CAPCAP

Controlling **A**dhesion between **P**articles for a better understanding of **C**ompaction, **A**eration and flow of **P**owders.

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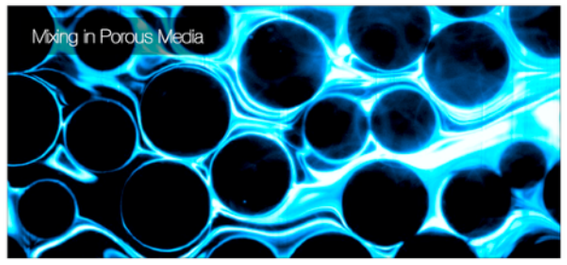
IUSTI, CNRS, Aix-Marseille University, France

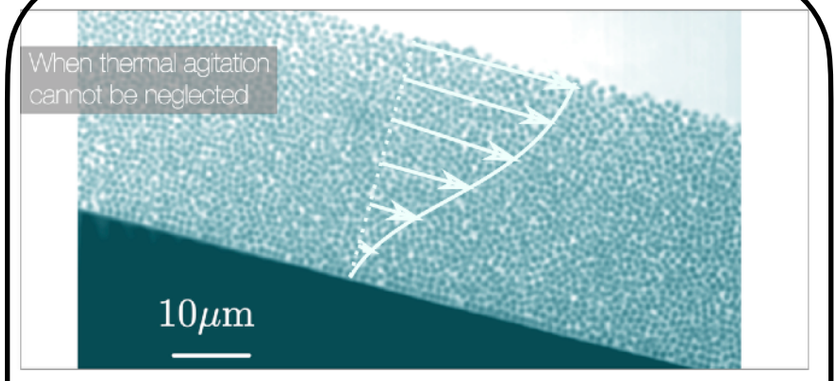
The « Soft » group in Marseille

https://iusti.cnrs.fr/la-recherche-a-liusti/milieux-divises-et-fluides-complexes-axe-mdfc/

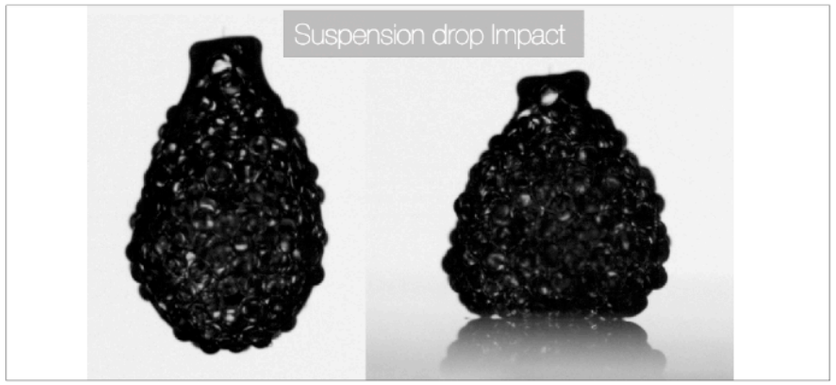


Mixing

Biomechanics, soft robotics



Granular flows



Rheology of suspensions and complex fluids

powder flows

The long term project :

Understanding the behaviour of powders under low stress conditions:
Rheology, aeration, compaction, flows,…

The strategy :

1) to develop and characterize model granular materials with controlled cohesion

2) to develop new tools to measure the rheology

3) to study flow in simple configurations

4) to study the coupling with air

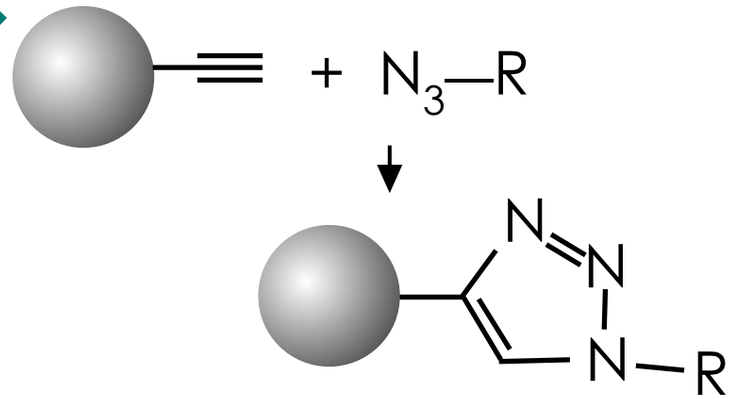
model cohesive materials

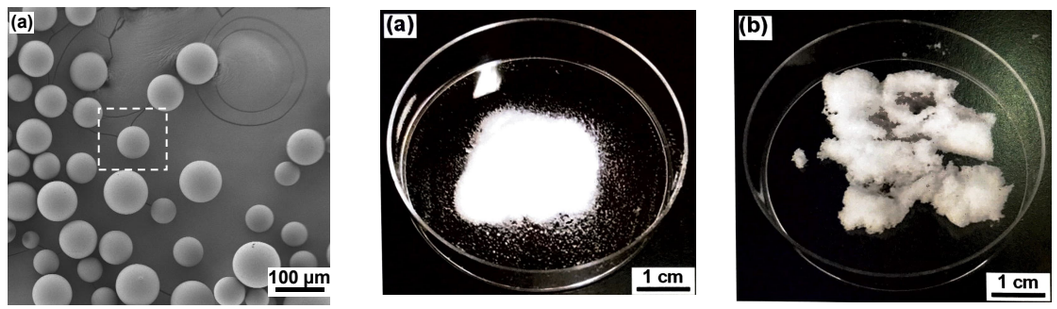
the most studied system: capillary bridges..
=> migration of liquid, complex dynamics…

Scheel et al Nature material 2008, Badetti et al EPJE 2018….

Under development

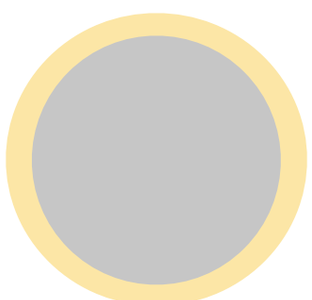
Tailored polymer micro-particles using the click chemistry

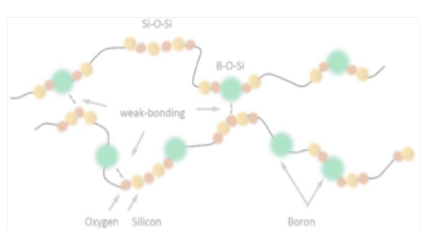




Moratille et al, J. Coll. Int. Sci. 2022

Polymer Coated particles





Silica Microbeads
+PDMS-OH,
+Boric Acid (H_3BO_3)

Tailored polymer particles

Eric Drockenmuller, Nathalie Sintes, Kkishen Haumeer IMP, lyon

The Click Chemistry approach

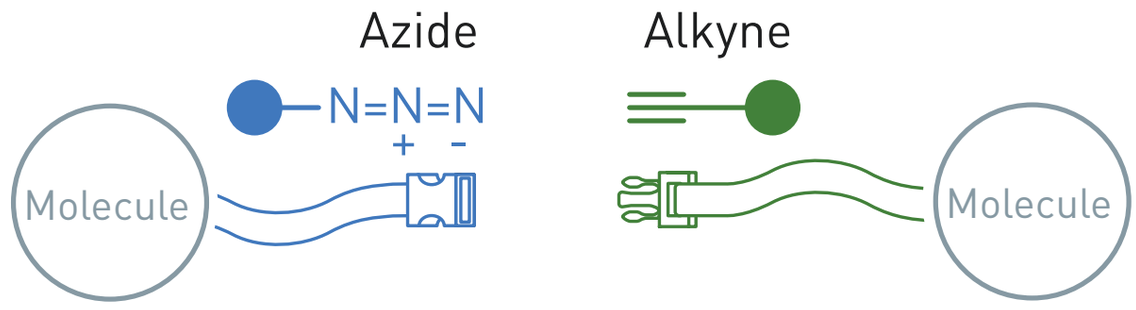
The Nobel Prize in Chemistry 2022

Ill. Niklas Elmehed © Nobel Prize Outreach
Carolyn R. Bertozzi
Prize share: 1/3

Ill. Niklas Elmehed © Nobel Prize Outreach
Morten Meldal
Prize share: 1/3

Ill. Niklas Elmehed © Nobel Prize Outreach
K. Barry Sharpless
Prize share: 1/3

1



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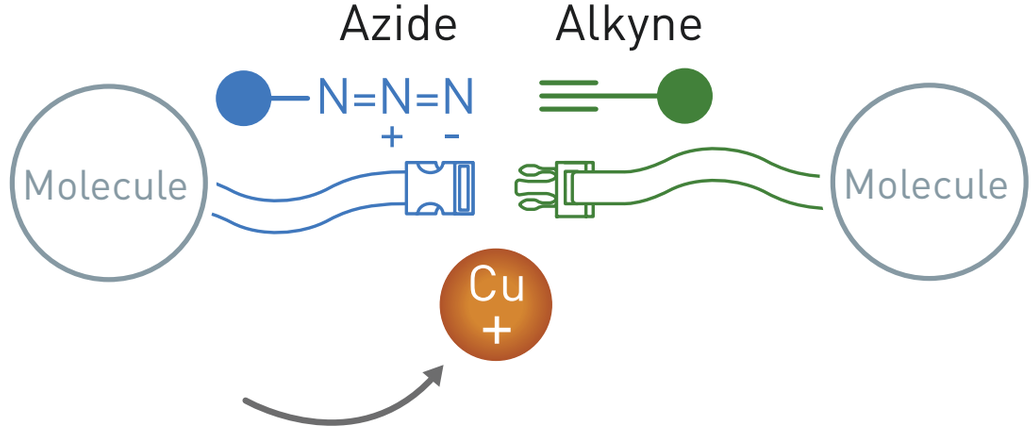

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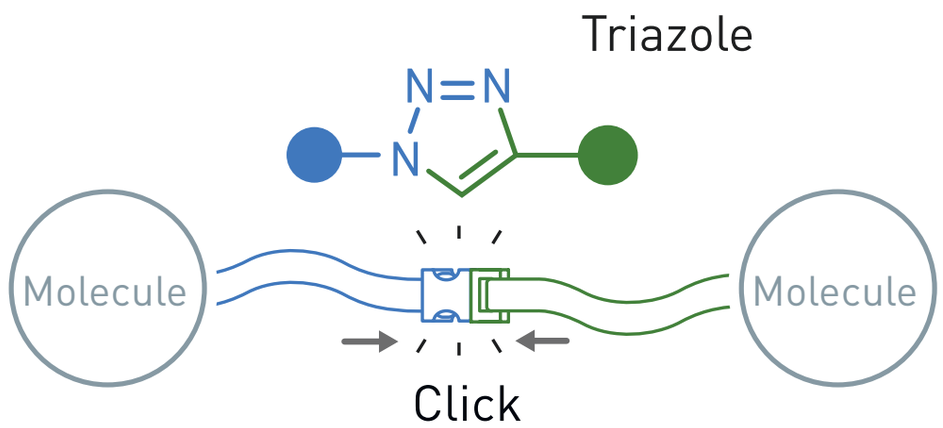
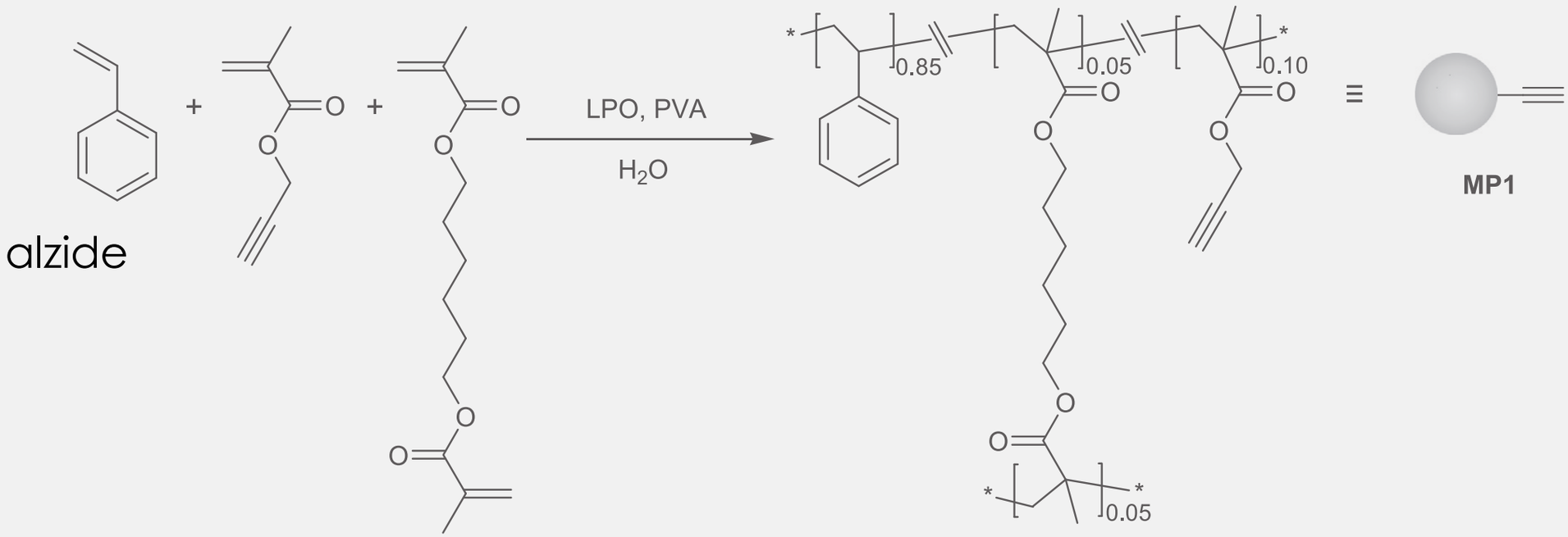
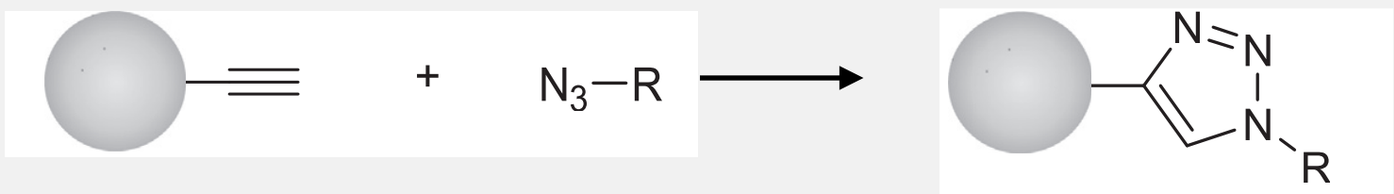
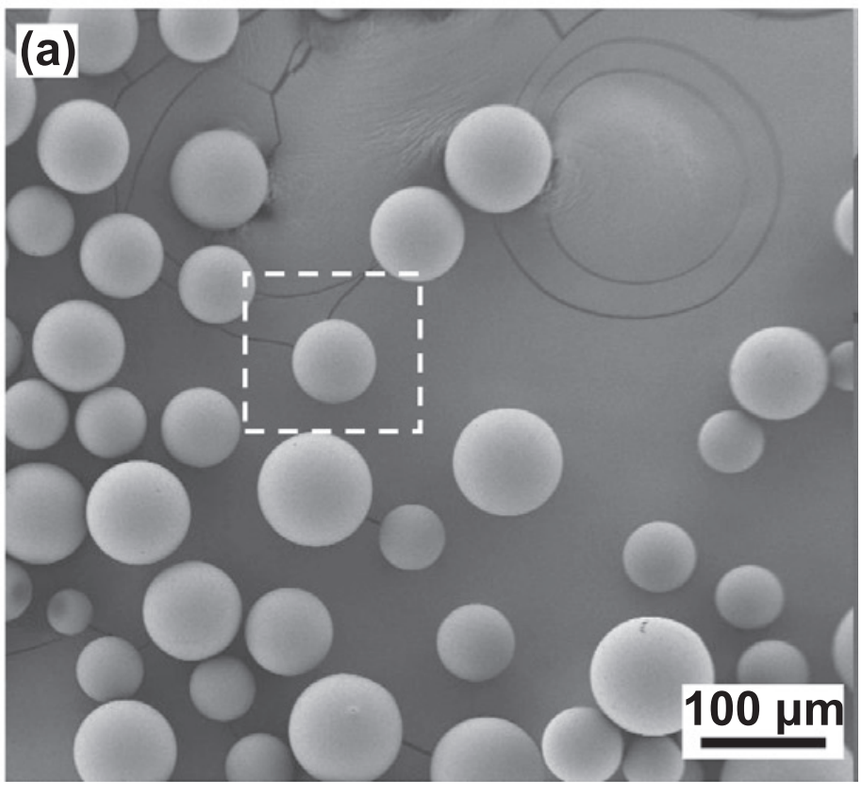


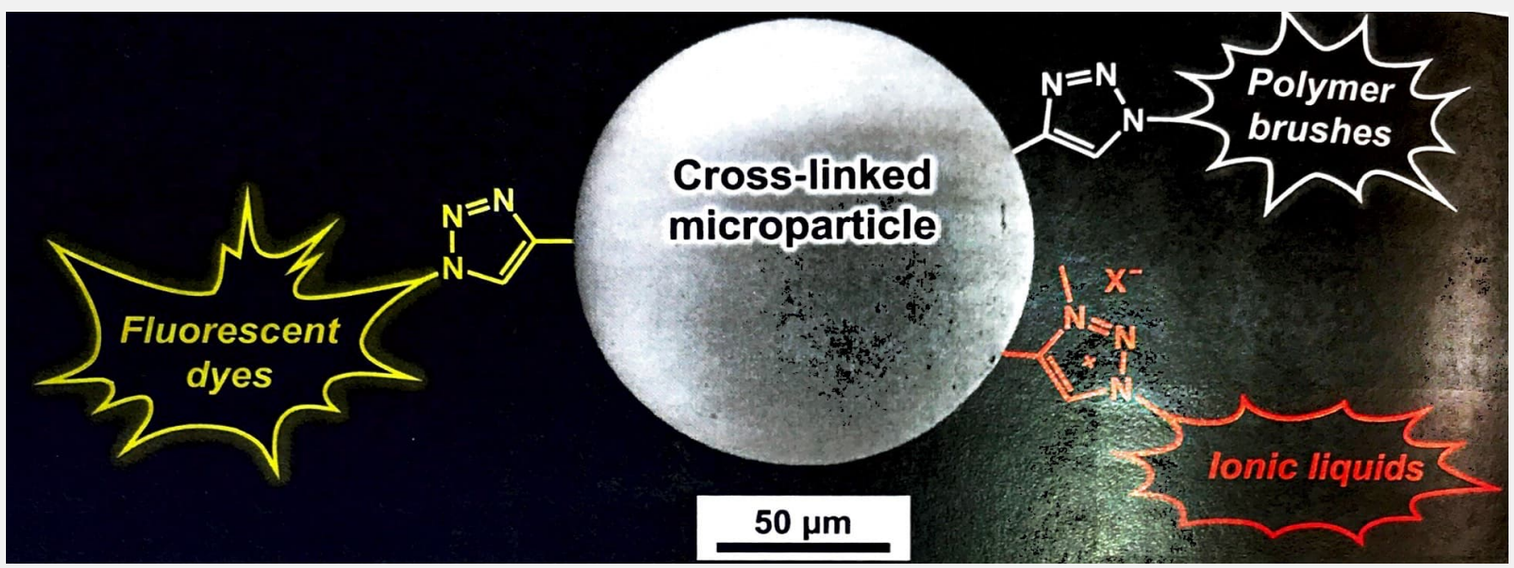
Synthesis of particles



Functionalisation







Synthesis of tailored micro particle (IMP Lyon, E. Drockenmuller)

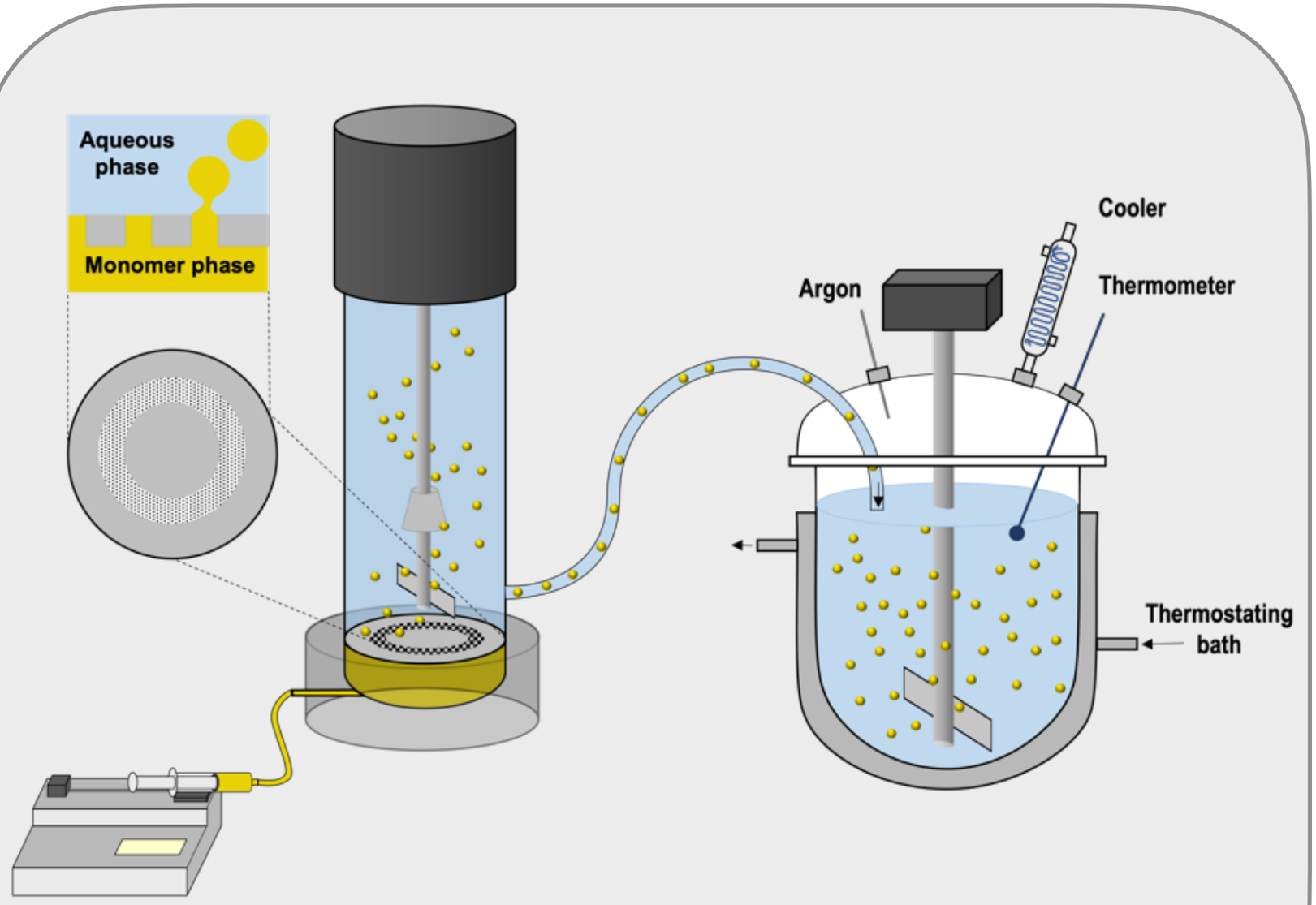


Fig. 5: membrane emulsification-assisted suspension copolymerization

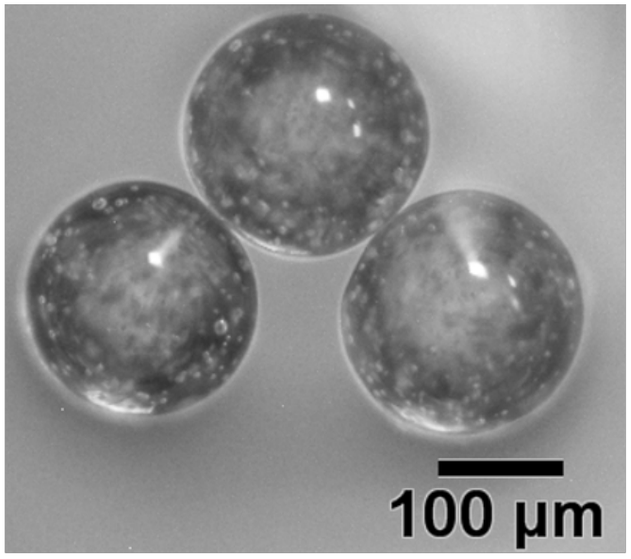
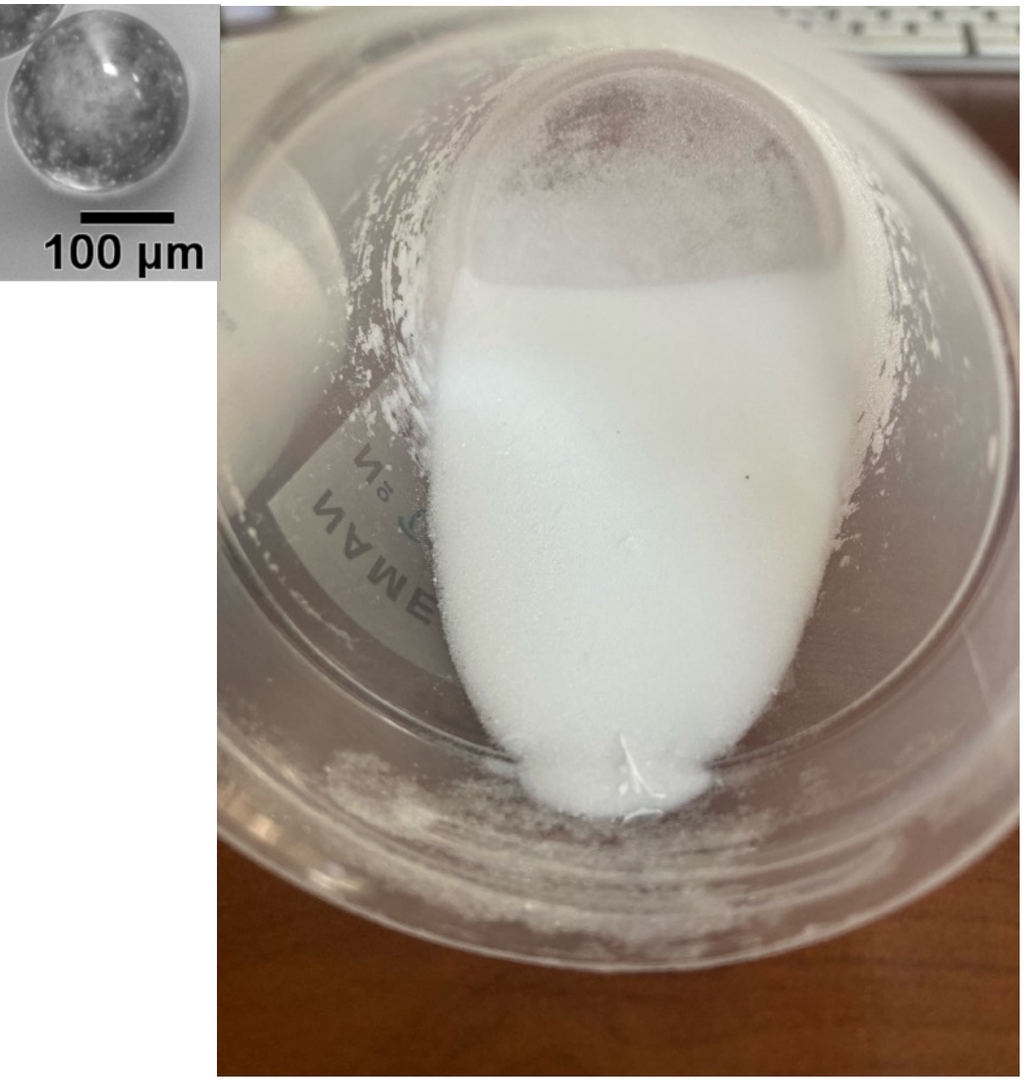
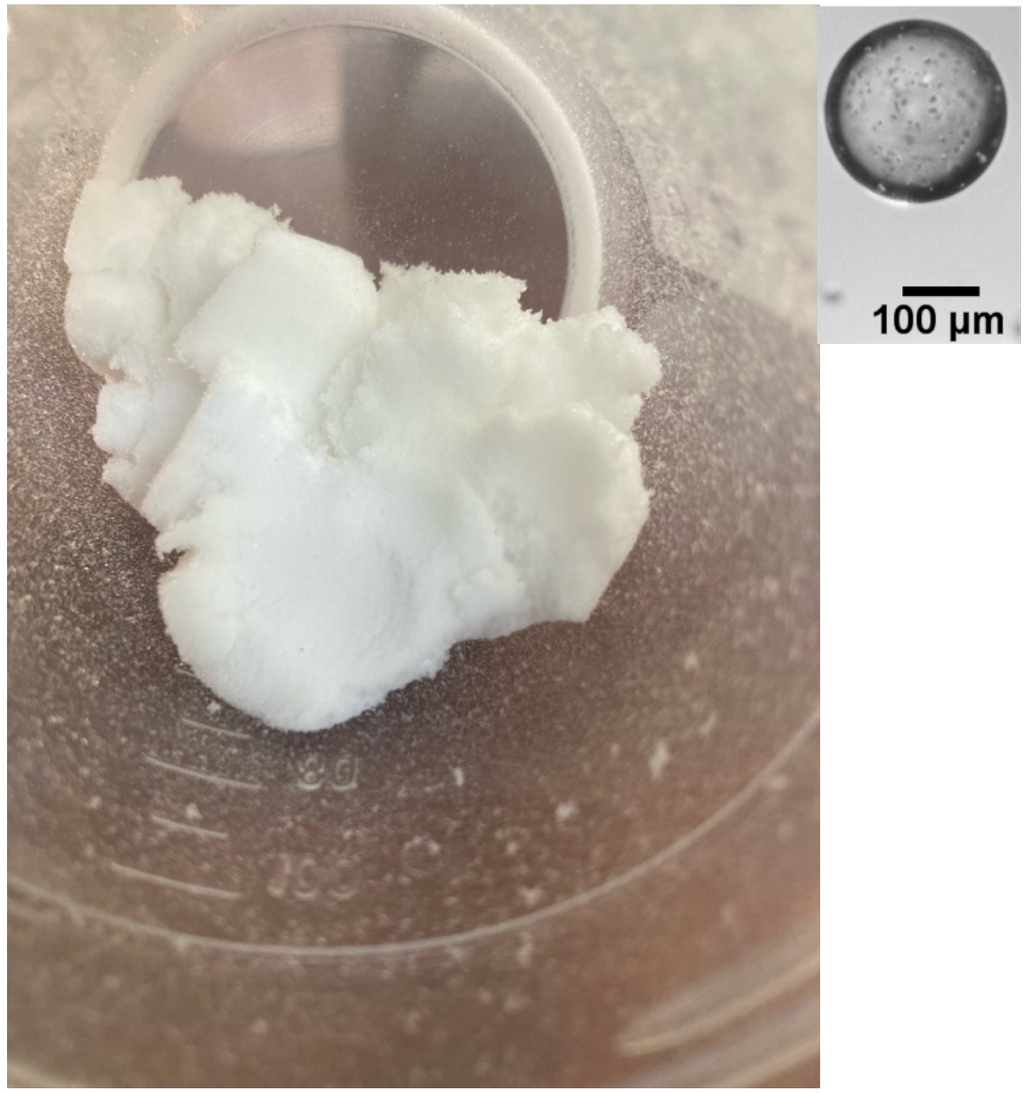


Image microscope optique
µ-particules PIBA d-50: 195µm

PIBA (below Tg)



PEHA (above Tg)



Possibility to change
the stiffness and the adhesion

the challenge:
characterisation of their mechanical properties

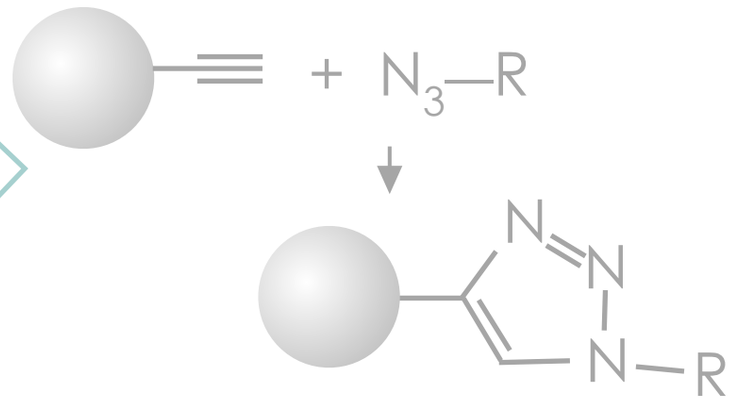
model cohesive materials

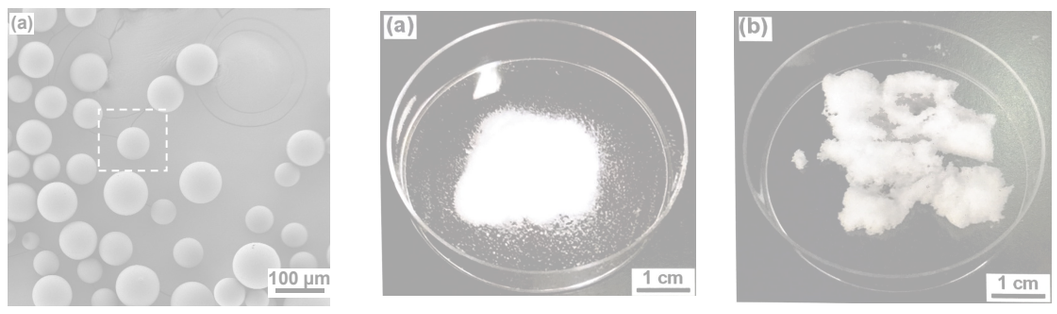
the most studied system: capillary bridges..
=> migration of liquid, complex dynamics…

Scheel et al Nature material 2008, Badetti et al EPJE 2018….

Tailored polymer micro-particles using the click chemistry

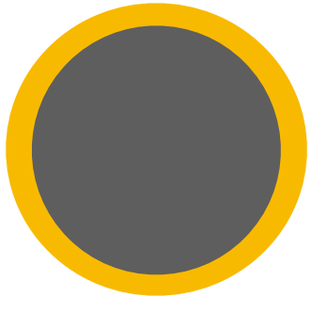
under development

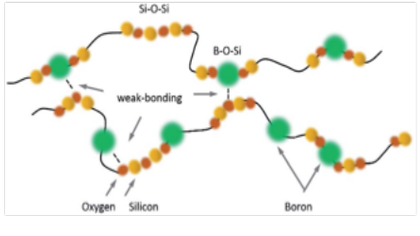




Moratille et al, J. Coll. Int. Sci. 2022

Polymer Coated particles





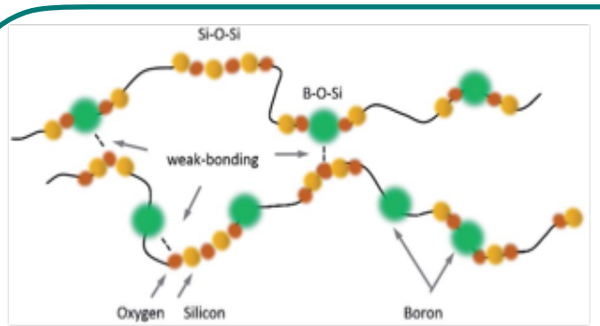
Silica Microbeads

+PDMS-OH,

+Boric Acid (H_3BO_3)

coated silica particles…

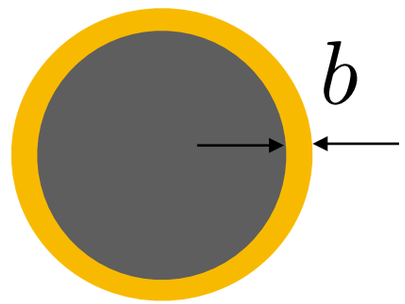
Gans et al PRE 2020



Silica Microbeads

+PDMS-OH,

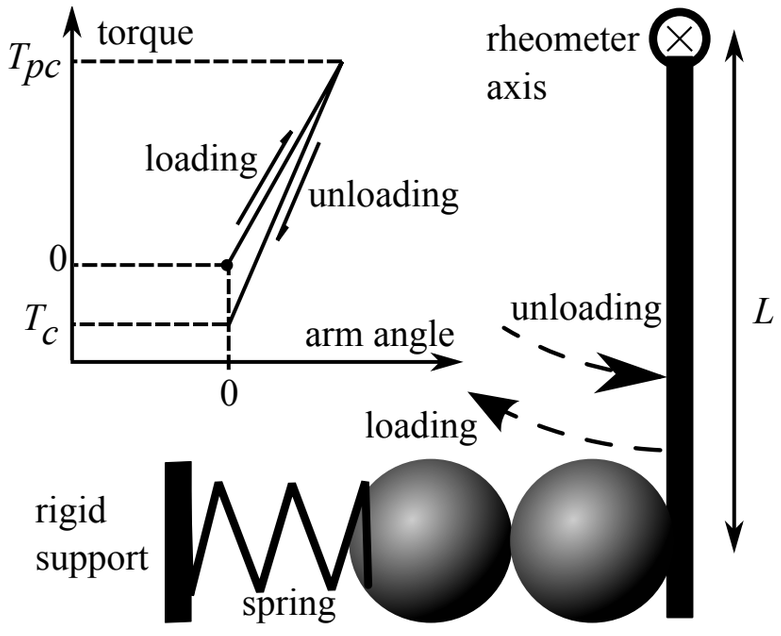
+Boric Acid (H_3BO_3) 14%wt PDMS

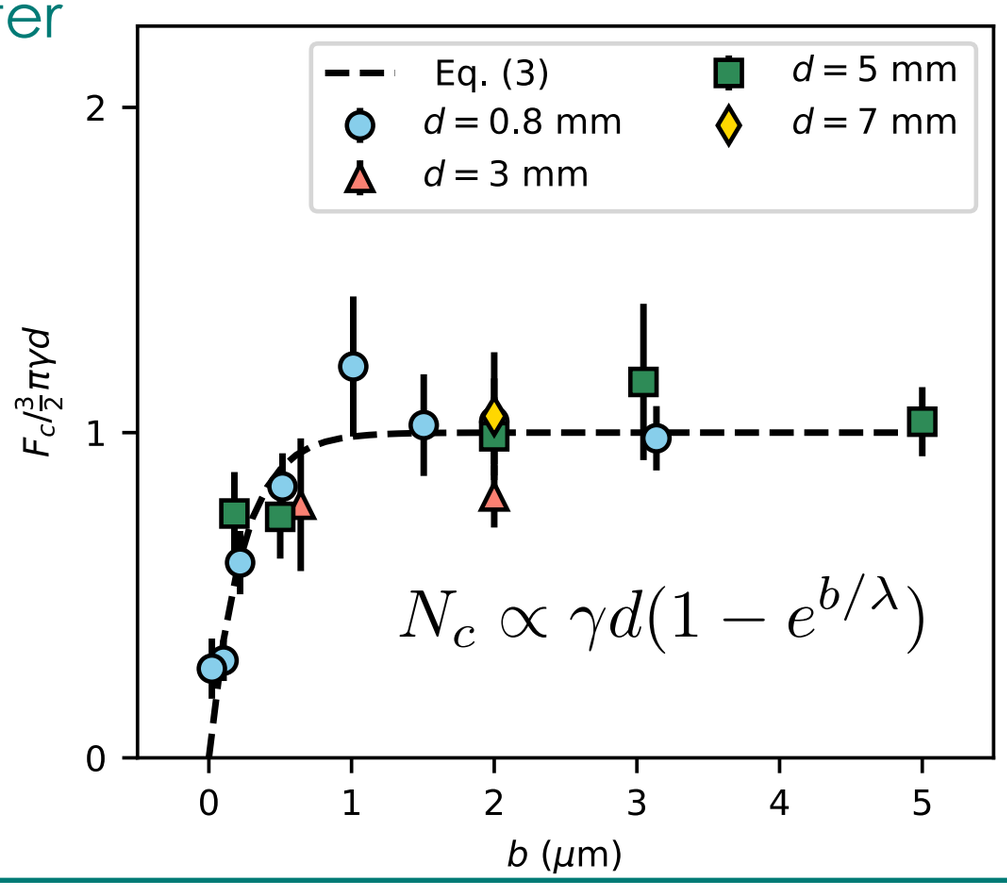


coated with PolyBoroSiloxane (PBS)

[Li *et al.* RSC Advances 2014, **4**, 32894]

the adhesive force is controlled by the thickness of the coating and the particle diameter

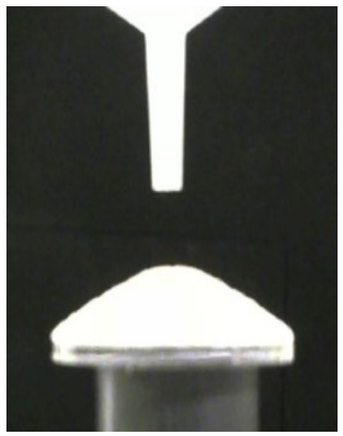




a controlled cohesive material very robust that can be reused once prepared..

Pile angle

BV480

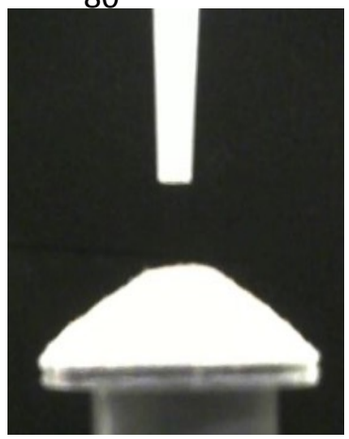


= 27,73

CCGM08-480

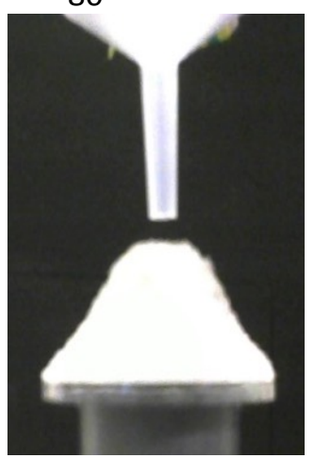
= 28,84

CCGM15-480



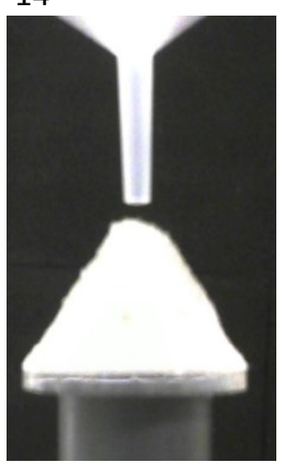
= 30,15

CCGM25-480



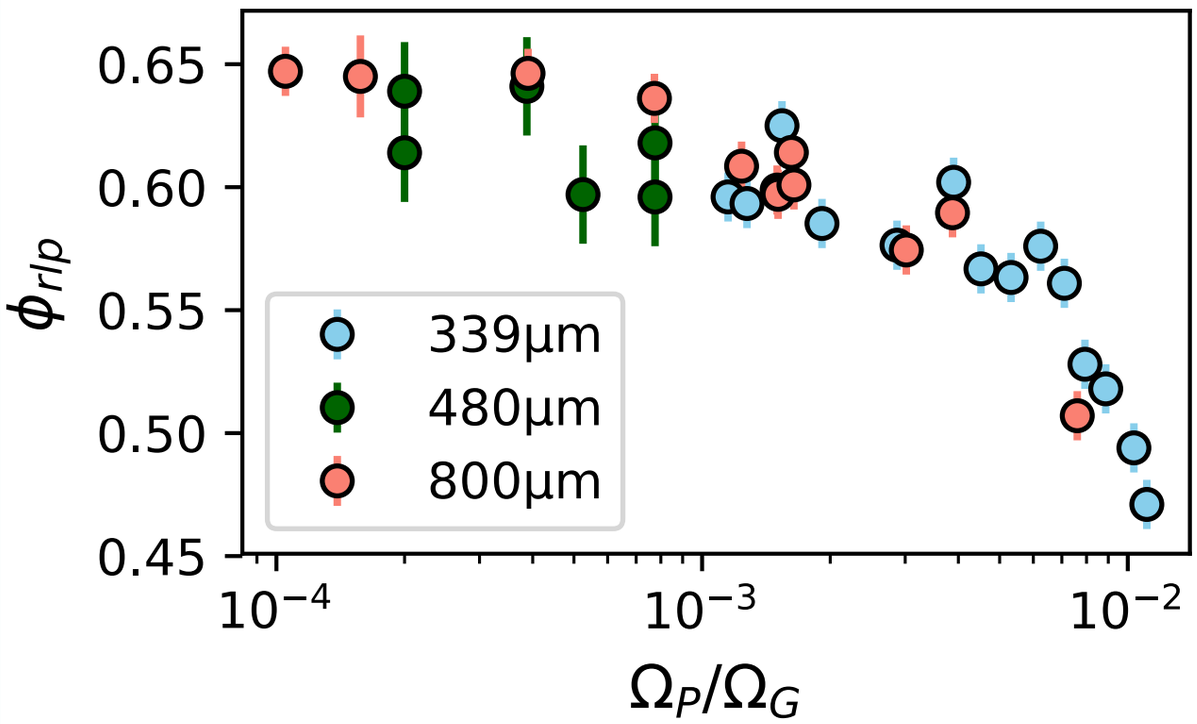
= 40,36

CCGM30-480-14



= 42,54

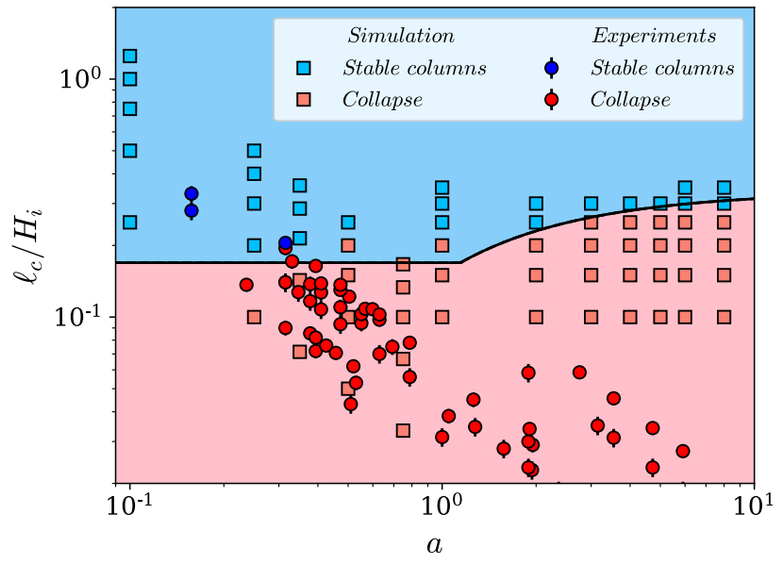
compacity



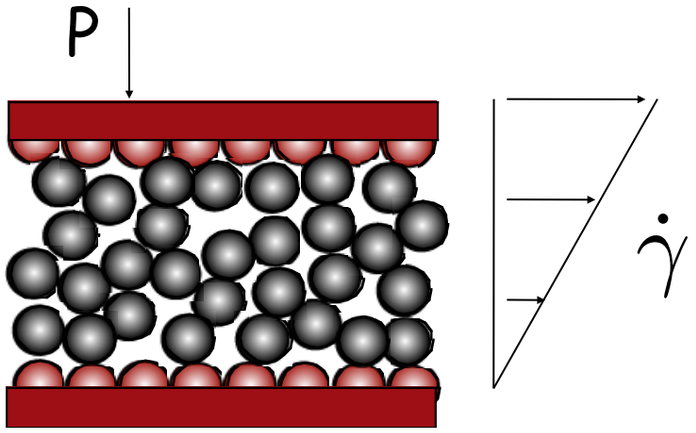
a controlled cohesive material very robust that can be reused once prepared..

cohesive granular collapse
(with A. Sauret, UCSB)

Gans et al, JFM 2023



Failure criterion



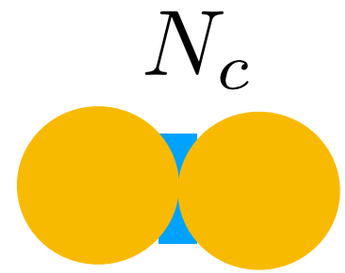
what about rheology ?

No adhesion, only friction
=>
no internal stress scale
=>
1 dimensionless parameter

$$I = \frac{\dot{\gamma} d}{\sqrt{P/\rho_s}}$$

$$\tau = \mu(I) P$$

$$\Phi = \Phi(I)$$



With adhesion N_c
=>
a new force scale
=>
2 dimensionless parameters

$$C = \frac{N_c}{P d^2}$$

$$I = \frac{\dot{\gamma} d}{\sqrt{P/\rho_s}}$$

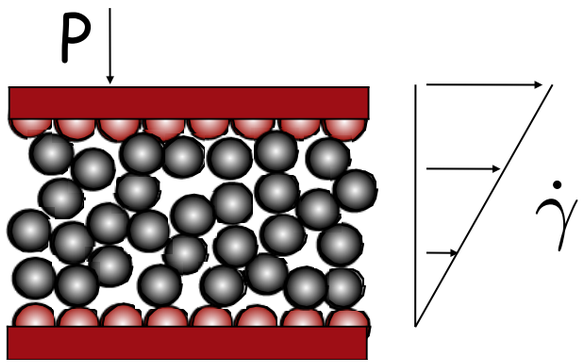
$$\tau = \mu(I, C) P$$

$$\phi = \phi(I, C)$$

Rognon et al JFM 2008, Berger et al EPL 2015, Kamshed PRE 2015, Vo et al Nature Com, 2020…

in DEM numerical simulations…

Rognon et al JFM 2008, Berger et al EPL 2015, Kamshed PRE 2015, Vo et al Nature Com, 2020…



$$C = \frac{N_c}{Pd^2}$$

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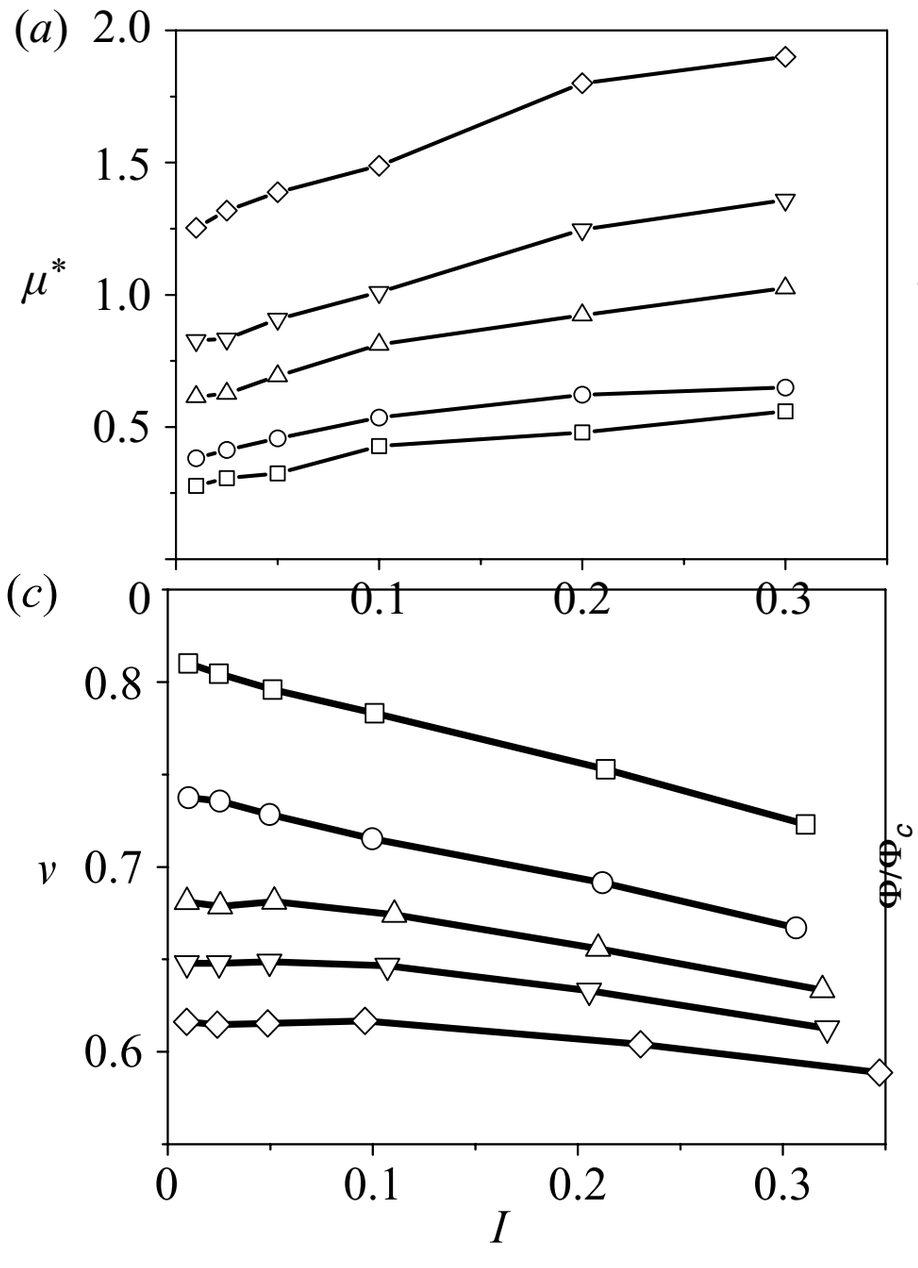
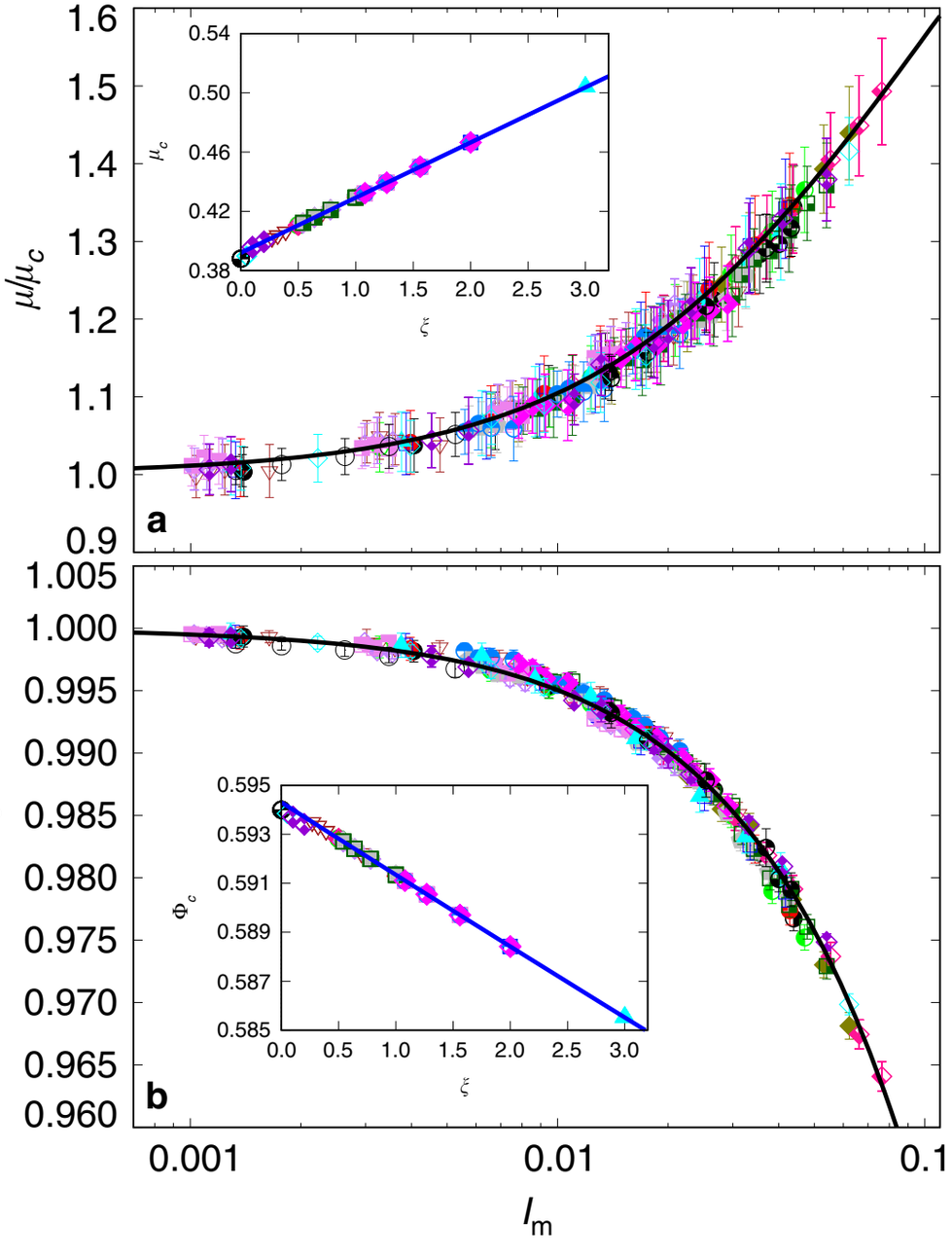


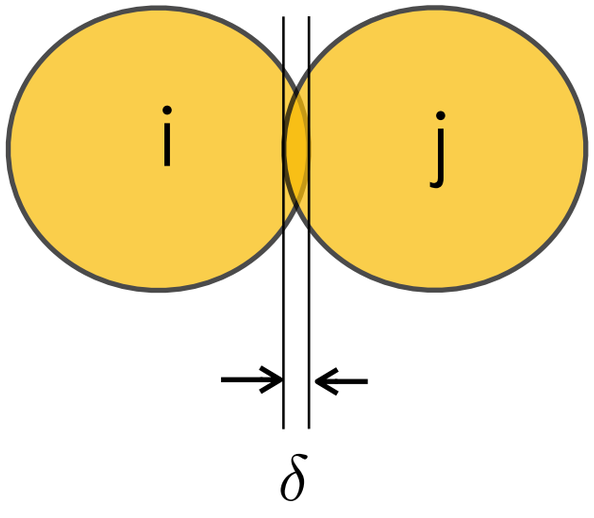
Rognon et al JFM 2008

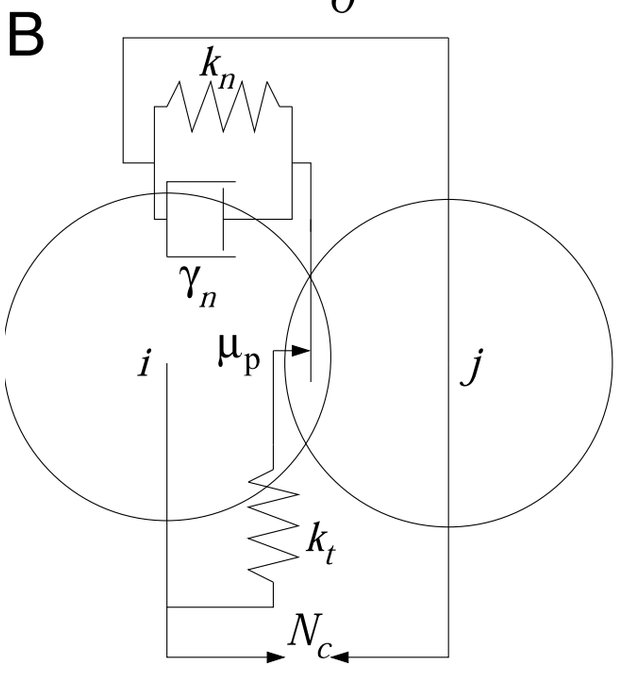


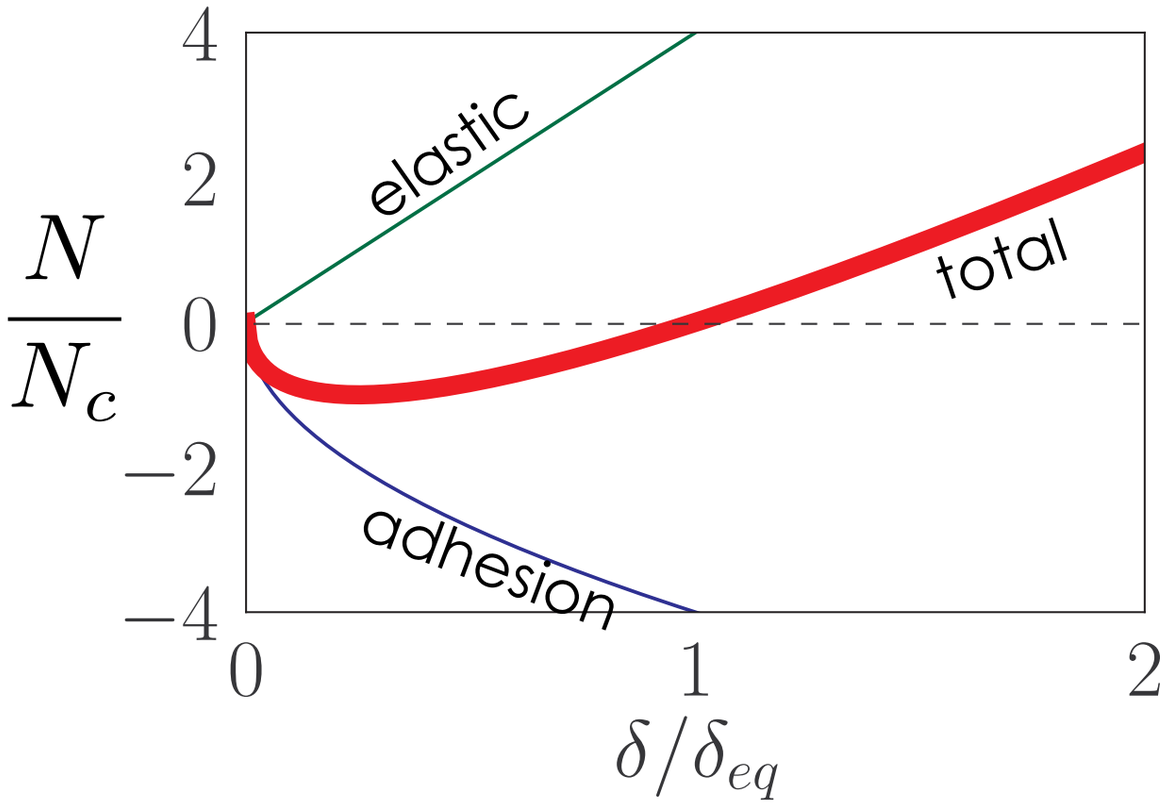
Vo et al Nature Com, 2020

A simple adhesion model in DEM simulations

Rognon et al, Europhys Lett. 2006,, Berger et al, Europhys. lett 2016,







N_c the adhesion force necessary to detach two particles

Two main results :

Role of stiffness, dissipation and cohesion :

Flow controlled by an effective adhesion :

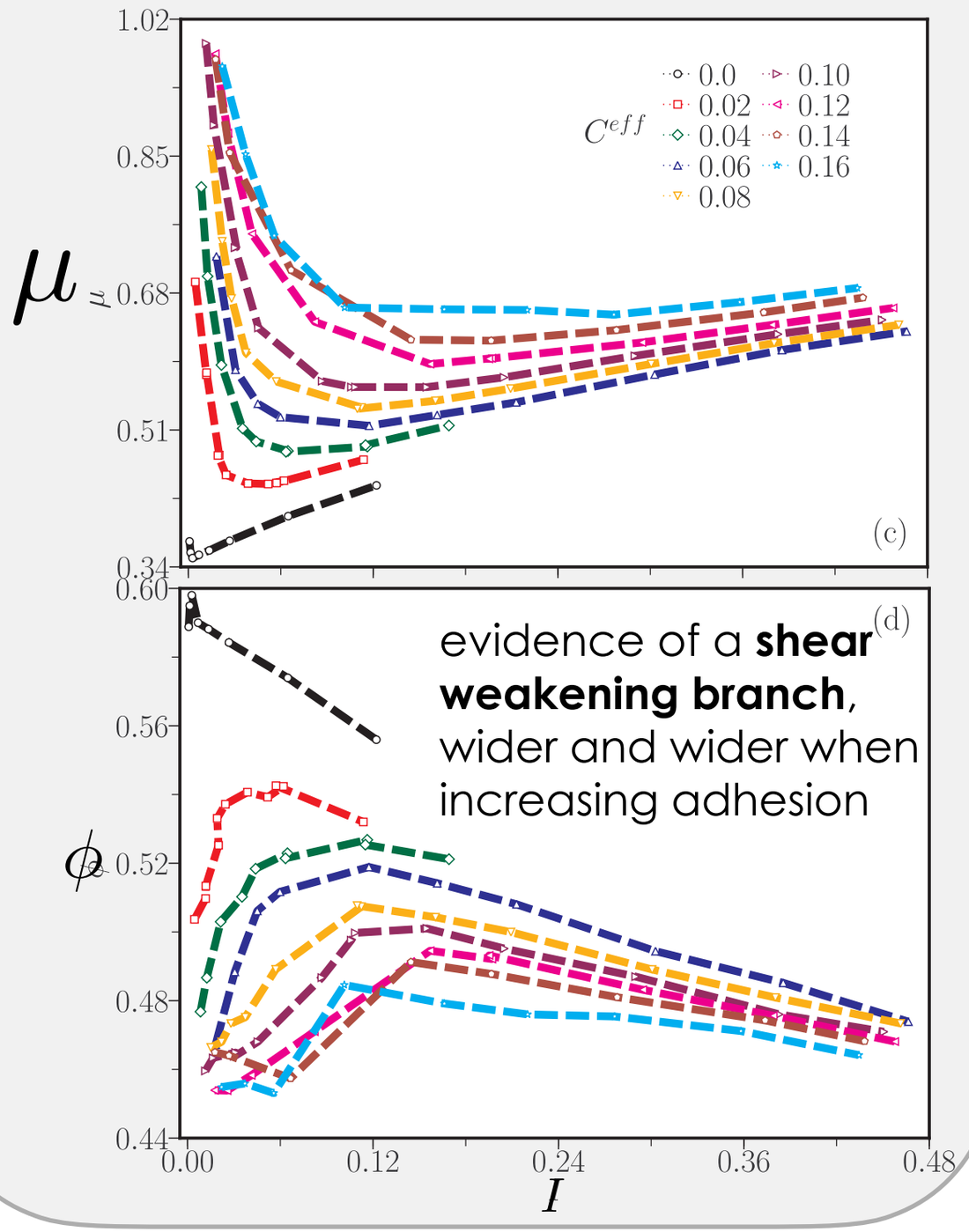
$$N_c^{eff} = N_c \left[\left(\frac{N_c}{k_n d} \right)^a \frac{1}{Q^b} \right]$$

Adhesion

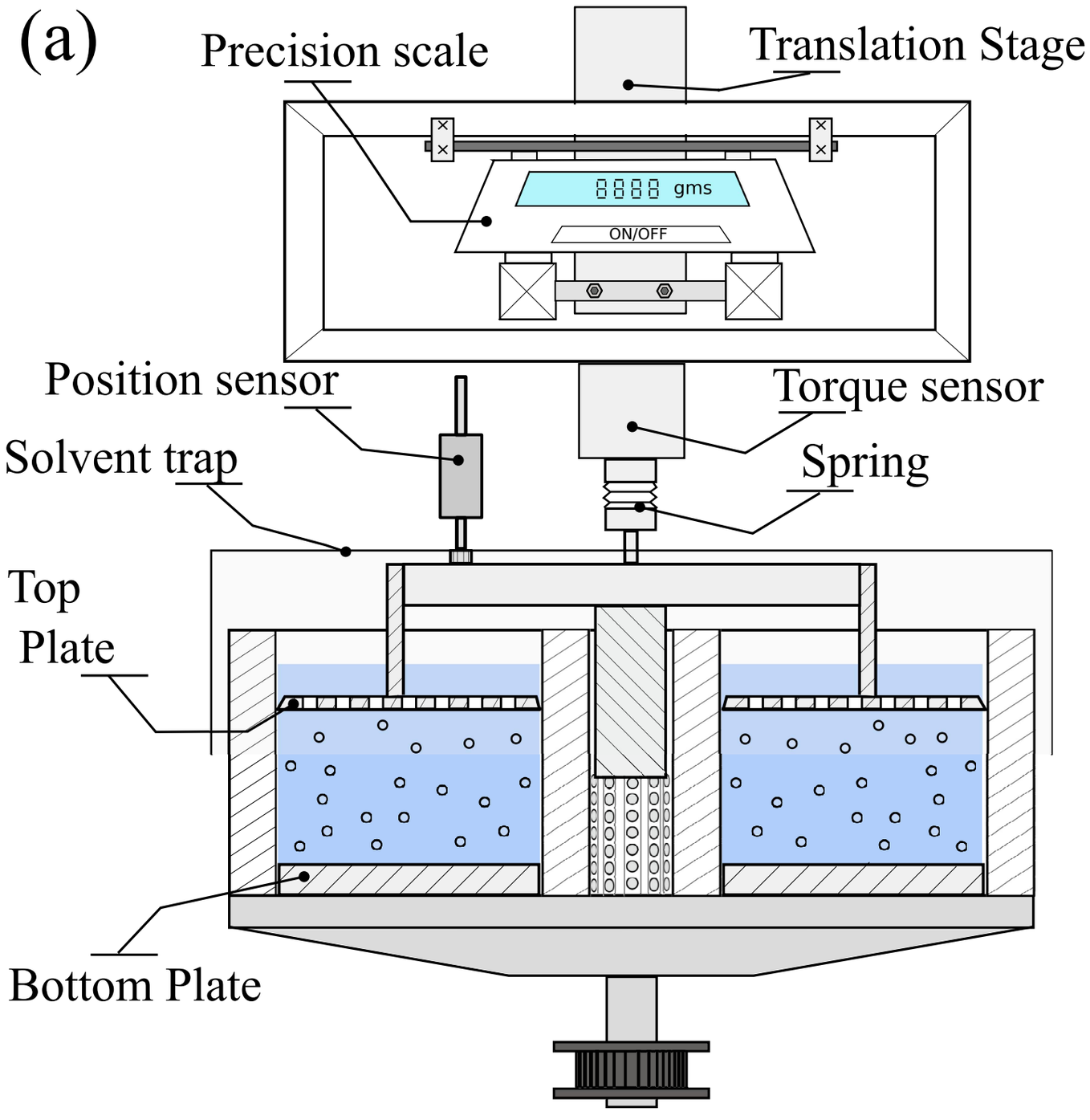
Stiffness

Dissipation

Unstable Rheology :



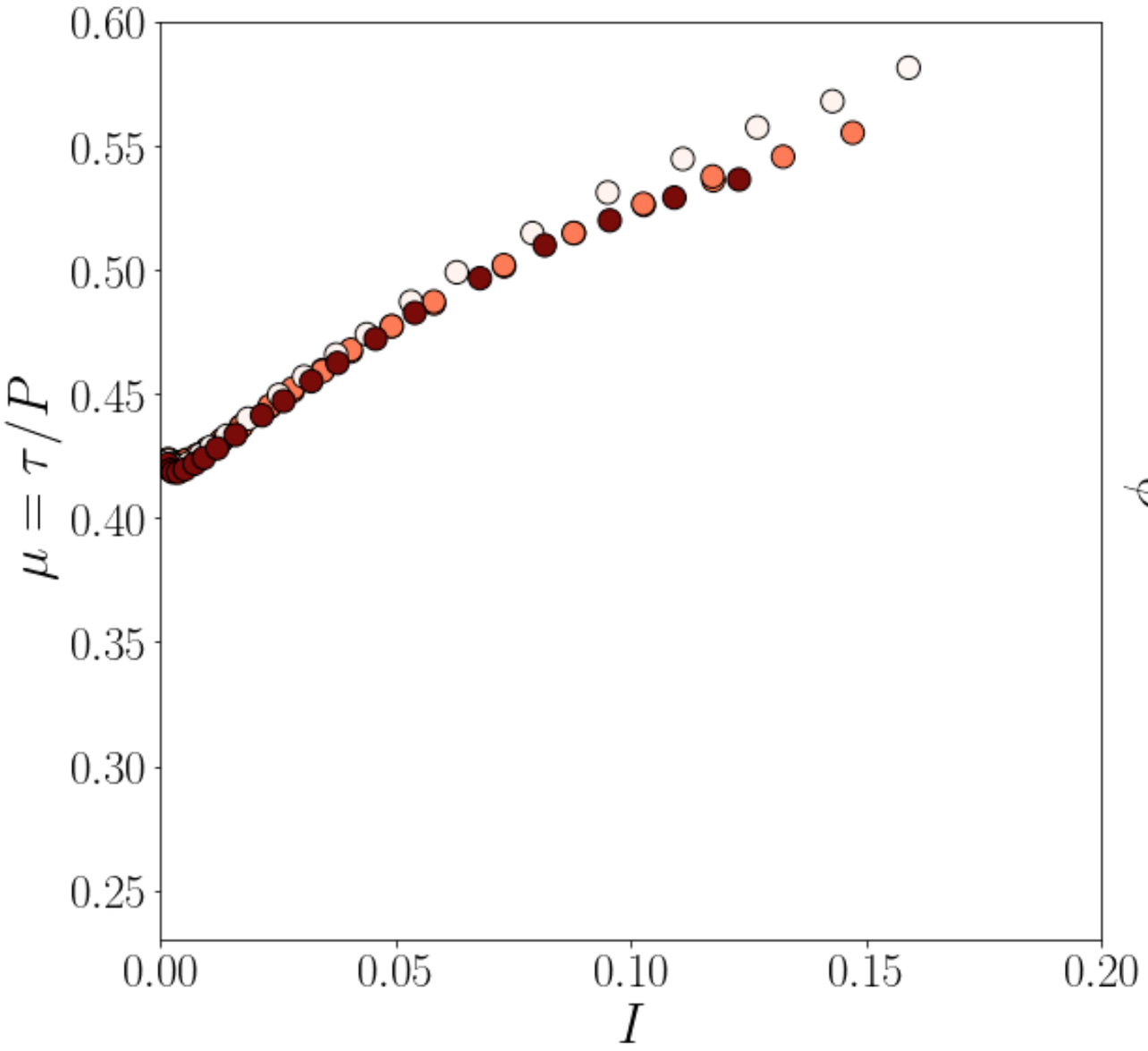
experimental pressure imposed rheometer

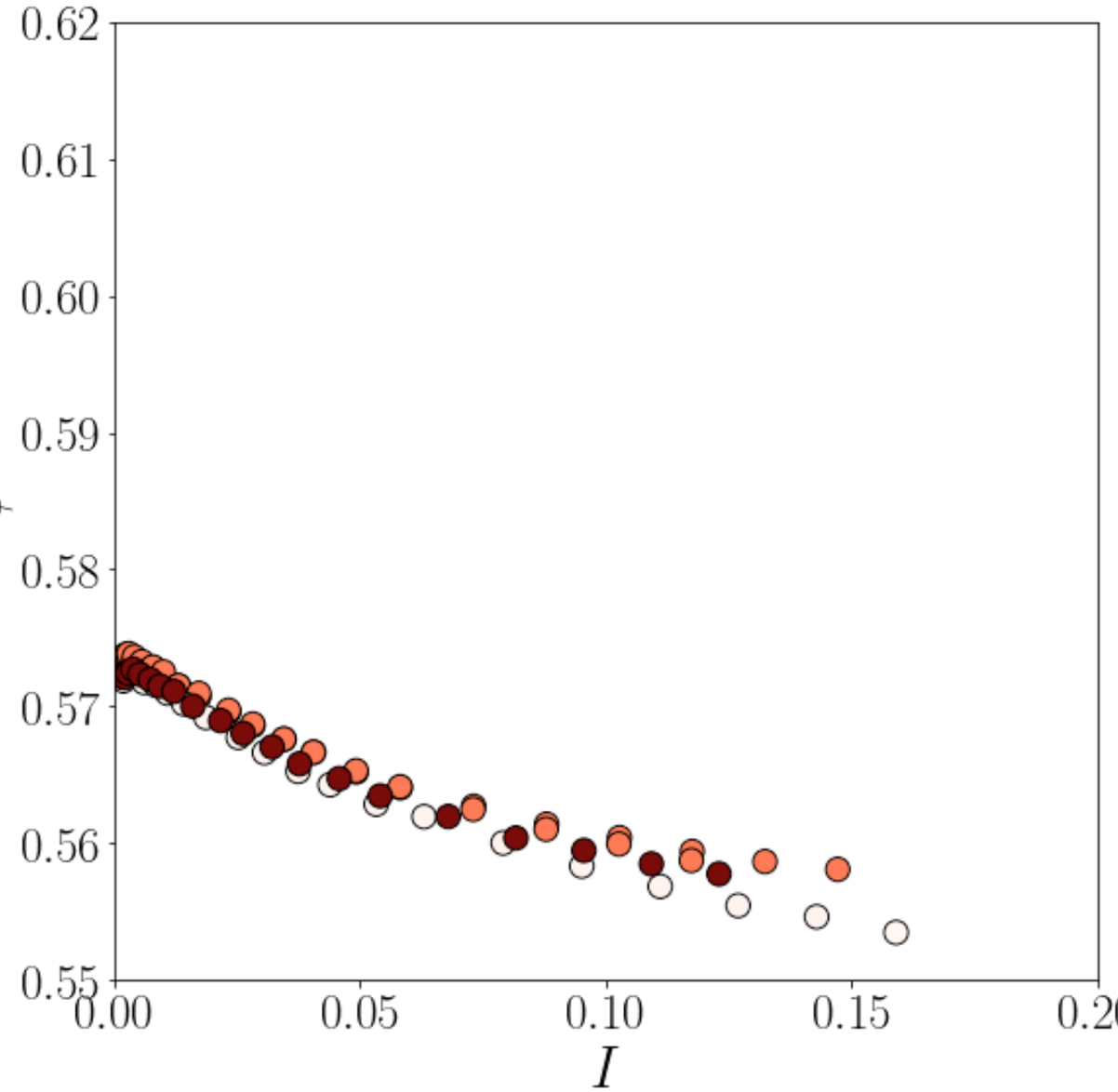


Limit:

measurements are possible only for pressure > cohesive stress

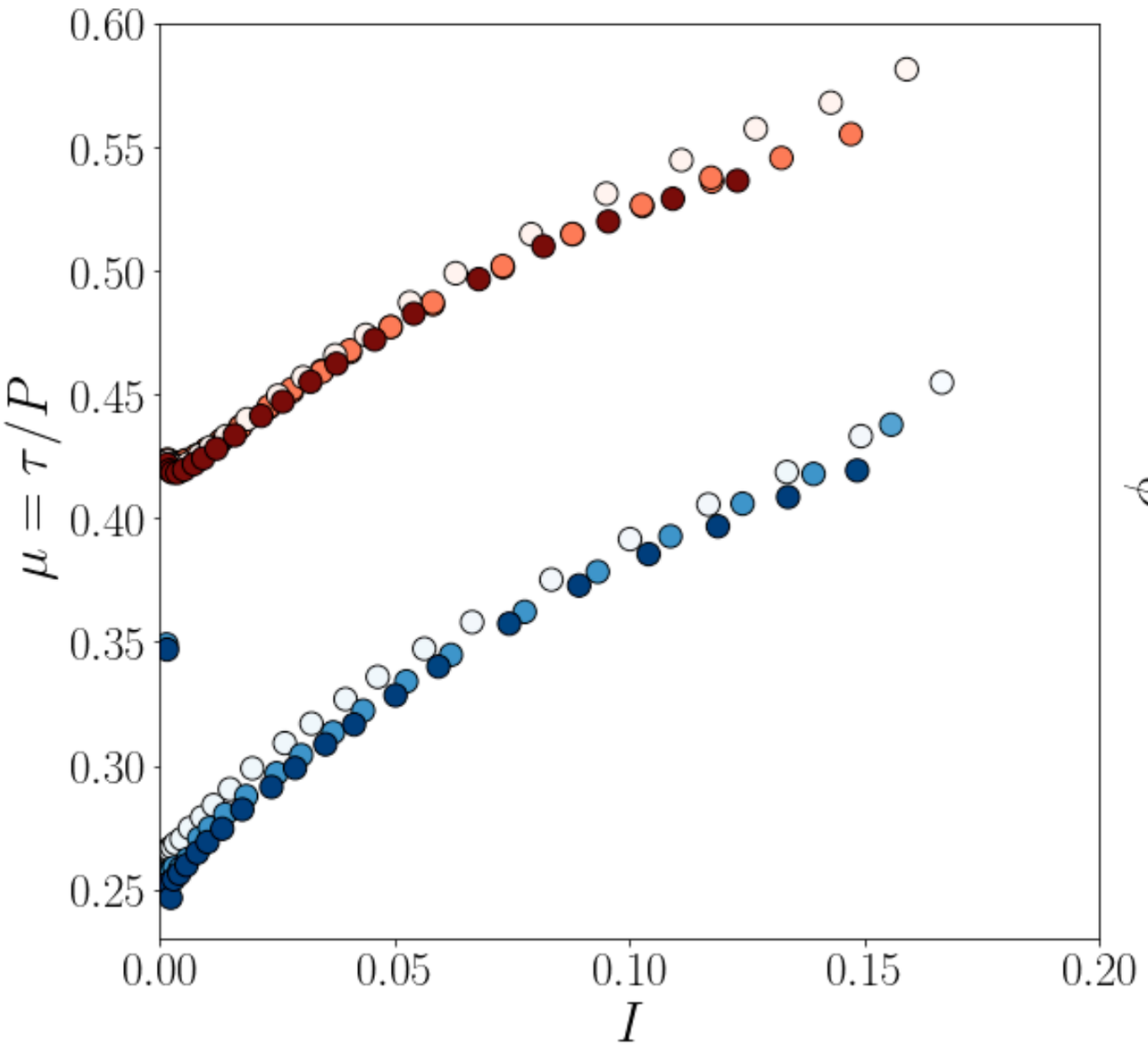
cohesionless 800microns particles

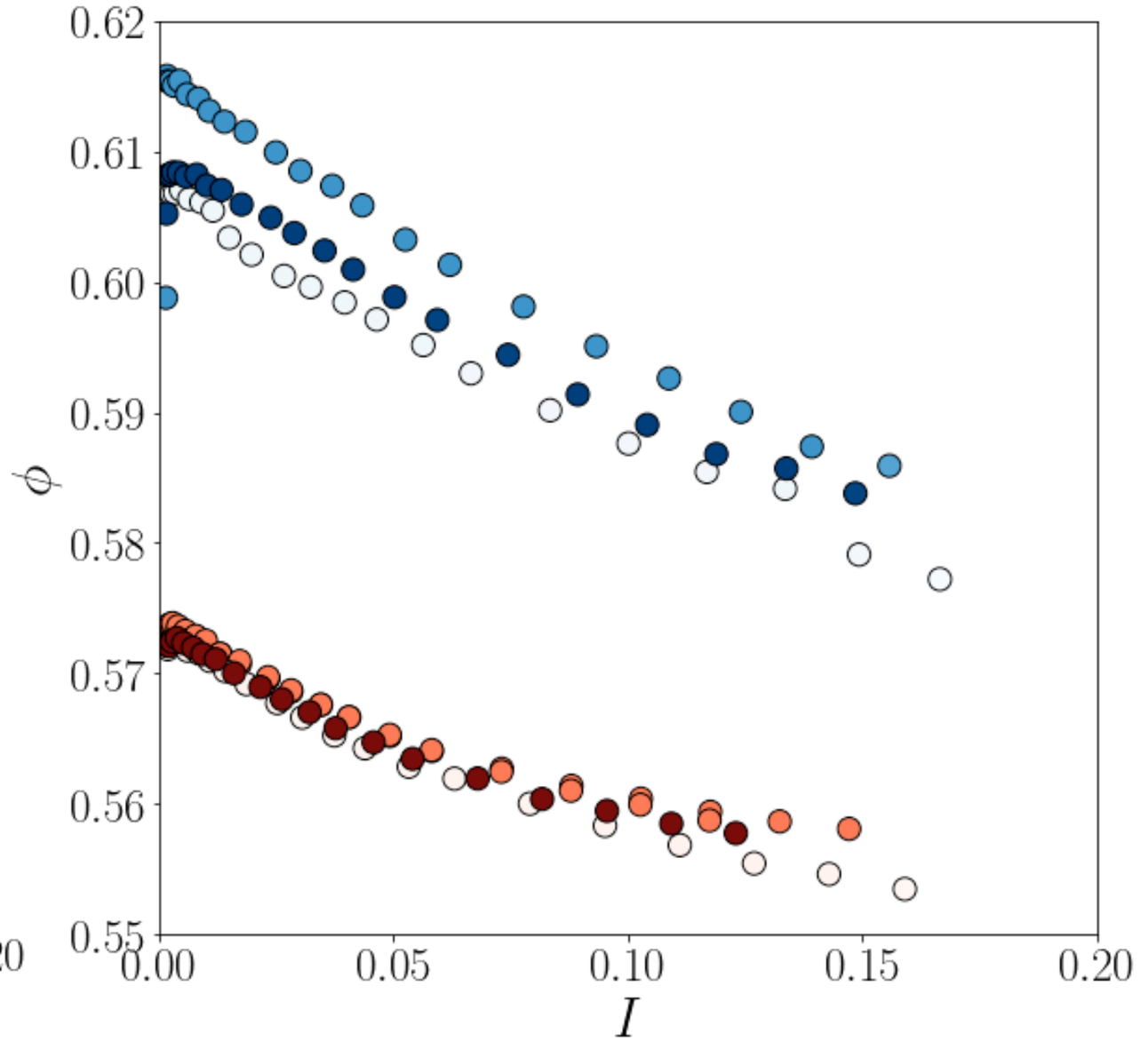




cohesionless 800microns particles

highly coated particles, b=100nm



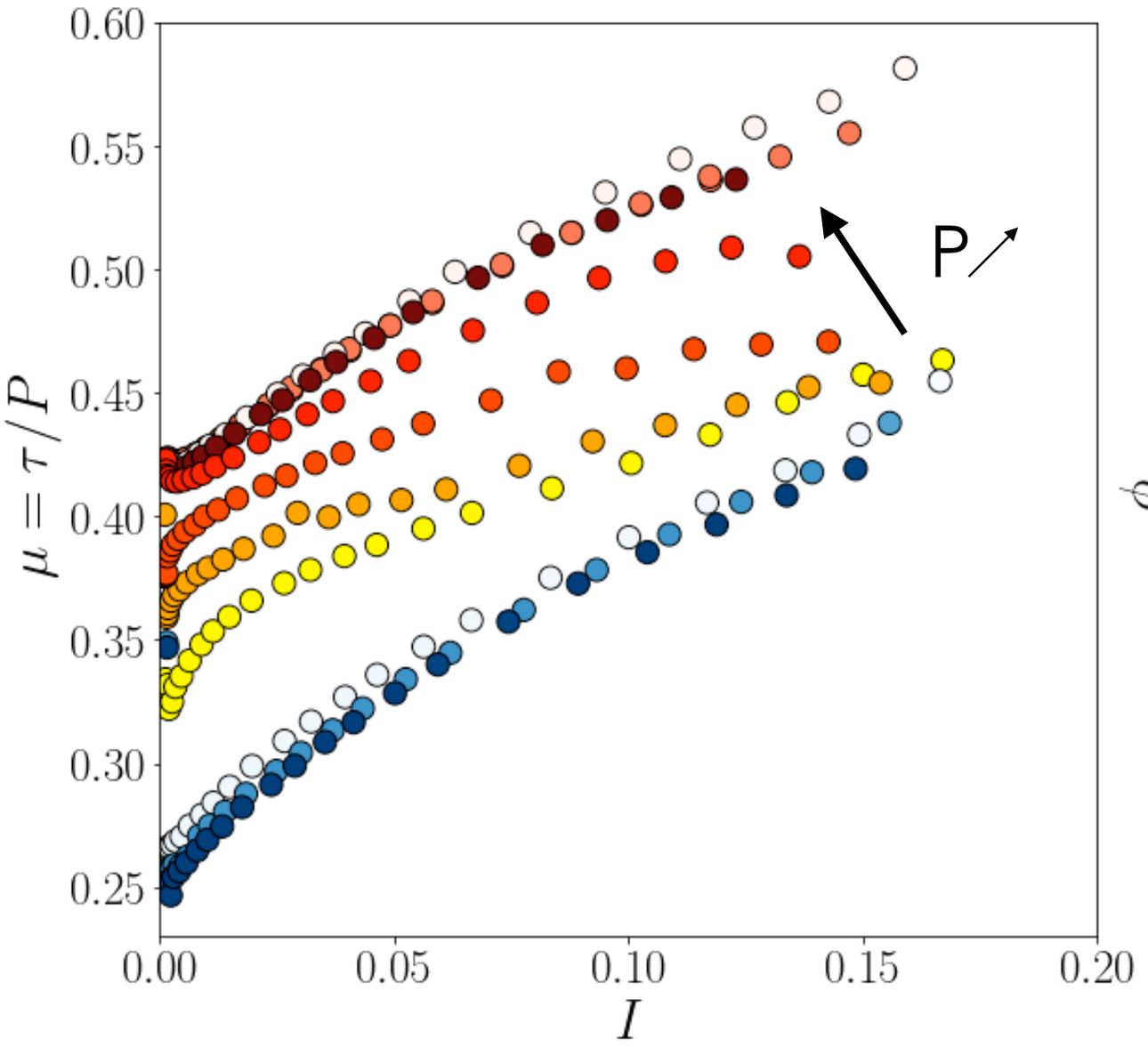


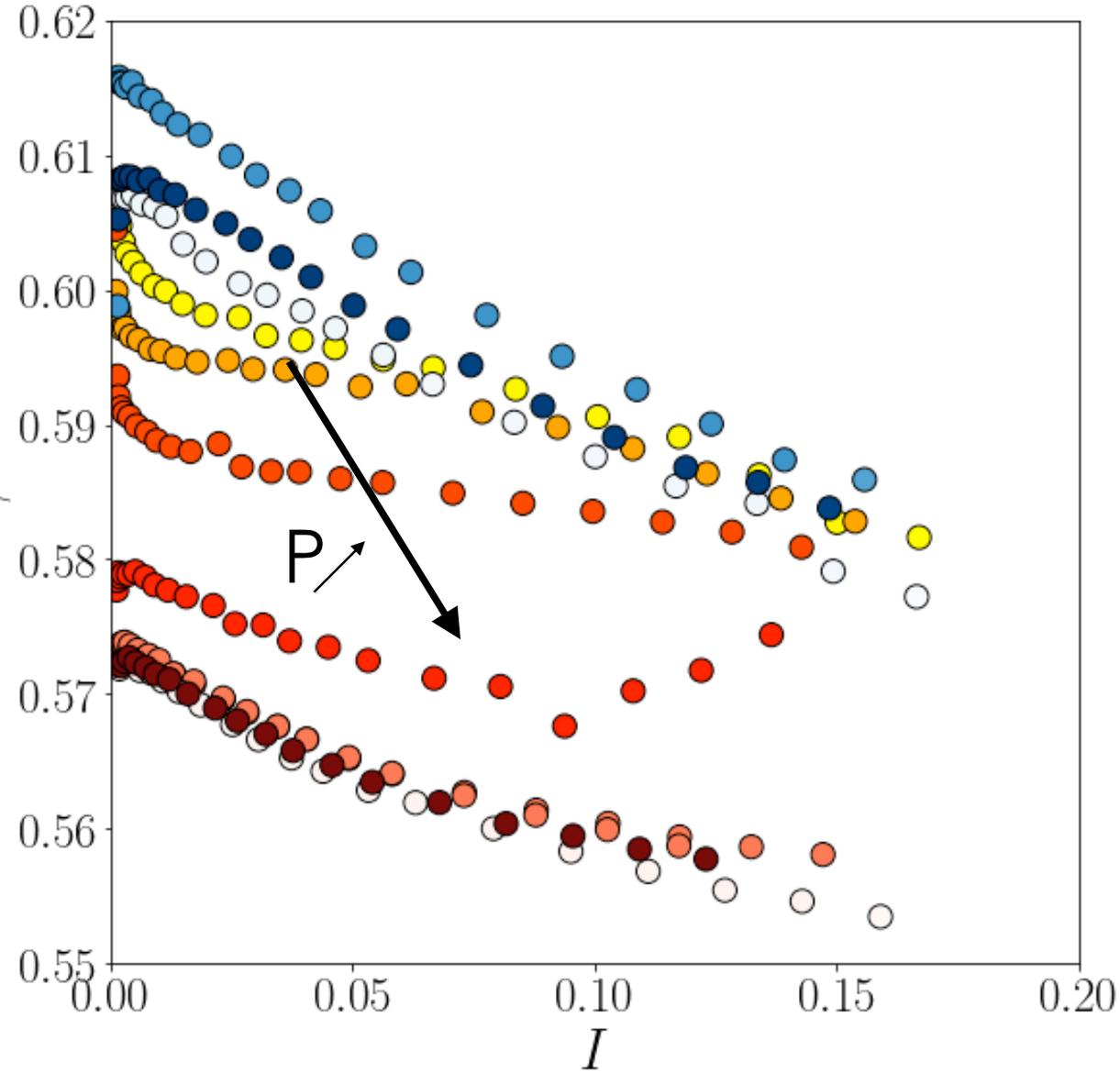
800microns particles

No coating, b=0

Thick coating, b=100nm

Moderate coating, b=35nm





800microns particles

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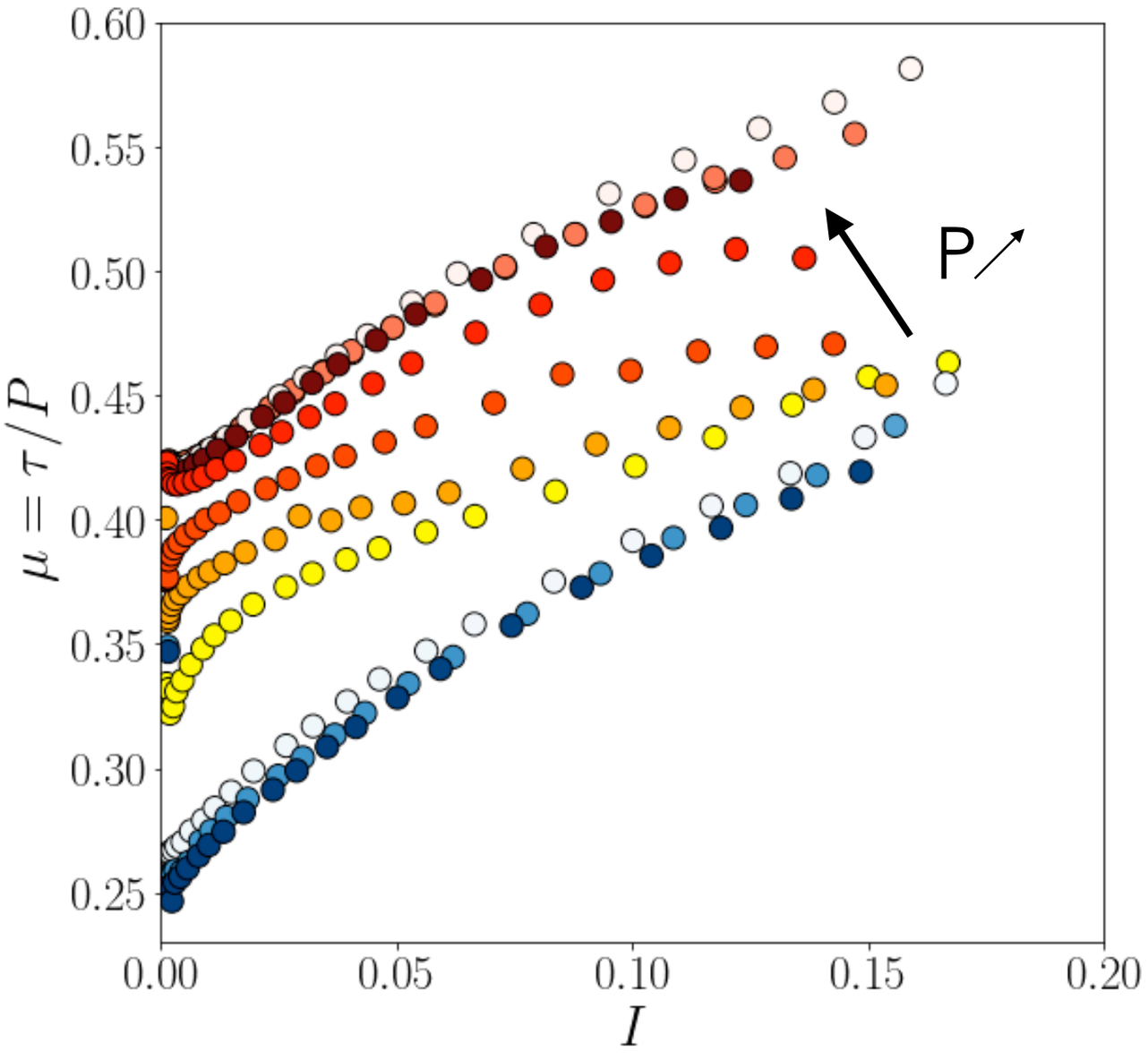
Moderate coating, b=35nm

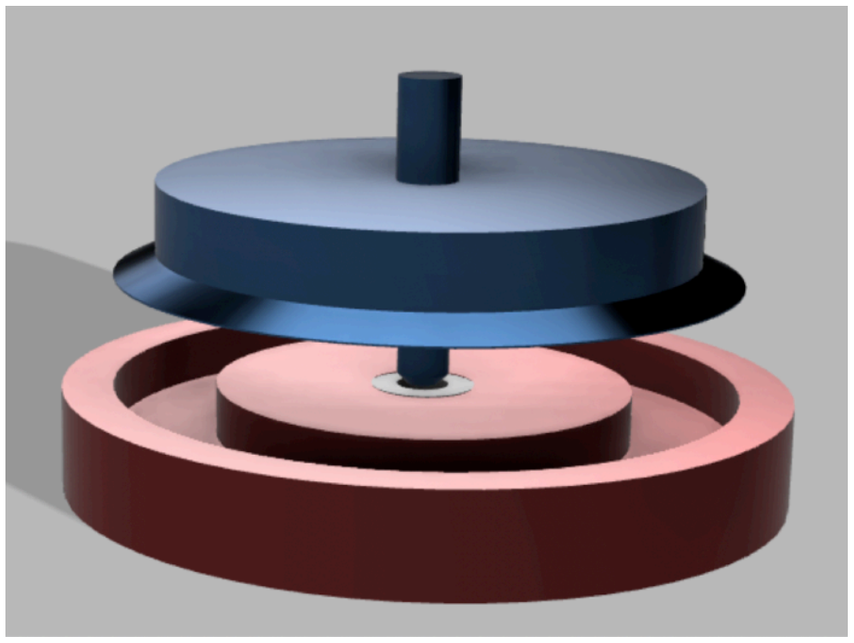


A frictionless to frictional transition when increasing the confining pressure

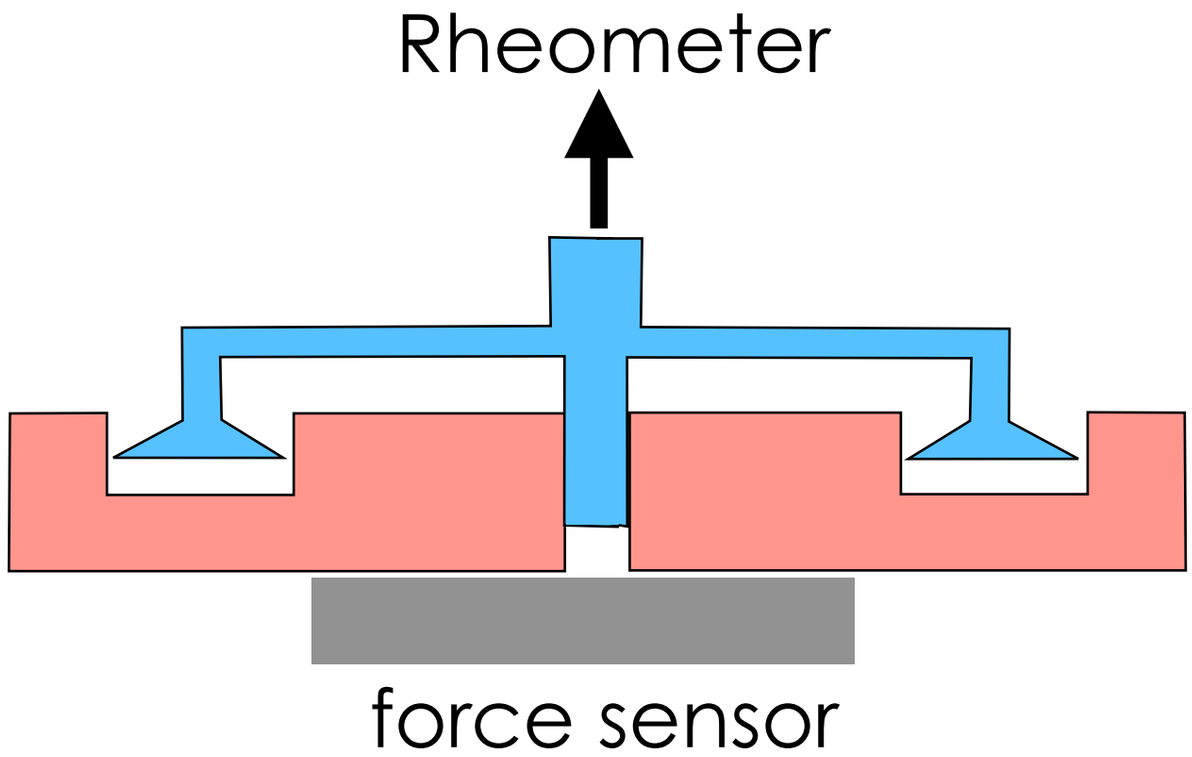
role of the coating on the particle/particle friction :
a flubrication transition at the grain scale
(see poster)

To analyse the influence of cohesion on the rheology => small particles

design of a new pressure imposed shear cell for small particles (50µm < d < 200µm)



50mm



Perspectives…

- fabrication and characterisation of cohesive polymer particles with tailored properties
- Role of coating in lubricating the contact and modifying the rheology at high stress
- Rheology at low stress level
- flow properties…

Thanks to

Chico Rocha
IUSTI, Marseille

Maxime Nicolas
IUSTI, Marseille

Franco Tapia
IUSTI, Marseille

Eric Drockenmuller
IMP, Lyon

Nathalie Sintes
IMP Lyon

Sandip Mandal
IIT Dhanbad

Adrien Gans
LEMTA, Nancy

Anais Abramian
JLDA, Paris

Pierre Yves Lagrée
JLDA, Paris

Alban Sauret
UCSD, San dieg