Prediction of Permeability of Multi-Scale Anisotropic Porous Media by a Novel Software Suite 'PoroS'

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In porous media science and engineering permeability is one of the key properties, which defines the capacity of porous structure to be penetrated by a fluid. Fibrous materials used as reinforcements of structural composites can be considered as the most general and complex class of porous media due to their anisotropic and multi-scale character: an engineering textile is composed of yarns at meso-scale, themselves composed of thousands of fibers at micro-scale. Experimental determination of permeability of fibrous textiles is a tedious task. It is time-consuming, requires a specialized and often costly equipment, and almost impossible to be conducted at micro-scale. Virtual characterization of permeability using numerical methods has important advantages over the measurements. It allows to reduce material waste, to analyze the influence on permeability of material microstructural parameters, while being capable of addressing high variability inherent to this class of materials. At present there is no widely accepted numerical approach for permeability prediction yet due to modeling challenges such as the choice of the RVE (representative volume element), boundary conditions, permeability identification technique, as revealed in the first international virtual permeability benchmark on fibrous media [1]. This motivated the development of a novel scientific software named `PoroS' [2], which includes a set of numerical solvers specifically designed for anisotropic multi-scale materials for the prediction of permeability.

This scientific software can calculate the saturated permeability of a porous material based on real 3D images of its micro/mesostructure. Alternatively, digital twins of the material can also be used as input to PoroS.

The first version of the software PoroS 1.0 has been developed to compute the permeability of materials with single-scale porosity. The Stokes flow problem is solved using the finite element method and specifically designed matrix-free iterative solvers to reduce the computational cost. The pseudo-compressibility formulation is employed, and the full-field homogenization method [3] then allows the full 3D permeability tensor to be calculated using only the computed velocity fields, giving the advantage of reducing the number of degrees of freedom without having to compute the pressure field.

After having validated the flow solvers using a set of test-cases from the literature, PoroS predictions were compared with the results of the first stage of the virtual permeability benchmark [1]. The input geometry was a 3D image with a nominal resolution of 0.5 µm/voxel representing the microstructure of a yarn composed of ~400 slightly misaligned fibers (available on the repository at https://doi.org/10.5281/zenodo.6611926). The results obtained using PoroS 1.0 fell within the main cluster of results of the benchmark (Figure 1) and are close to the mean value defined after elimination of outliers.

The second version of the software PoroS 2.0 [4] addresses the permeability of materials with dual-scale porosity by using the Stokes-Brinkman flow problem formulation. Poros 2.0 is officially involved in the second stage of the virtual permeability benchmark [5] dedicated to permeability of the material at the mesoscopic scale of the textile, in particular, a textile for which experimental measurements were available. The comparative analysis of results is ongoing.

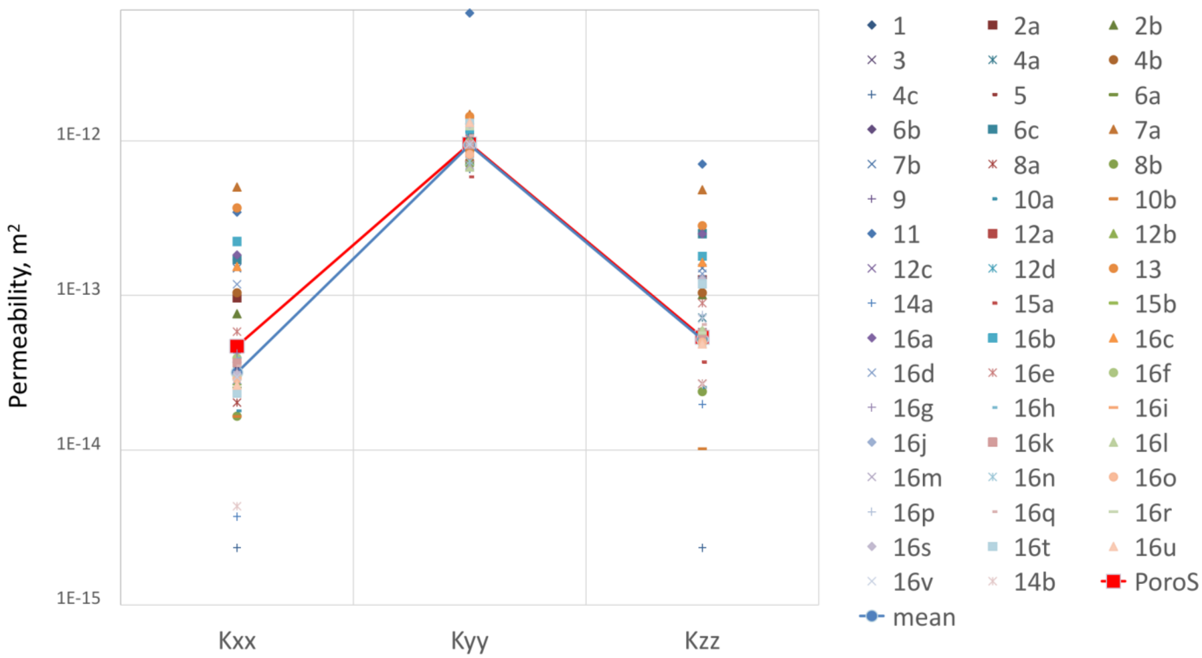

Figure 1: *Comparison of permeability tensor main components computed using PoroS 1.0 with the results of the virtual permeability benchmark [1].*

References

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