

# Numerical Simulation of Filling Process in Resin Transfer Molding

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The quality of a composite material produced using a textile reinforcement depends largely on the entire wetting of the textile. To ensure the fabrication of high quality parts and minimise costs in designing and producing such parts it is necessary to develop methods for predicting the flow of the resin. This work concentrates on the macroscopic flow simulation of the impregnation process.

In this work an isothermal, incompressible two phase fluid flow is considered. At the microscopic scale the flow of one phase is described by the Navier–Stokes equations. Since knowledge of the resin flow at macroscopic scale is needed, to avoid voids and to guarantee that the resin is well distributed, the set of equations is homogenized. Following Whitaker [5] and Bear [2] the volume-averaging techniques is used to obtain the following one-fluid formulation:

$$\nabla \cdot (\rho \phi \mathbf{u}) = 0, \quad (1)$$

$$\frac{\partial \rho \phi \mathbf{u}}{\partial t} + \nabla \cdot (\rho \phi \mathbf{u} \otimes \mathbf{u}) + \phi \nabla p - \nabla \cdot (\phi \mu \mathbf{u}) - \nabla(\phi \mathbf{u}) \cdot \nabla(\mu) - \mathbf{S} = 0, \quad (2)$$

here  $\mathbf{u}$  and  $p$  are the averaged velocity and averaged pressure. The porosity  $\phi = \frac{V}{V_t}$  is spatially variable. In this equation  $V_t$  is the total volume and  $V$  is the volume of the voids. The resistance to the flow through the fiber material, which is modeled as a porous media, is given by Darcy’s law. This law implies a pressure drop, therefore it is written as the sink term  $\mathbf{S}$ . The mixture density  $\rho$  and viscosity  $\mu$  depend on the volume fraction field  $\alpha$ . This scalar field  $\alpha$  is tracked by the transport equation

$$\frac{\partial \phi \alpha}{\partial t} + \phi \mathbf{u} \cdot \nabla \alpha = 0. \quad (3)$$

The phase interface is captured by a Volume-of-Fluid method. This approach is implemented in OpenFOAM<sup>®</sup> [1, 4]<sup>1</sup>.

At the first stage of the RTM process the fabric gets deformed and distorted. To fully take into account these changes at the microscopic, mesoscopic and macroscopic scale of the textile, a very fine computational mesh is needed, leading to an unacceptable amount of computational costs. This paper employs a multi scale modelling approach in predicting the permeability. For predicting the flow resistance at the microscopic scale the Gebart model [3] is used. Due to the regularity of the textile, the permeability is predicted by employing an unit-cell impregnation model. This model concentrates on the microscopic and mesoscopic scales leading to results applicable to the macroscopic scale. An external drape simulation provides the required inputs like the local porosity and the fiber orientations.

The curved geometry “saddle” is in total 20 cm × 20 cm × 5 cm large and the channel height varies between 0.5 mm and 2.7 mm. Fig. 1 a) shows a topview of the “saddle”. At the lower and upper boundary of the geometry parallel to the x-axis the resin outlet is realised. The injection port is located in the middle of the geometry with radius 2 mm. The magnitude of the pressure gradient between inlet and outlet is 1 kPa. As textile reinforcements a fiber layup of three UD fabrics (Toray T620SC 50C 24k) is used. The first / lowest UD layer is facing in y-direction (0° orientation). The middle fabric is located in −45° orientation, this means pointing from top left to right bottom. The third / top layer is perpendicular to the first (90° orientation, x-direction). Glycerin is used

<sup>1</sup>OpenFOAM<sup>®</sup> is a registered trade mark of OpenCFD Limited, producer and distributor of the OpenFOAM software.

as resin compensatory. Through the curved shape of the “saddle” geometry, porosity, shear angle and fiber orientation vary significantly. This makes the simulation challenging and the geometry is representative for composite structures from high-tech industries.

The aim of the macroscopic flow simulation of the impregnation process is to ensure the quality of the composite material. Therefore the main goal is to figure out, where voids possibly arise. Results can be seen in Fig. 1, where a comparison from experiment (left) and simulation (right) at

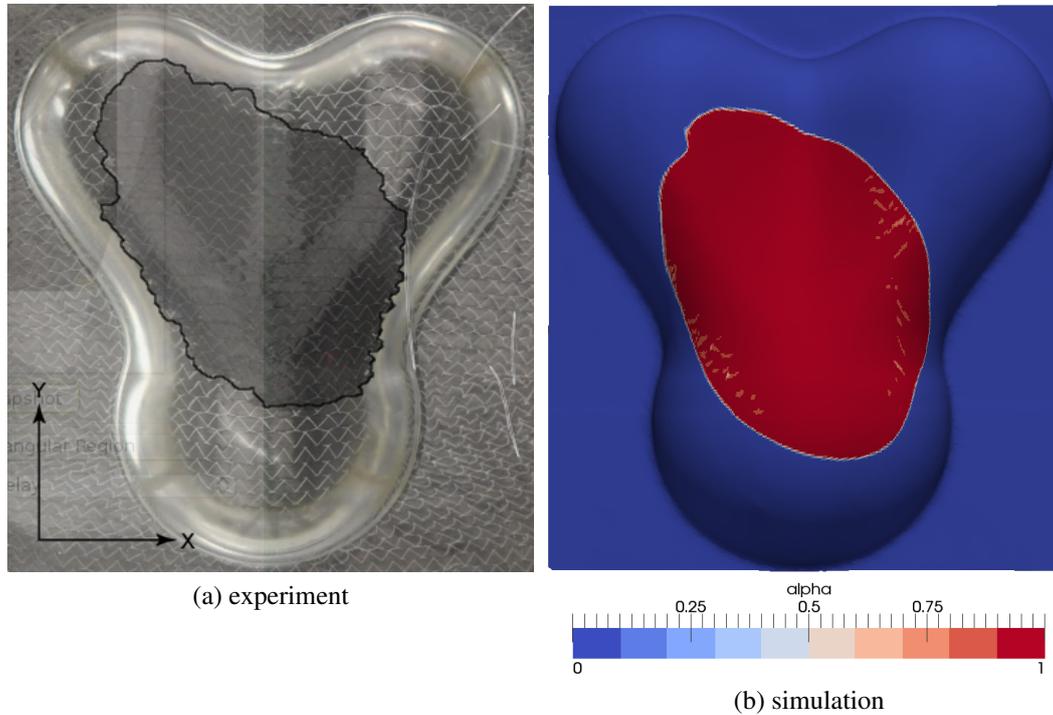


Figure 1: Flow front of resin in the “saddle” geometry at  $t = 90s$ .

$t = 90s$  is shown. The simulation shows good agreement with the experiments. The general behavior of the simulated flow front is consistent with the experimental data. Especially, the noticeable notch in the flow front in the top left of the simulation is comparable with the experiment. The simulated velocity of the flow front is slightly underpredicted at the top and slightly overpredicted at the bottom. One explanation is that only the top layer (orientation:  $90^\circ$ , x-direction) is visible in the experiment in contrast to the simulation, where we see a homogenized flow front.

## References

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