EXPLORATORY STUDY FOR THE USE OF DIFFUSIVE TRANSPORT AND THE TORTUOSITY FACTOR, EXTRACTED FROM X-RAY CT GEOMETRICAL MODELS, AS PROXY FOR PERMEABILITY IN COMPOSITE MATERIALS

J. Soete, S.V. Lomov, L. Gorbatikh, M. Wevers

Materials Engineering (MTM), KU Leuven, Kasteelpark Arenberg 44, 3001 Leuven, Belgium.
*Corresponding author (jeroen.soete@kuleuven.be)

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Introduction

Permeability of composite materials is critical for the design of liquid composite molding processes, which aim to achieve full impregnation between preformed reinforcing fiber bundles. Fluid Flow modelling is computationally expensive and minor increases in geometrical complexity often preclude analytical solutions. Here, a preliminary study is conducted, which investigates if diffusive transport and the tortuosity factor (Matlab, TauFactor [1]) can serve as a proxy for permeability in composites.

Methodology

The used reinforcement is a 2 x 2 twill carbon fabric, provided by Hexcel Fabrics. It is composed of 6K fiber yarns in both warp and weft direction. Interyarn effective diffusivity (D^{eff}), tortuosity (τ) and Navier-Stokes flow (K_{NS}, FlowTex) are back-calculated by scanning the reinforcement with X-ray CT and segmenting voxel models into the yarn and matrix domains, by means of a grey-scale and anisotropy based K-means clustering in VoxTex [2]. Diffusivity can be modelled directly on large microstructural voxel data with complex geometries, incorporating intrinsic anisotropy. The tortuosity factor quantifies the apparent decrease in diffusive transport as a consequence of flow path convolutions. The aim is to correlate D^{eff} and τ with K_{NS} and to test their applicability to be used as proxy for permeability.

Results

Fibrous reinforcements are hierarchical porous materials in which permeability is anisotropic. As such, simulations were performed along the three principal axes of the composite: In plane (0° and 90°), along warp and weft direction, and through plane (Table1). The highest effective diffusion and permeability are found in plane (90°), along the weft direction and are associated with the largest median channel diameter and lowest tortuosity. Simulated in plane permeability correlates well with, but is lowered compared to experimental permeability (K_{Exp}), obtained during a benchmark exercise [3], in which participants used the same values for fiber volume fraction, injection pressure and fluid viscosity, and applied the squared flow front or least square fit permeability method.

Table 1: *Measured and simulated physical properties, with effective diffusion (D^{eff}), Tortuosity (τ)*, *median channel diameter ($d_{channel}$), Katz-Thompson permeability (K_{KT}), Navier-Stokes flow (K_{NS}), experimental permeability (K_{exp}).*

2 x 2 Twill carbon fabric	D^{eff} (m²/s)	τ (L/L_0)	$d_{channel}$ (µm)	K_{KT} (D)	K_{NS} (D)	K_{Exp} (D)
In plane (0°)	0.0452	1.91	300	34.7	30.7	82.1
In plane (90°)	0.0755	1.47	450	101	110.8	131.7
Through plane	0.0024	8.35	100	0.9	0.4	/

Through plane tortuosity is remarkably higher, which together with smaller interyarn channels (median diameter of 100µm) results in lower effective diffusion and estimated Katz-Thompson permeability (K_{KT}).

$$K_{KT} = \frac{\O d_{channel}^2}{226\tau} \quad (1)$$

This equation (1) usually relies on mercury intrusion capillary pressure measurements of pore throat diameters, and '$d_{channel}$' is generally defined as the main peak pore diameter. In this study, the median channel diameter, porosity and tortuosity are calculated based on CT geometrical models. The diffusion simulations are shown as a volume rendering of the total flux (Figure 1) and allow locating bottle necks and preferential flow paths. Effective diffusion and tortuosity are plotted against Navier-Stokes flow. Effective diffusion (Figure 2A) yields a positive power-law correlation with K_{NS}, while an increase in tortuosity (Figure 2B) will lower permeability.

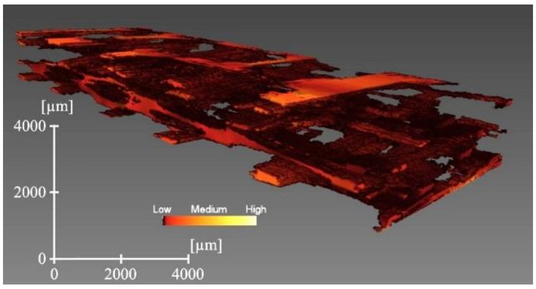

Figure 1: *Volume rendering of the total flux through the inter-yarn channels.*

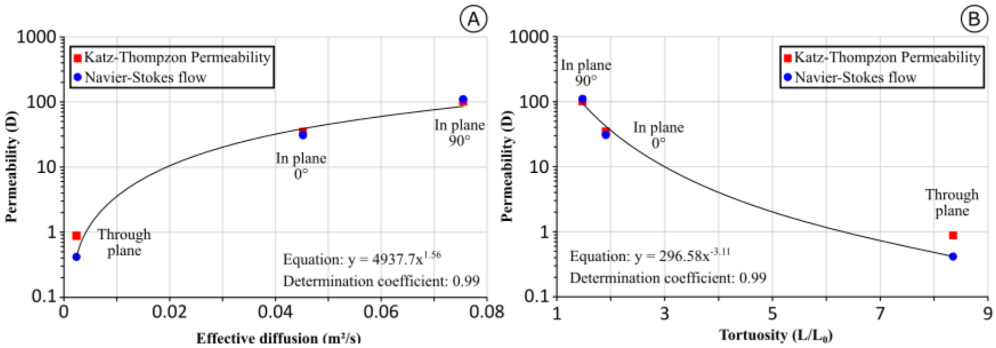

Figure 2: *Cross plot of (A) Effective diffusion and (B) Tortuosity versus Navier-Stokes flow.*

Discussion and conclusion

The methodology allows describing geometrically complex interyarn systems in composite materials based on more accessible parameters. Simulated permeabilities are slightly lowered compared to experimental data. This possibly relates to intrayarn porosity, which is neglected here for the matter of simplification. Increasing the number of test subjects should confirm the validity, but also the material and weave pattern dependency of the obtained relations. Diffusion and permeability are similarly affected by tortuosity and found to be closely related. A power-law relation between these two quantities seems to well describe the data and demonstrates the potential for diffusive transport to be used as a permeability proxy.

Acknowledgements

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References

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