Master 1 or Master 2 internship

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A minimal constitutive model for strain-hardening in colloidal gels

Colloidal gels are ubiquitous in major industries with applications such as colloidal crystals, energy storage devices, advanced ceramic materials, and biomaterials. They consist of polymer and/or nanoparticles in attractive interactions that form a percolated space-spanning structure, which confers to the gel solid-like elastic properties [1]. However, harnessing the interplay between the building blocks' properties (shape, size, surface chemistry, etc.) and that of the resulting gel remains an outstanding challenge for manufacturing a vast range of applied materials.

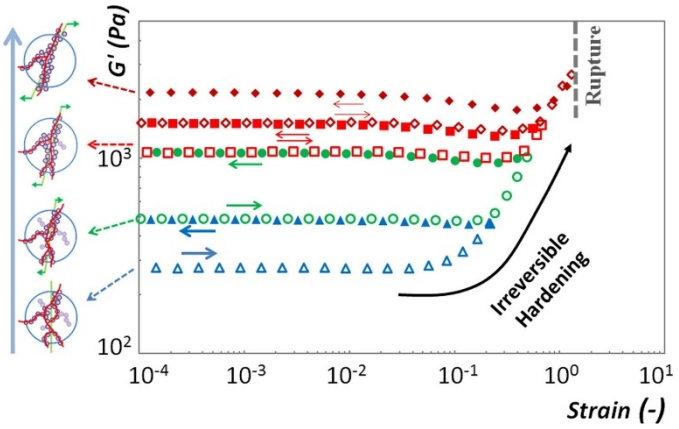

***Illustration of strain hardening in a natural colloidal gel**: Evolution of the elastic modulus G' during successive strain sweeps (from blue to red) in a natura rubber latex. Each cycle consists of (i) a continuous increase in strain amplitude γ (empty symbols) up to a predetermined maximum strain γ_{max}, followed (ii) by a continuous decrease in strain amplitude (filled symbols). Extracted from [2].*

An **intriguing phenomenon** observed in colloidal gels **is the so-called "strain hardening,"** which occurs when gels are subjected to shear or extensional deformation: the gel elastic modulus increase by as much as a factor of 100 as reported in various systems such as particulate gels and countless biopolymer gels [3]. Furthermore, the phenomenon is either reversible or irreversible (see Figure 1), which hints at a subtle connection with local plasticity.

The goal of this M2 internship is to propose a minimal model that captures as many features as possible of strain hardening in colloidal gels. We will rely on the vast collection of experimental data available in the literature, and the work will be, first and foremost, theoretical. The candidate will use the multiple natural configuration theory that produces thermodynamically admissible stress tensor equations, together with a simple λ-model to account for the evolution of the gel microstructure under shear [4]. In practice, the candidate will use numerical simulations to identify the proper forms of the stress tensor equations. This internship will take place at LaMCoS, under the supervision of L. Palade and in close collaboration with T. Divoux for selecting experimental data.

Duration – 4 to 6 months at Master 1 or 2 level between February and August 2023. Possibility to apply for Ph.D. funding at the Lyon Physics & Astrophysics graduate school.

Keywords – Strain-hardening, Rheology, Colloids, Polymers, constitutive modeling

References

[1] Cao & Mezzenga, *Nature Food* **1**, 106 (2020); Johnson *et al.*, *J. Rheol.* **63**, 583 (2019)
[2] Oliveira Reis et al., *J. Colloid Interface Sci.* **539**, 287 (2019)

[3] Storm *et al.*, *Nature* **435**, 191 (2005)
[4] Larson & Wei, J. Rheol **63**, 477 (2019)