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Stress and Relax: Hydrogel swelling in a confined granular medium and relaxing after extraction

Thursday, 2 June 2022 09:25 (15 minutes)

Hydrogels hold promise in agriculture as reservoirs of water in dry soil, potentially alleviating the burden of irrigation. However, confinement in soil can markedly reduce the ability of hydrogels to absorb water and swell, limiting their widespread adoption. Unfortunately, the underlying reason remains unknown. Here, we report the first direct visualization of hydrogel swelling within a model three-dimensional (3D) granular medium with tunable confining stresses and grain sizes. Our experiments enable us to measure, in situ, two key quantities that were previously inaccessible: the extent of hydrogel swelling and medium restructuring. Unlike an imposed osmotic or hydrostatic pressure, confinement in a granular medium subjects the surface of a hydrogel to a spatially nonuniform stress. We therefore extend the classic Flory-Rehner theory of hydrogel swelling by coupling it to Hertzian contact mechanics that explicitly treats the stresses exerted by the medium at the hydrogel-grain contacts. Using this approach, we show that the extent of hydrogel swelling is determined by the balance between the osmotic swelling force exerted by the hydrogel and the confining force transmitted by the surrounding grains. Furthermore, we demonstrate that a balance of the same forces, also including intergrain friction, determines the onset of restructuring of the surrounding medium. Our work therefore reveals the physical principles that describe how hydrogel swelling in and restructuring of a granular medium both depend on the properties of the hydrogel, the properties of the medium, and confining stress. We show that our theoretical framework not only describes our measurements but also helps to rationalize previous measurements of hydrogel water absorption in soil. Moreover, upon extraction of the originally spherical hydrogel spheres, we noticed multiple indentations, resulting in the gels having raspberry shapes. Such indentations relax at a characteristic time - the poroelastic time - that we were able to measure and confront to typical indentation measurements. Together, our results provide (1) quantitative principles to predict how hydrogels behave in confinement, and (2) a new cost-effective method to measure the poroelastic diffusion coefficient of hydrogels, potentially improving the use of hydrogels in agriculture as well as informing other applications such as oil recovery, construction, mechanobiology, and filtration.

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References

Under pressure: Hydrogel swelling in a granular medium
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Jean-François Louf, and Sujit S. Datta,
Soft matter 17.14 (2021): 3840-3847
DOI: 10.1039/D0SM02243H

Time Block Preference

Time Block A (09:00-12:00 CET)

Participation

In person

Primary authors: LOUF, Jean-Francois (Auburn University); Dr LU, Nancy; O'CONNELL, Margaret; Prof. CHO, H. Jeremy (University of Nevada Las Vegas); DATTA, Sujit (Princeton University, USA)

Presenter: LOUF, Jean-Francois (Auburn University)

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