Minicolloque n° 12 **Oral**

Mechanics of frictional fibers assembly

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From birds' nests to pine needles, fibrous aggregates in the natural world are proof that they are easier to shape when compressed. One striking difference between aggregates of flexible frictional fibers and other granular materials like rigid spheres is the effective cohesion of their assembly. We need to add glue or water capillary bridges between grains to shape aggregates of spherical particles and build sandcastles. For fibers, no need for glue to build a nest.

Here we study an assembly of monodisperse flexible fibers. Such assemblies of slender frictional fibers behave as a flexible mechanical metamaterial: the mechanical properties of the assembly are dominated by their structural organization.

Figure 1 :Aggregate of flexible frictional fibers

We first use X-ray microtomography to characterize the geometry of the initial assembly, the number of frictional points and bending curvatures of the fibers. Using force-displacement measurements, we characterize the variation of the macroscopic cohesive strength of the aggregate with the geometry of the fibers, the fibers mechanical properties and the packing preparation. We observe that the mechanical response is highly nonlinear with large hysteresis and plasticity, i.e. permanent compaction of the assembly. We relate the macroscopic behavior of the assembly to the filament reorganization at the microscopic scale and develop micromechanical experiments with a minimal number of fibers to characterise the dissipation associated with the coupling between friction and bending of filaments and explore the minimum conditions to capture plasticity and the hysteresis observed in the assembly. We then characterize the macroscopic cohesive strength of the assembly in traction and rationalize how the cohesive strength depends on packing precompression and fiber elastic flexibility (bending rigidity and aspect ratio of the fibers).