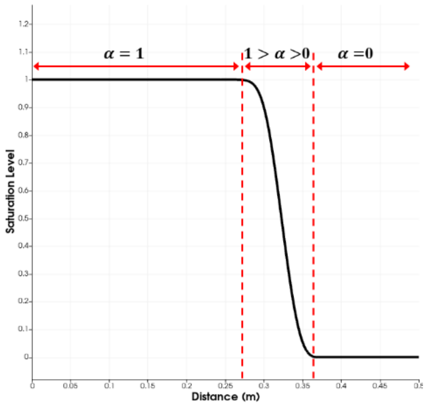

Figure 2: Saturation of the porous medium at $t = 193\ s$

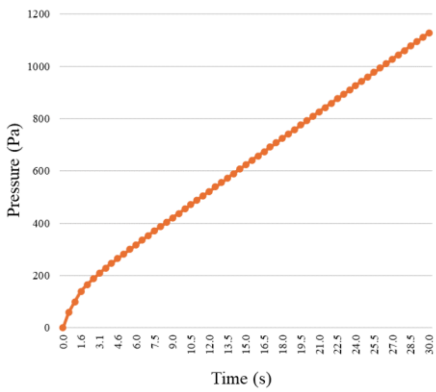

Figure 3: Variation of the inlet pressure with time at the start of injection

It can be seen that the partially saturated flow of resin occurring during the mould-filling stage of RTM can be reproduced using the scalar transport approach. This method is advantageous compared to the currently used mesh modification technique which requires several parameters and geometric simplifications [5]. However, further analysis is needed to obtain a better control of the dynamics of the partially saturated region, such as the variation of its width over time.

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