Asymptotically based optimization of flow-induced deformation of periodic flexural structures made of thin yarns

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Abstract

The two-way coupled fluid-structure interaction of Stokes flow through a linear elastic, thin porous structure is considered. The micro-resolved structure is deterministic with an in-plane periodicity of ε and consists of long thin yarns in contact. It can be described by a handful of geometrical and mechanical parameters such as distances between yarns, friction coefficients, linear material properties and yarn's cross-sections. Such problems typically arise e.g. in filtration applications with woven filter media.

Due to drastically differing length scales between fluid domain and the micro-resolved structure, direct numerical approaches for the problem are impractical in most scenarios. An asymptotic model was derived in [1, 2, 3] for the limit $\varepsilon \to 0$ by means of two-scale convergence. In the asymptotic limit, the problem is reduced to 3D Stokes flow coupled to a 2D Kirchhoff plate with non-standard interface coupling: the plate's vibration is proportional to the jump of fluid stresses across the plate.
The plate's effective elasticity tensors are determined by auxiliary problems on the smallest periodic unit of the structure, so called cell problems [4, 5]. The model is augmented by an interface flux term obeying Darcy's law to incorporate mass transport through the plate. The corresponding permeability tensor is attained by Stokes flow problems in the micro resolved periodic unit.

An optimization problem of tracking type is considered: The microscopic design of the structure is to be chosen such that a desired flow-induced deformation profile of the structure in steady-state is reached. The deformation profile is directly linked to the structure's filtration efficiency and is therefore of high interest in industrial application. An adjoint based optimization approach is considered.
In this presentation, a complete overview over the numerical workflow is given. On the micro-scale, the elasticity cell problems are solved utilizing a dimension reduction approach to 1D beams with additional contact conditions [5], while the permeability tensor is attained by solving three Stokes problems. On the macro-scale, a monolithic FEM formulation for the fluid-structure interaction is employed both for the arising forward and adjoint systems.

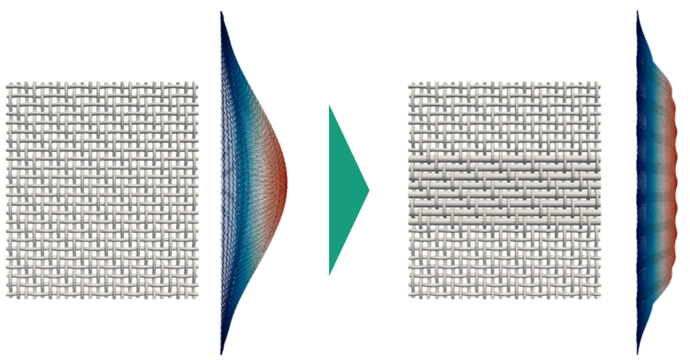

Figure 1: Design of periodic unit of micro-resolved structure and flow-induced deformation profile. Optimization through local reinforcements with thicker yarns.

References

[1] J. Orlik, G. Panasenko, R. Stavre: Asymptotic analysis of a viscous fluid layer separated by a thin stiff stratified elastic plate, Applicable Analysis, 100(3), 589-629, (2021)

[2] M. Gahn, W. Jäger, M. Neuss-Radu: Derivation of Stokes-plate-equations modeling fluid flow interaction with thin porous elastic layers, Applicable Analysis, 101(12), 4319-4348, (2022)

[3] G. Griso, J. Orlik, S. Wackerle: Asymptotic behavior for textiles in von-Kármán regime Journal de Mathématiques Pures et Appliquées, 144, 164-193, (2020)

[4] G. Griso, L. Khilkova, J. Orlik, O. Sivak: Asymptotic Behavior of Stable Structures Made of Beams. J. Elast (2021). https://doi.org/10.1007/s10659-021-09816-w

[5] J. Orlik, G. Panasenko, V. Shiryaev: Optimization of textile-like materials via homogenization and dimension reduction. SIAM Multiscale Model. Simul., 14(2), 637–667 (2016)