PoroS : a Software Suite for the Prediction of Permeability of Anisotropic Multi-Scale Porous Structures

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Résumé

1. Introduction
Permeability is one of the key properties of porous materials in general. This work focuses on the permeability of fibrous materials used as reinforcements of structural composites that represent the most general and complex case of porous media properties due to their multi-scale and anisotropic character. The permeability measurement of fibrous engineering textiles is not a trivial task. This is due to their anisotropic multi-scale character (the finest scale characteristic size is several μm) and their inherent natural variability. Virtual characterization of permeability using numerical methods has important advantages over experimental measurement. It does not require a specialized and often costly measurement equipment, it reduces material waste, allows to analyze the influence on permeability of material microstructural parameters, while being capable of addressing the material variability. However, at present there is no widely accepted numerical approach for permeability prediction due to modeling challenges such as the choice of the RVE (representative volume element), boundary conditions, numerical approximation, permeability identification technique, as revealed in the international virtual permeability
benchmark (1).

2. PoroS : a numerical solver for the prediction of saturated permeability
A novel scientific software named 'PoroS' (2) has been developed, which contains a set of numerical solvers specifically designed for anisotropic multi-scale materials for the prediction of permeability. The objective of the development of this scientific software is to calculate the saturated permeability of a porous material based on the real 3D images of the micro/meso structure. Alternatively, digital twins of the material, built, for example, using an open-source TexGen software (3) in case of textile structures, 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 the materials with single-scale porosity. The Stokes flow problem is solved using the Finite Element Method and specially designed matrix-free iterative solvers. The voxel-based discretization was used with hexahedral Taylor-Hood elements (4) that satisfy the LBB condition. The pseudo-compressibility formulation was employed, and the full-field homogenization method (5) then allowed the full 3D permeability tensor to be calculated using only the computed velocity fields, giving the advantage of reducing the number of

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degrees of freedom without having to compute the pressure field.

3. Results and discussion

After validating the flow solvers using a set of conventional test-cases from the literature, PoroS was compared with the results obtained in the first stage of the virtual permeability benchmark (1). The input geometry was a 3D segmented microscopic image (Fig. 1) of 1003×973×124 voxels with a nominal resolution of 0.52 μm/voxel (available on the repository at https://doi.org/10.5281/zenodo.6611926). It can be seen that the results obtained using PoroS fall within the cluster of the results reported by the participants of the benchmark (Fig. 2) and are close to the mean value defined after eliminating the benchmark outliers.

References

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