Drying of complex fluids on soft substrates

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In this short document, we present some of the results obtained during the project SOFTEVA, on the drying of complex fluids on soft substrates. Soft substrates become widely used in novel industrial domains and these materials bring fundamental questions involving physics, chemistry and mechanics [1]. In this project, we focused on the deposition of material on soft substrates, which is of interest when the control of soft interfaces is desired.

1 Particle deposition on hydrogels by solvent absorption of drops containing a dilute suspension

When a drop containing small particles as in coffee, dries on a surface, it leaves a caracteristic stain with a ring-like shape. The accumulation of particles at a contact line can be explained by liquid flow in a droplet, which rationalizes the formation of a so called coffee stain (Fig. 1). This final pattern is often seen as a defect in industrial processes where uniform coatings are desired. To suppress the coffee stain effect, different strategies have been proposed such as the addition of surfactants of the particle shape.

At present, methods for suppressing the coffee stain effect mainly focus on the properties of the liquid phase, which evaporates. In contrast, our approach consists in removing the liquid with absorption by the substrate, which leaves the particles at the surface of the substrate. We studied model swelling substrates made of hydrogels, where the adsorption kinetics can be adjusted by changing the initial composition of the gel [2, 3]. We have demonstrated experimentally and theoretically that the absorption of a colloidal drop on an absorbing gel leads to a nearly uniform deposition pattern (Fig. 1).

In addition, we have evidenced that these particles can be manipulated to tune their deposition [4]. The manipulation is achieved by diffusiophoresis, which describes a directed motion of particles induced by solute gradients. By letting the solute concentrations for the drop and the hydrogel be different, we control the motion of particles in a stable suspension, which is otherwise difficult to achieve.

The homogeneous coating of gels with particles can be used to tune locally their interfacial properties including roughness, wetting properties, rigidity, bonding capacities or permeability. Combined with simple microdispensing techniques such as ink-jet printing, our idea is amenable to produce scalable and complex graphics. Such patterns offer the possibility to control the precise location and kinetics of drug delivery but also to inhibit microbial growth with silver particles that can be used on soft contact lenses or surgical implants.

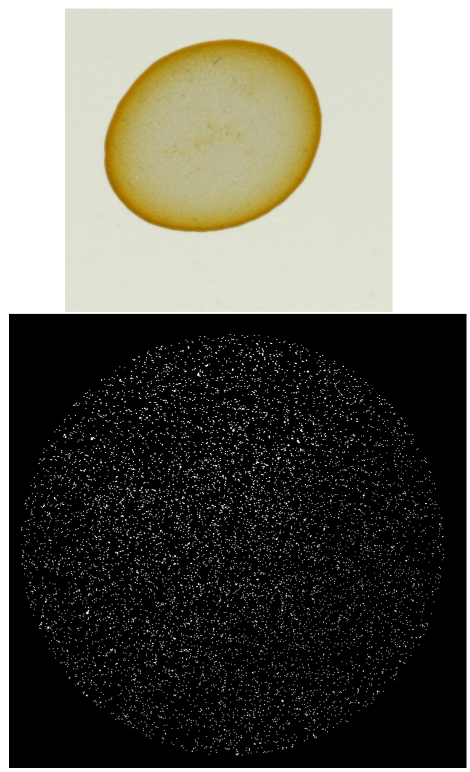

Figure 1: Top: Picture of a coffee-ring stain of a centimeter of diameter. Bottom: Homogeneous particle deposition on a hydrogel.

2 Stress measurement of concentrated colloidal suspensions from the substrate deformation

Drying of concentrated colloidal droplets is ubiquitous in processes such as ink-jet printing technologies or spray painting. Recently, new directions for printing techniques have been developed for soft materials to enable applications such as conformable electronics, soft robotics and wearable devices. For instance, electronic circuits can be printed on elastomers and human skin. However, deformations of the surface can be induced by the surface tension of a liquid drop or the consolidation of a colloidal material, which could affect the final quality and the function of the printed device.

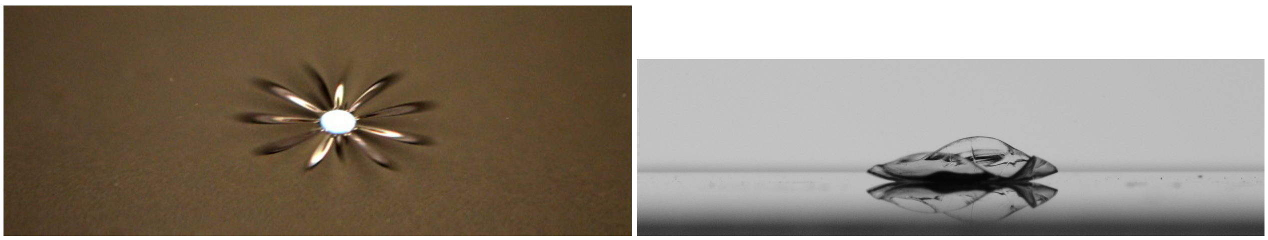

Figure 2: Left: dried drop of silica nanoparticles on a thin elastic membrane on which wrinkles formed. Right: Self-peeled elastic sheet (5 mm diameter) after drying of a coating made of silica nanoparticles.

To better understand the origin of tensile stresses arising during the consolidation, we performed model experiments, which allows us to reveal the significance of particle polydispersity [5]. This method relies on the buckling of a floating elastic membrane caused by the tensile stress of the drop (Fig. 2). It is known that the particle size is a crucial parameter for the final stress, with larger stress for small particles. With our novel method, we have shown that the largest particles of a broad particle size distribution dominate the tensile stress. Therefore, without modifications of the chemical composition of products, we have evidenced that tuning the physical parameters of colloidal materials could be advantagiously used in the coating industry.

Another study relying on the same nanoparticle suspensions shows the significant effects of tensile stresses appearing during the drying [6]. By coating these suspensions on a thin membrane, we are able to peel this membrane off a surface (Fig. 2). We have illustrated that this technique could be used to clean a surface contaminated, for instance, of dust. This could of interest for applications where delicate surfaces have to be treated such as art paintings.

References

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