EFFECT OF YARN CROSS-SECTIONAL SHAPE ON RESIN FLOW THROUGH INTER-YARN GAPS IN TEXTILE REINFORCEMENTS

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Introduction

The impregnation of reinforcement fabrics in the manufacture of composite components employing Liquid Composites Moulding processes is determined mainly by resin flow through inter-yarn gaps. In this study, numerical flow simulation is employed to quantify the equivalent permeability of inter-yarn gaps as a function of the yarn cross-sectional shape, which can vary between rectangular and lenticular, and the fibre volume fraction.

Modelling

The permeability is analysed for a periodic layer of aligned yarns, where the geometry is characterised by the spacing, thickness, and width of the yarns. The layer can be represented by a repetitive unit cell, where an empty gap is bounded by yarns (left and right) and flat impermeable walls (top and bottom). The cross-sectional shape of a multifilament yarn is approximated by a power-ellipse.

Numerical flow simulation

Computational Fluid Dynamics simulations of steady-state Navier-Stokes flow were run to analyse unit cell models with different yarn cross-sectional shapes and fibre volume fractions. Equivalent axial permeabilities of the inter-yarn gaps were determined from the applied pressure gradients and the calculated average flow velocities.

Results and discussion

The simulations indicate that, at given fibre volume fraction, equivalent gap permeabilities have a maximum when the ratio of gap cross-sectional perimeter and area has a minimum, and the ratio of gap width to height is near 1. Higher equivalent permeabilities can be obtained for gaps bounded by yarns with near-rectangular cross-section than by yarns with lenticular cross-section. This implies that increasing the gap cross-sectional area by changing the gap shape does not necessarily translate into increasing equivalent permeability.

At any fibre volume fraction and yarn spacing studied here, the maximum and minimum values for the equivalent permeability of inter-yarn gaps differ by factors of up to 3.7. This may contribute to the wide variation in experimental permeability data for fabrics, and explain why accurate permeability prediction is in practice found to be difficult, even if the fibre volume fraction is known. It illustrates also that, in unit-cell based numerical prediction of textile permeabilities, accurate modelling of yarn cross-sections is critical. If the equivalent permeability of inter-yarn gaps is approximated by the equivalent permeability of gaps with abstracted geometry, the error can be significant even if the gap cross-sectional area is matched.

Approximations for the hydraulic friction factor (reflecting different flow velocity distributions as shown in Figure 1) and the hydraulic diameter in Hagen-Poisseuille duct flow were derived as a function of fibre volume fraction, yarn cross-sectional aspect ratio and exponent describing the shape of the power-elliptical yarn cross-section. This allows the equivalent gap permeability to be predicted for any fibre volume fraction and yarn cross-section.

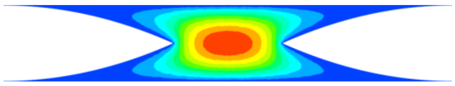
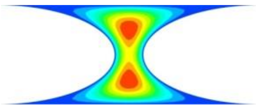
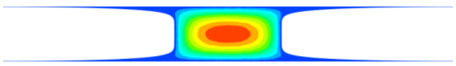
axial flow velocity distributions in inter-yarn gaps (qualitative)	yarn shape	fibre volume fraction	yarn spacing / mm	equivalent gap permeability / 10^{-10} m^2
	lenticular	50 %	1.98	37.694
	elliptical	70 %	1.12	14.136
	near-rectangular	70 %	1.97	26.312

Figure 1: *Examples for results of flow simulations.*

Based on the equivalent gap permeability, the permeability of a layer of aligned yarns can be calculated employing a rule of mixtures. Varying the fibre volume fraction and estimating its effect on the yarn cross-sectional shape at constant cross-sectional area allows the effect of through-thickness compaction on the layer permeability to be estimated (Figure 2).

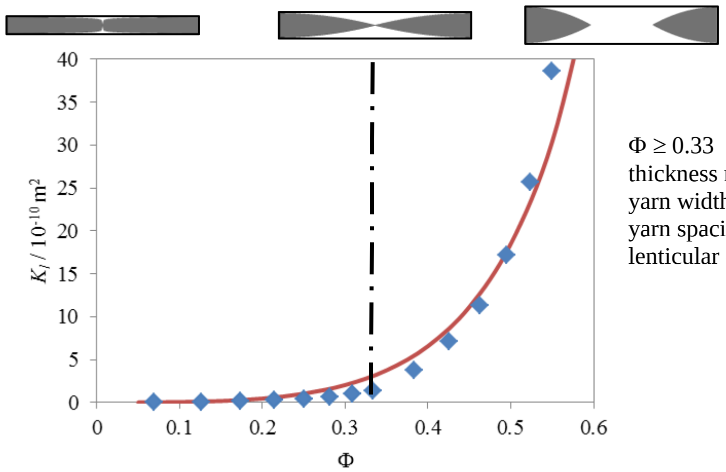


Figure 2: *Example for permeability of a reinforcement layer, K_l, as a function of porosity, Φ; level of yarn compaction increases from right to left.*

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