Experimental Physics - Complex liquids - Saarland University

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Granular Matter Rheology

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We investigated the stress strain behavior of confined sand under steady and oscillatory shear with and without small amounts of water. By pushing the sand through a tube quasistatically with an enforced parabolic or Poiseuille like profile we minimize the effect of avalanches and shear localization. We found out that the system starts to flow when a critical shear of the order of one particle diameter is exceeded. We observe that under confinement the resistance against the flow of wet sand is much smaller than that of dry sand. For the dissipative flow we propose a non-equilibrium state equation for granular fluids. In both systems we measured that the dissipation under flow is originated in an energy barrier. This is confirmed by an analysis with the classical frictional approach.

Mystery of How The Egyptians Moved Pyramid Stones Solved PRL **112**, 175502 (2014)

May 5, 2014 by Janet Fang

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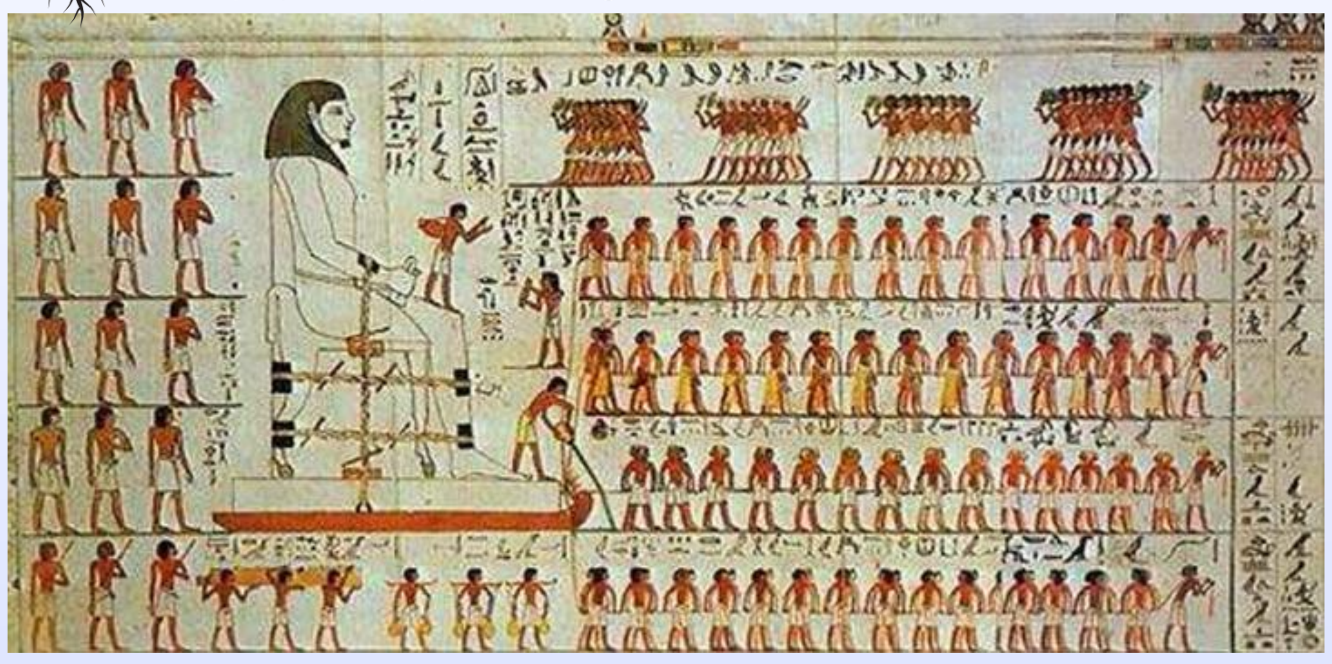


Wet sand flows better than dry

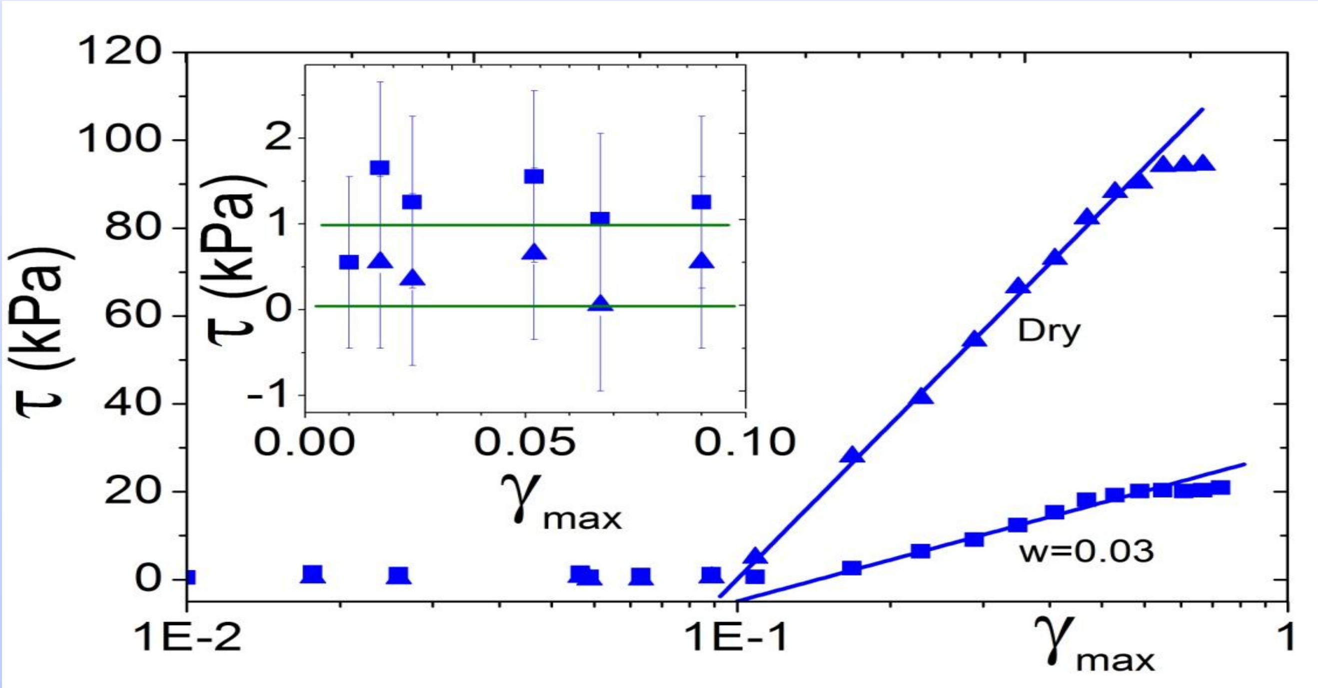


FIG. 3: Stress - strain behavior for increasing shear amplitude for dry (triangles) and wet sand with water content 0.03 (squares) and the corresponding fittings for the dissipative flow range (equation (1)). The inset shows, for the wet sand, the range where the stored stress is the yield stress.

$$\frac{\gamma}{\gamma_0} = \exp\left(\frac{\tau}{\tau_0}\right) \quad (1)$$

Rheological measurements

Our sand was composed of glass spheres of diameter D = 140−150 μm with and without additional deionized water. The content of water in the paste is defined as the quotient between the liquid volume and the volume occupied by the grains.

The measuring of rheological/ viscoelastic properties was carried out with a device which hold the structural integrity of the liquid bridge network FIG 1. The wet granular material is poured into a cylindrical cell with a packing factor 0.63, where the sides of the cell consist of a latex membrane of 300 μm. Two adjacent chambers filled with water and two pistons complete the set up, which permits to shear the sample at constant volume and well defined velocity. We run experiments with a plexiglass cell of longitude 24 mm, and diameter 24 mm.

The pressures in both adjacent chambers, *p*1 and *p*2, were recorded, while the sample was sheared back and forth with a quasi-statically. A plot of the pressure difference, p1-p2 as a function of the strain, yielded a well developed hysteresis loop.

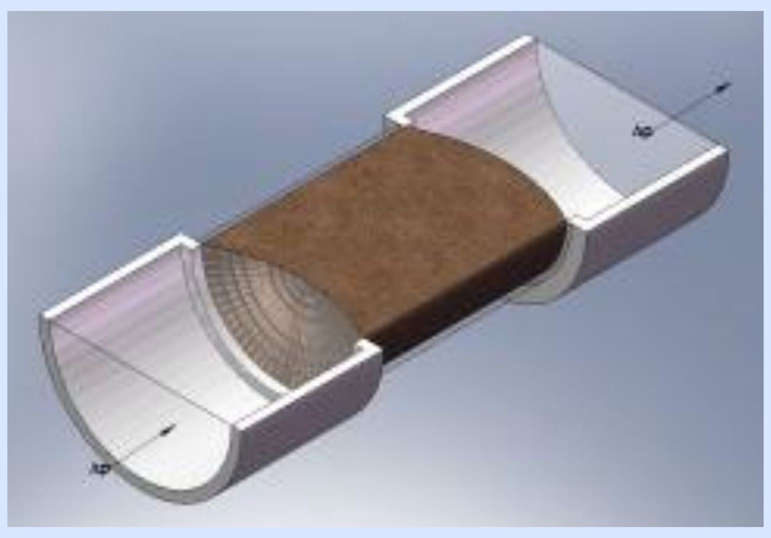
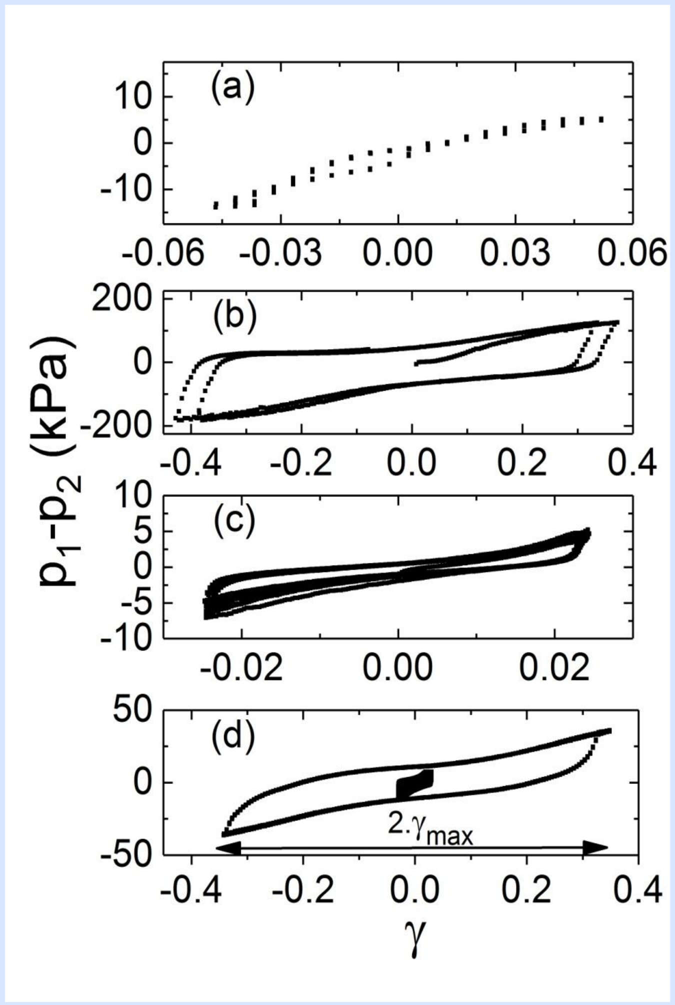


FIG. 1: Experimental device for measuring the differential pressure curve. Adjacent chambers and the plexiglass cell where it is the sand.

FIG. 2 (right): Differential pressure versus the shear displacement. (a),(b):A sample of dry sand (26% humidity 26°C) is compared with (c),(d): a paste of the same sand content mixed with water content 0.03. The opening of the loop at cero shear displacement is either the yield stress or the stored stress:

$$\gamma_{\max} = \frac{32 \cdot \Delta V}{\pi \cdot D^3}$$

$$2 \cdot \tau = 2 \cdot \left| p_1 - p_2 \right|_0$$



Phys. Rev. E . **86**, 020103 (2012)

Compaction of wet granular assemblies

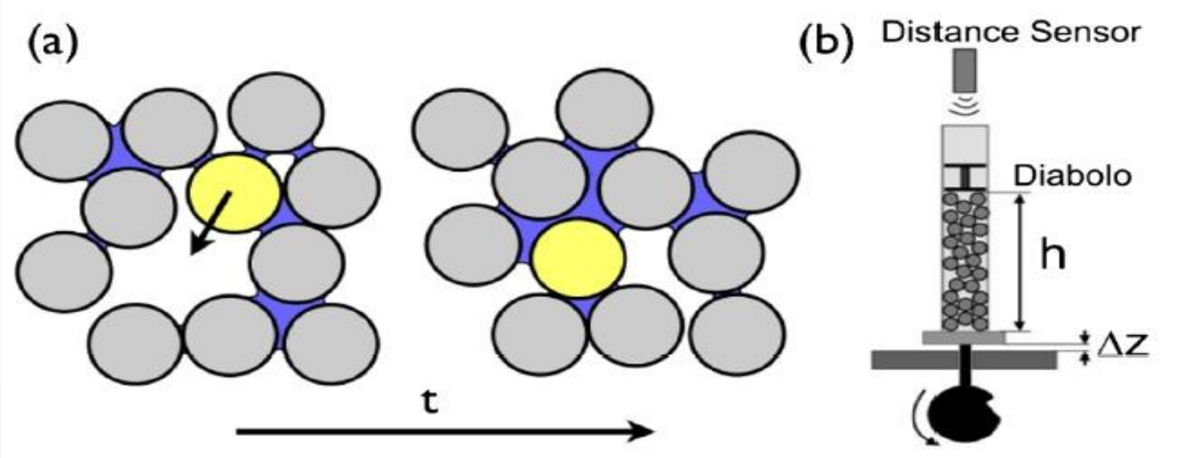


FIG. 4 (a) Sketch of a grain rearrangement, which implies to overcome an energy barrier related with the capillary forces. Liquid bridges are present everywhere in the packing. The coalescence of some bridges is observed. (b) Sketch of the setup used to measure the compaction dynamics.

$$\frac{\eta - \eta_0}{\eta_\infty - \eta_0} = 1 - \frac{1}{1 + k \log(t/\tau)}$$

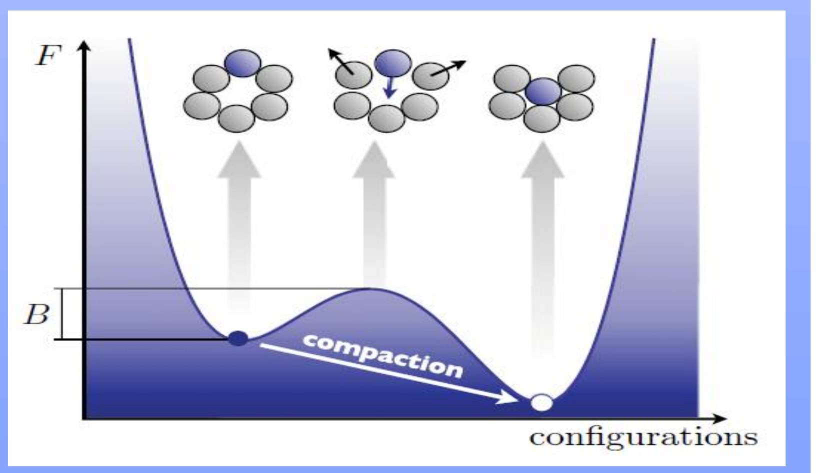


FIG. 6: A naive representation of granular compaction within a free energy diagram F in the space of local configurations.

$$\frac{\eta - \eta_0}{\eta_\infty - \eta_0} = 1 - \exp\left[-\left(\frac{t}{\tau}\right)^{\delta}\right]$$

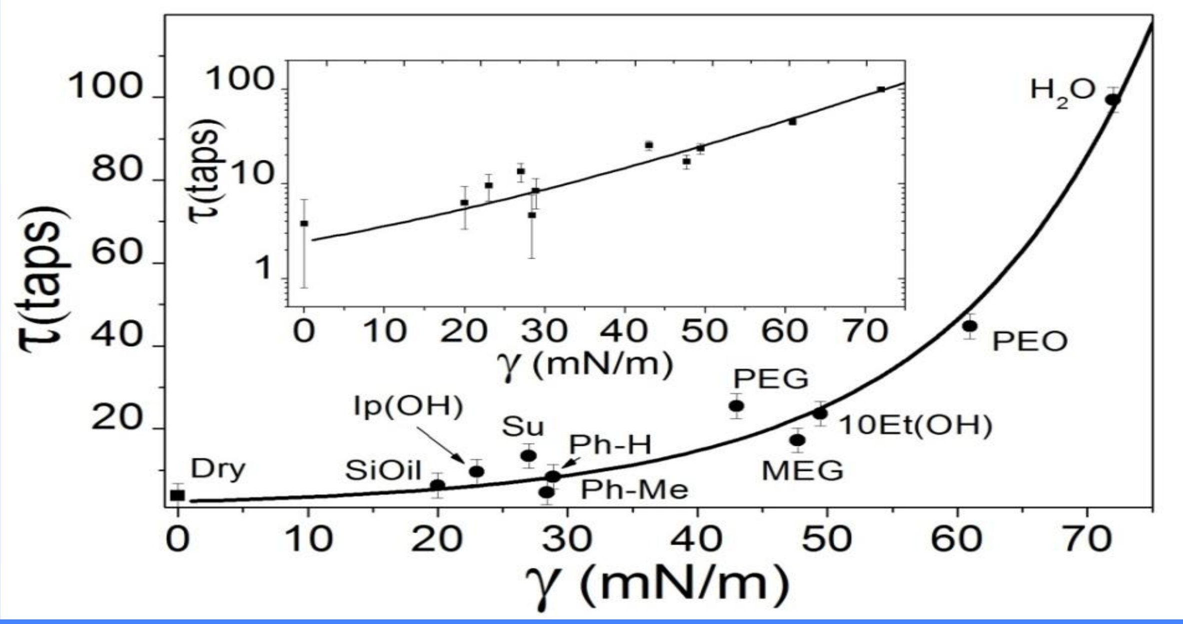


FIG. 5: Experimental data of the relaxation time for small additions of liquid with different surface tensions (circles), and the corresponding fit related with the energy approach. The square corresponds to "dry" sand with RH 46%, 22 °C. For a better appreciation the inset shows the data in a semi log plot.

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Triboelectricity and Capillarity

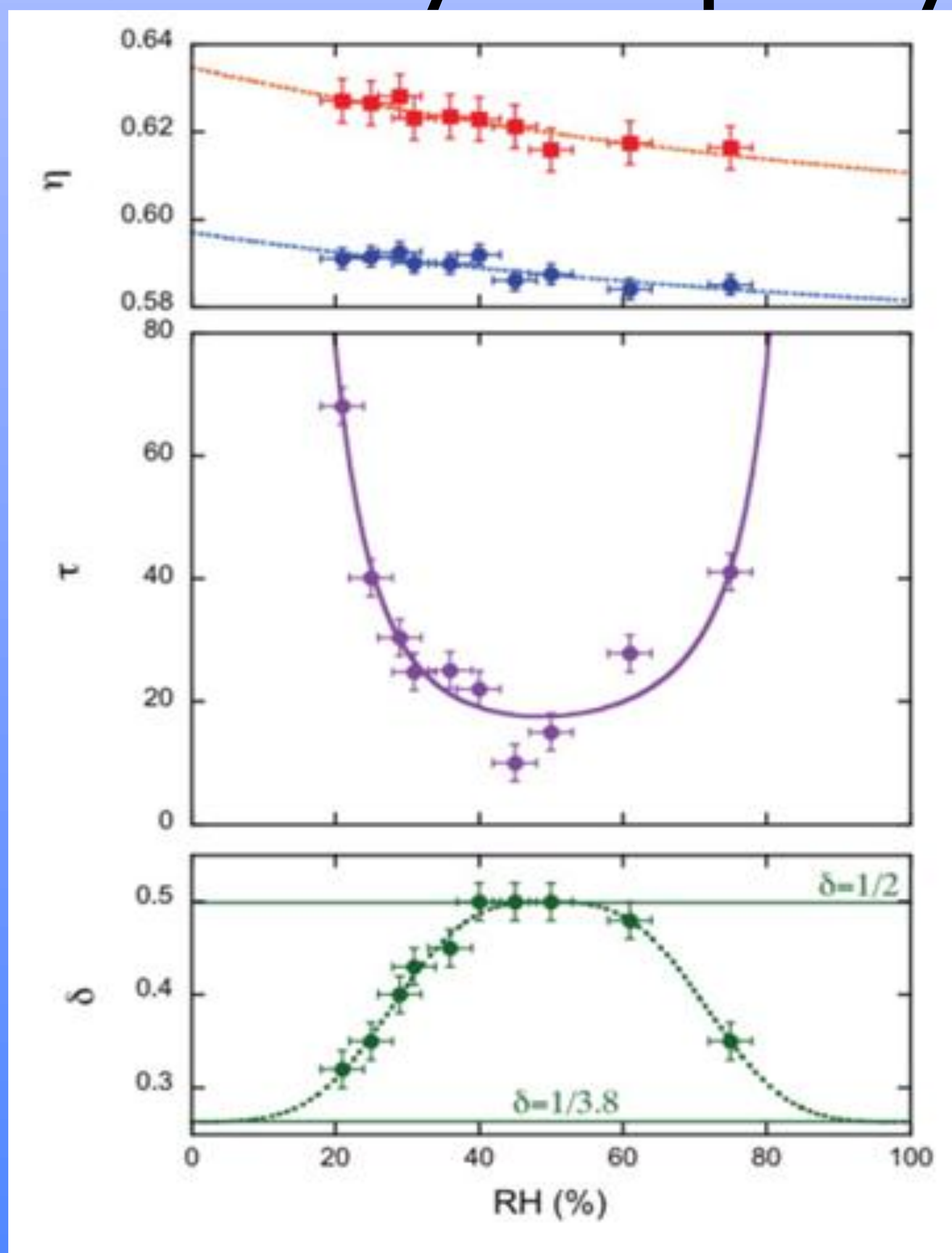

FIG 7 (right): Top: The initial packing fraction η0 (disks) and the final packing fraction η∞ (squares) as functions of RH. Middle: The relaxation time τ as a function of the relative humidity RH. A clear minimum is seen for relative humidity HR ≈ 45%. The continuous curve is a fit using our model explained in the text. Bottom: The stretching exponent δ as a function of RH. The dashed curve is a guide for the eye. Error bars are drawn for all data points. Horizontal lines at δ = 1/2 and 1/3.8 correspond to limiting values of anomalous diffusion in disordered (percolation) systems.

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CONCLUSION: In conclusion, we have found that it is much easier to push wet sand than dry granular matter in a Poiseuille-like profile through a tube. Even if the capillary forces increase the yield stresses, it looks like the water promotes the cluster formation and reduces the inter-grain friction. The leading dissipation mechanism results from the rupture and formation of liquid bridges, and we are able to explain our data quantitatively within the framework of an excluded volume theory. Finally, we find indications that the yield of the system is related to the microscopic size of the grains.