3D geometry of hyperelastic hydrogels studied with fast lab x-ray tomography

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Keywords: x-ray tomography, hydrogel, fast tomography, geometry

Summary: In this paper we present geometrical measurements made on aqueous polyacrylamide gels with lab-based micro-tomography, one of the most convenient ways of accessing a quantitative measurement of the fascinating shapes that these materials make when hanging under their own weight.

1. Material: Hydrogels

Many materials such as biological tissues can withstand huge elastic deformations of more than several hundred percent. The amplitude of the stress is then of the order of the elastic modulus, a situation commonly encountered with soft materials. Specific and fascinating patterns can then occur spontaneously.
Here we consider the deformation of heavy centimetric vertical cylinder attached from the top and subjected to the earth's gravity.

We use aqueous polyacrylamide gels consisting in a loose permanent polymer network immersed in water. The density of this incompressible elastic material is almost equal to that of water. It behaves as an elastic solid for strains up to several hundreds of percent. The shear modulus μ can be tuned over a wide range by varying the concentrations in monomers and cross-linkers. In the experiments reported here, it lies between 10 and 60 Pa.

The reagents generating the gel are dissolved in ultrapure water and poured into cylindrical dishes up to the brim. The dishes' radii lie between 3.6 cm and 15 cm, and height between 0.8 and 3 cm. After the gel is made, its top surface is glued by capillary action onto a rigid horizontal surface, and the dish is removed from below. This results in a hanging cylinder of gel attached from the top.

2. Hanging Geometry

Due to the low shear modulus, the deformation of the gels are significant. The hydrostatic stress at the top surface of the cylinder is $P = \rho g h$ with ρ the density of the gel, h its initial height, and g the gravitational acceleration. With $\rho \simeq 1$ g/cm^3, $g \simeq 10$ m/s^{-2} and $h \simeq 10^{-2}$ m, one gets $P \simeq 100$ Pa. This stress is far larger that the shear modulus, hence large deformations in the gel. These large deformations are responsible for the rich variety of equilibrium shapes taken by the specimen once gravity is applied. Schematically, these configurations results from the superposition of an almost homogeneous deformation, with deformations induced by instabilities such as those observed with hyper-elastic material subjected to large strains [1, 2, 3].

This study aims to study the different equilibrium shapes of these centimetric pendant gels. They can be easily qualitatively characterized since they are easily observable by human eyes. However a quantitative description, which is requested to get insight into the mechanisms leading to the observed complex shapes, is challenging.

Metrological studies of the shape of this material are difficult: the stickiness and softness of its surface makes contact-measurements impossible, and given its transparency to visible light, photography and laser-based measurements are also difficult. Acoustic methods are not suitable for these hydrogels which consist to more than 99% water.

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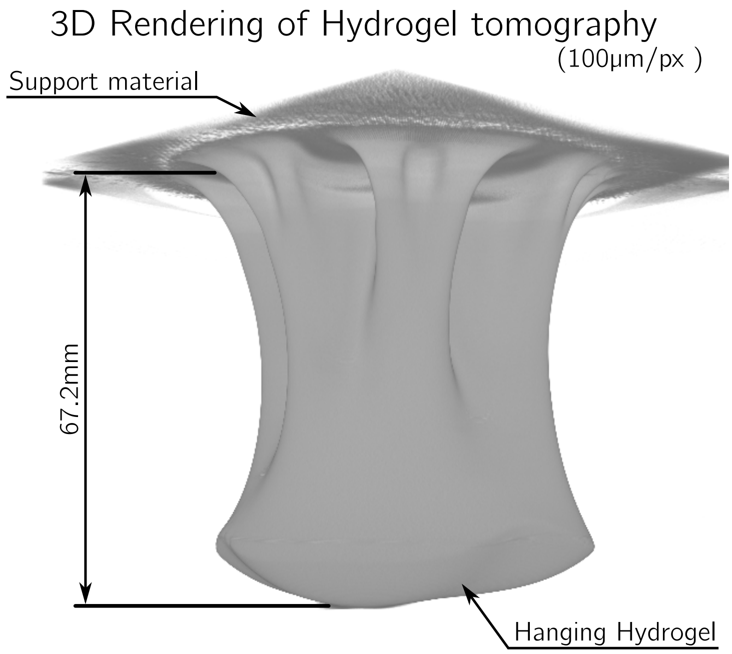

Figure 1: 3D rendering of one of the hydrogels studied, a cylinder 74mm diameter and 24mm height hanging under its own weight

3. X-ray tomography

The difference in x-ray absorption between air and water makes x-ray tomography a valuable tool to reveal the structure of these materials in 3D

Furthermore, the relatively large size of the objects studied makes them ideal for lab-based x-ray tomography.

Here we use an RX-Solutions x-ray scanner in Laboratoire 3SR with a micro-focus source and a (new) Varian Paxscan DX2520 amorphous silica detector. A number of specific challenges needed to be overcome in order to make high-quality scans of the hanging hydrogels:

- The quality of the top boundary condition is precarious; The suction that holds each hydrogel from the top can reduce with time
- Drying of hydrogel has to be limited.
- The low Young's modulus and the boundary conditions make the samples particularly sensitive to accelerations and vibrations.

To this end, the machine is set to limit accelerations and decelerations when rotating the specimen, and is set to perform *continuous* rotation during tomography acquisition (plus a roll-in period in order to start the scan with no rotational acceleration) to help ensure the sample doesn't move while scanning. To limit drying and risk of specimen collapse, scanning time is reduced by accepting a degraded spatial resolution (using the detector in 2x2 binning) which allows scans in the 3-15 minute range.

In a recent experimental campaign we have proved that by resolving these experimental difficulties, it is possible to obtain high quality 3D reconstructions, for example Figure 1. This technique will allow us to quantitatively penetrate the complex physics responsible for the intriguing shapes observed at equilibrium.

References

[1] S. Mora, M. Abkarian, H. Tabuteau, and Y. Pomeau. Surface instability of soft solids under strain. *Soft Matter*, 7:10612–10619, 2011.

[2] B. Saintyves, O. Dauchot, and E. Bouchaud. Bulk elastic fingering instability in hele-shaw cells. *Phys. Rev. Lett.*, 111:047801, 2013.

[3] S. Mora, T. Phou, J.M Fromental and Y. Pomeau. Gravity driven instability in solid elastic layers. *Phys. Rev. Lett.*, 113:178301, 2014.