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A Study of Funicular Water Bridge Effect between Three Spheres

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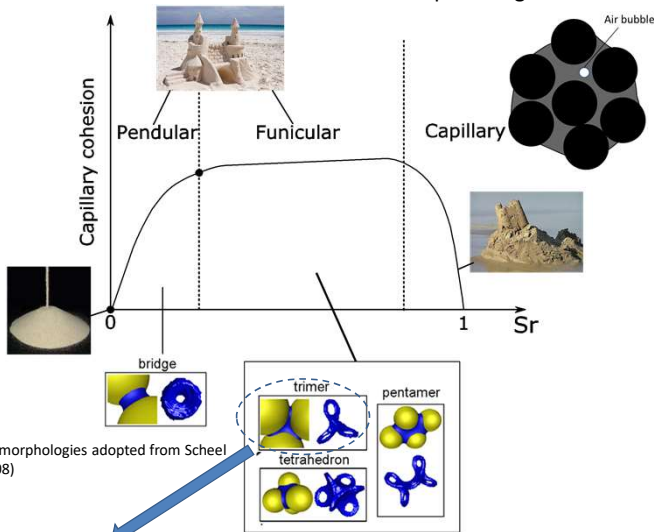
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Background

Cohesion in granular materials changes with water content (degree of saturation, S_r). The liquid phase has different morphologies from pendular rings to funicular bridges. Unlike the pendular rings, not much research effort has been done on funicular state liquid bridges.

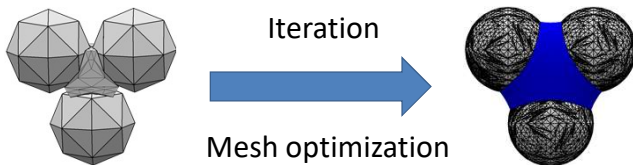


Objective

To understand the capillary force, water bridge coalescence effect and rupture behaviours on the most fundamental funicular water bridge between three spheres.

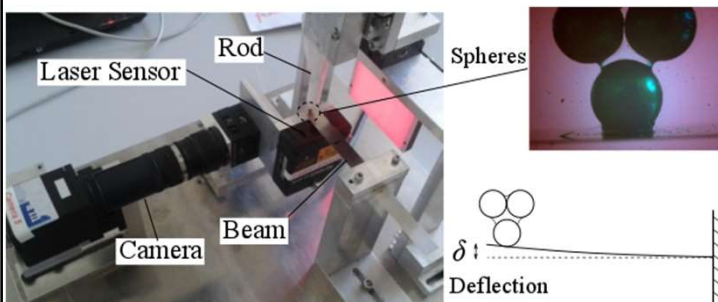
Methodology

Simulation: Numerically solved by 'Surface Evolver' towards minimal surface energy iteratively.



$$\text{Capillary force: } F = \frac{E_s(z+dz) - E_s(z)}{dz}$$

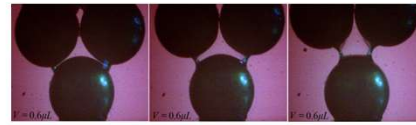
Experiment: Test on three brass spheres, stainless cantilevered acting as spring to measure force.



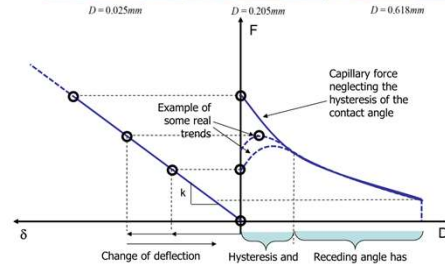
$$\text{Capillary force: } F = k\delta$$

Results

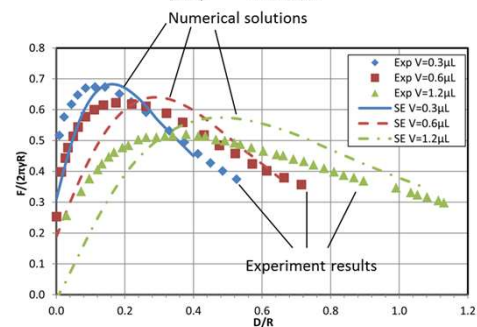
Comparison of Numerical and experimental results



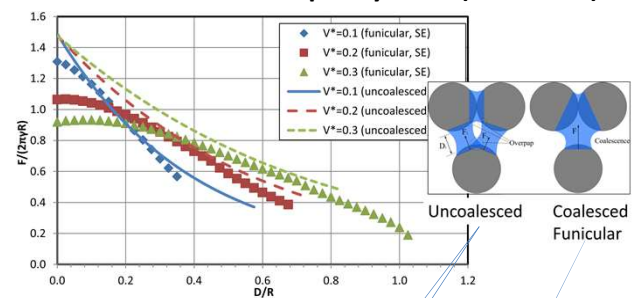
Observed water bridge and contact angle hysteresis with displacement



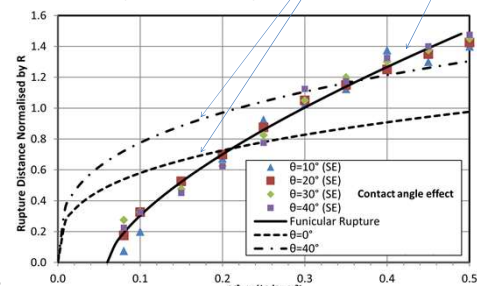
Due to the pinning effect, the capillary force increases and then decreases.



Coalescence effect on capillary force (numerical)



Rupture distance (numerical)



Conclusions

- Numerical solutions agree well with the experimental results.
- From pendular to funicular regime, water bridge coalescence slightly reduces capillary force especially when inter-particle gap is small.
- Coalescence may reduce rupture distance when water volume is relatively small but can extend the rupture length with a larger liquid volume.

References

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Wang, J.-P., Gallo, E., François, B., Gabrieli, F., and Lambert, P. 2016. Capillary Force and Rupture of Funicular Liquid Bridges between Three Spherical Bodies. *Powder Technology*.