A meso-scale BC to include micro-scale effects in textile impregnation processes

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Introduction

The production of fibre reinforced plastics involves the infiltration of a viscous resin into a reinforcing textile. The flow physics in these processes are typically simulated using Darcy's law:

$$\mathbf{u} = -\frac{\mathbf{K}}{\mu}\frac{\mathrm{d}p}{\mathrm{d}x}$$

in which the complicated interaction between fluid and fibrous reinforcement is lumped into the permeability tensor $\mathbf{K}$. Accurate permeability data is therefore essential in the simulation and optimisation of these flow processes. The textile permeability can be obtained by modelling the fluid flow through a representative volume element and substituting the obtained fluid velocities and pressure gradients in Darcy's law. Incorporating the multiscale character of textile reinforcements, Fig. 1, provides a challenge. A no-slip boundary condition in a meso-scale permeability model overestimates the flow resistance of a porous bundle. Therefore, a bundle slip boundary condition is proposed.

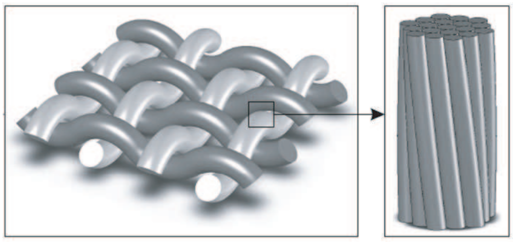

Figure 1: Dual scale character of textiles: meso-scale (left) and micro-scale.

Slip Coefficient

The slip velocity on the bundle surface is defined as:

$$\mathbf{u}_b = \overline{\beta}\nabla\mathbf{u}_b$$

The Stokes flow equations are solved in a micro-scale unit cell, depicted in Fig. 2, to yield the slip coefficient β for the case of flow transverse to the bundles. The unit cell represents the surface of a bundle consisting of square packed filaments. The slip coefficient is a function of both micro- and meso-textile geometry (i.e. filament radius and bundle spacing). The averaged fluid velocity on the bundle surface is divided by the averaged velocity gradient to yield the slip coefficient. The coefficient is determined for different relative filament radii, r/w, and shown in Fig. 3.

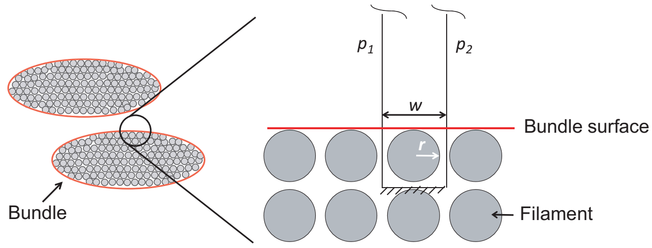

Figure 2: Micro-scale unit cell (right) consisting of one single filament on the bundle surface.

Conclusions

The interaction effects between inter- and intra-bundle flow are accounted for in a meso-scale model by applying a slip boundary condition on the bundle surface. Application of the proposed slip coefficient yields improved results compared to a no-slip boundary condition.

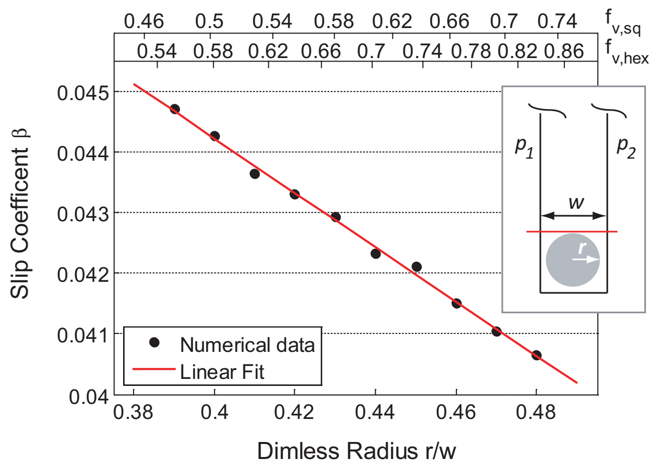

Figure 3: Dimensionless slip coefficient as function of dimensionless filament radius.

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