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Effect of water on granular matter mechanics, local scale: evaporation, extension and rupture of liquid bridges.

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Abstract

The mechanical strength and cohesion of granular matter depend strongly on water content (i.e. in soil). Water exists in different forms between the solid particles, due to surface tension generates internal stresses in granular material and develops mass exchange with the environment during the evaporation process. During evaporation the internal stress evolves, which may lead to the medium shrinkage, air entry and damage. The most sensitive is the final stage of evaporation, which corresponds to the rupture of capillary bridges (Péron et al., 2010). In this study, the phenomenon of air entry, evolution of intergranular forces and behavior and rupture of capillary bridges are analyzed experimentally at the local scale, on the example of capillary bridges between two and three spherical grains.

Capillary bridges are made from distilled water and exposed to evaporation under constant atmospheric conditions, with constant separation between the grains. For comparison, the liquid bridges are also tested for mechanical extension at constant volume, with constant extension rate.

The evolution of the capillary bridge profile is recorded by still photo camera and high-speed camera (prior and at the moment of rupture), in correlation with direct measurements of evaporation rate and capillary force with the use of precision balance. Further image processing allows to measure several geometric parameters (Fig. 1), used then to trace the evolution of global and local variables, as surface area of evaporation, evaporation flux, Laplace pressure Δp , capillary force F_C and its component forces, with use the solutions of Young-Laplace equation (Adamson, 1976).

Obtained results of experimental measurements are compared with calculated values based on the geometrical parameters. The behavior of liquid bridges depends strongly on the separation distance between the grains. Substantial differences are observed also between the evolution of capillary force due to evaporation and due to extension of the liquid bridges.

Negative Laplace pressure noted at small separations significantly decreases during evaporation,

and becomes positive toward the end and prior to rupture. At larger separations the pressure is positive all the time, changing a little. Rupture of the bridge occurs at positive pressure; however, the resultant total capillary forces are always tensile, and decreasing toward zero, in all cases. None of the dynamic variables characterizing capillary bridges i.e. Laplace pressure, capillary force qualify as state variables of volume and separation upon evaporation and/or extension, but rather depend on additional variables. In particular, the evolution (pinning/depinning) of the diameter of the three-phase contact line and the "apparent" contact angle at the solid/liquid/gas interface seem to control the capillary force evolution (Mielniczuk et al., 2014a).

The rupture of the bridge is accompanied by air entry and a decrease in cohesion of the material. Several rupture modes are observed, depending on the liquid bridge configuration: disjunction in the middle, creation of water-wire (Mielniczuk et al., 2014b), nucleation and growth of an air bubble or a movement of water volume. Water body instability generated by dynamic penetration of air may also provide an imperfection for the granular system, potentially leading to cracking. The findings are of relevance to the mechanics of unsaturated granular media in the final phase of drying.

References

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Illustrations

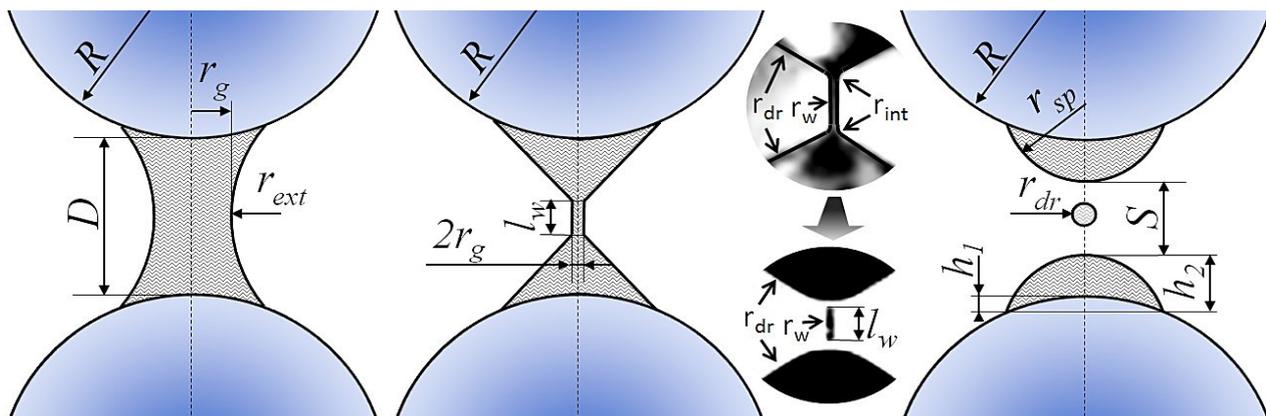


Fig. 1. Scheme of capillary bridge between two spheres during evaporation/extension processes and at the moment of rupture.