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A statistical approach for permeability prediction in random fibrous media : influence of morphological parameters and fluid slip

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Multiscale flows are observed in numerous fields such as manufacturing processes for composite materials. At a local scale, a liquid resin flows within a complex fibrous architecture. Since this scale is generally not appropriate for industrial applications, results are then upscaled through Darcy law. This involves a permeability tensor that expresses the ease with which the fluid flows across the porous media. This tensor thus encompasses microscale information such as the local porous geometry or the interfacial interaction between fluid and fibres. As the fibres show a local disordered arrangement, the fibrous medium should be considered as random leading to represent permeability through a statistical approach [1], going further towards industrial observations.
In this study, a high number of numerically-generated random fibrous microstructures is thus considered. A flow simulation is performed on each one by solving Stokes equations with a stabilised finite element method. This first allows to determine a representative volume size. Next the statistical study on permeability is achieved [2]. From Kolmogorov-Smirnov statistical tests, the permeability tensor can be reduced to a single scalar as the behaviour is statiscally isotropic. Permeability is then related to some morphological parameter especially the fibre volume fraction that is shown to be a first-order descriptor.
One of the novelties of this work is to consider fluid slip at the fluid/fibres interface through Navier law. Permeability turns out to be bounded between its free-slip and no-slip values. This finally allows to propose an explicit stochastic law that links permeability to fibre volume ratio and slip length. This law has been especially validated through the use of a machine learning method namely Gaussian process regression to naturally incorpore the statistical dispersion within the regression and to deal with a relatively small dataset.

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