Macroscopic friction of fibrous assemblies

M1-M2 Research Internship 2025

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Hosting Laboratory: ELAN team @ Grenoble (INRIA/LJK), `https://team.inria.fr/elan/`

Practical details: Paid internship (INRIA scale)

Context: Fibres constitute an essential component in the design of many mechanically efficient materials, from clothes to insulating board or even bird nests (Weiner et al., 2020). When assembled in large dry systems, fibres interact through plastic frictional contact, and deform elastically through bending, resulting in remarkable properties at the macroscopic scale. Reminiscent of granular material, they in particular exhibit "solid" (plasto-elastic) and "liquid" (flowing) regimes, but with a much more complex transition, as the rich space of geometrical configurations couples with friction and elasticity. Within such assemblies, both the friction and geometrical entanglement of the fibres contribute to a macroscopic stability, which can be interpreted as a material yield strength. Understanding the microscopic contributions of elasticity and friction to this macroscopic yield strength is a crucial step to study the rheological properties of fibrous materials.

Figure 1: Dry black tea leaves forming a static heap.

Objectives: The yield strength of the fibrous assembly macroscopically leads to the existence of stable heap structures under gravity, with an upper bound on the slope angle corresponding to the yield strength. In analogy with granular materials, we propose to use this heap configuration as a first step to characterise macroscopic friction within fibrous materials.

The objective of the internship is to study numerically the stability of heaps of entangled fibres under gravity, and investigate the impact of microscopic quantities (length and natural curvature of the fibres, friction between fibres) on the limit angle attainable with static macroscopic heaps. These numerical experiments will in particular help identify the relevant non-dimensional microscopic parameters which control the macroscopic static friction of the medium.

The work will benefit from robust models and contact solvers for Kirchhoff rods developed in the team (Crespel et al., 2024; Daviet et al., 2011; Bertails et al., 2006), and will explore direct discrete element approaches as a first step towards continuum rheological closures.

Required skills: Good skills in numerical analysis and computer programming (C/C++) are required. Curiosity and taste for applications in physics would be appreciated.

References

Bertails, F., Audoly, B., Cani, M.-P., Querleux, B., Leroy, F., and Lévêque, J.-L. (2006). Super-helices for predicting the dynamics of natural hair. *ACM Transactions on Graphics (TOG)*, 25(3):1180–1187.

Crespel, O., Hohnadel, E., Métivet, T., and Bertails-Descoubes, F. (2024). Contact detection between curved fibres: high order makes a difference. *ACM Transactions on Graphics (TOG)*, 43(4):1–23.

Daviet, G., Bertails-Descoubes, F., and Boissieux, L. (2011). A hybrid iterative solver for robustly capturing coulomb friction in hair dynamics. In *Proceedings of the 2011 SIGGRAPH Asia Conference*, pages 1–12.

Weiner, N., Bhosale, Y., Gazzola, M., and King, H. (2020). Mechanics of randomly packed filaments—the "bird nest" as meta-material. *Journal of Applied Physics*, 127(5).

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