

Dry systems forward look

Michel Louge,
IFPRI AGM, Purdue
June 13, 2023

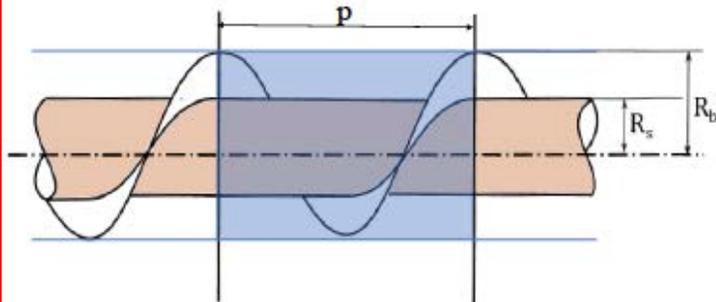
Dry systems portfolio

- Nott/Daniels (non-local model) until now
- Kit Windows-Yule (round robin) until now
- Prabhu Nott (screw feeding) renewal
- Casba Sinka (powder adhesion) renewal
- Arno Kwade (milling additives) renewal
- Ken Kamrin (air-induced defects/compaction) until 2024
- Raj Dave (flow aids & cohesion) until 2024
- Pouliquen (Aeration Geldart C) until 2025
- Alban Sauret (drying wet powders) until 2025

What we learned

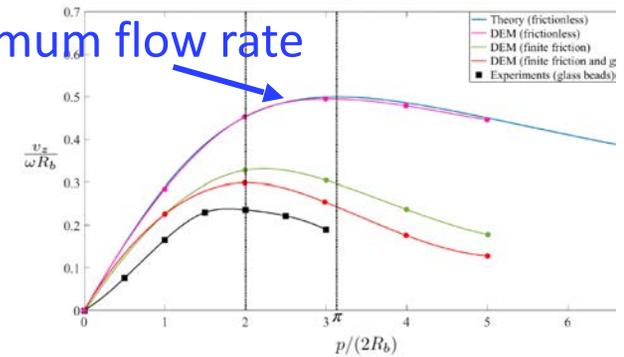
screw feeders

Prabhu Nott



formal calculations

Optimum flow rate

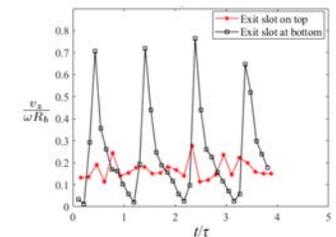
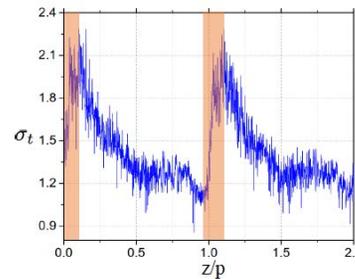


repaired "critical state" plasticity for non-local interactions

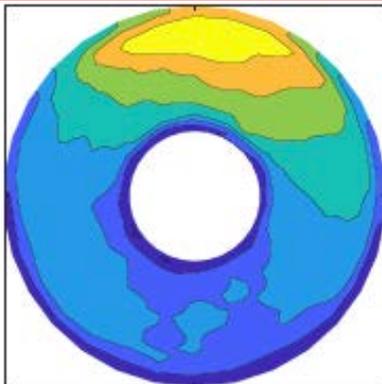
Janssen effect for stress

role of cohesion

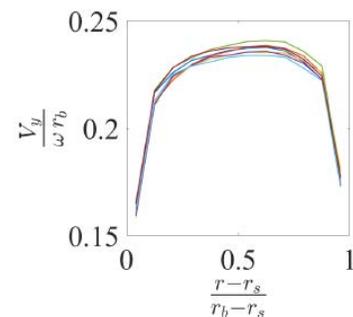
mitigate feed rate fluctuations



instrumented experiments

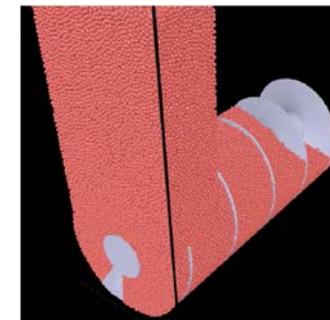


role of cohesion



DEM

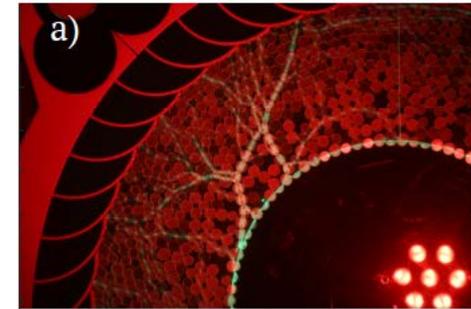
feed rate fluctuations



Collaboration

non-local rheology

Prabhu Nott and Karen Daniels



J. Fluid Mech. (2020), vol. 888, R3, doi:10.1017/jfm.2020.62

JFM RAPIDS
journals.cambridge.org/rapids

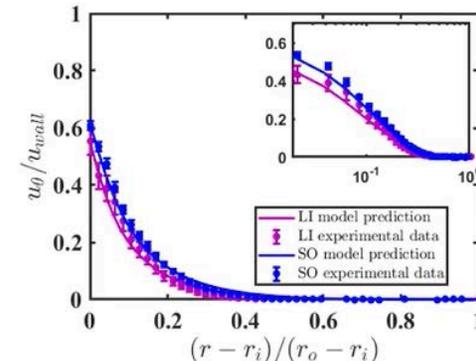
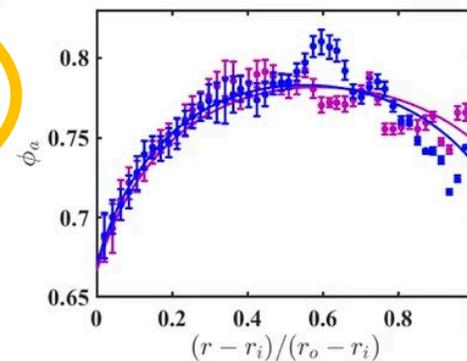
A non-local constitutive model for slow granular flow that incorporates dilatancy

Peter Vasan Dsouza¹ and Prabhu R. Nott^{1,†}

¹Department of Chemical Engineering, Indian Institute of Science, Bangalore 560 012, India

(Received 5 November 2019; revised 27 December 2019; accepted 16 January 2020)

Validation of the non-local model
with Karen's data



$$\sigma = -p\delta + \frac{2\mu}{\gamma} \left(p_c D' - \ell^2 \Pi \nabla^2 D' \right), \quad p = p_c \left(1 - \frac{\mu_b}{\gamma} \nabla \cdot u \right) - \ell^2 \Pi \frac{\mu_b}{\gamma} \nabla^2 \nabla \cdot u$$

non-local terms \rightarrow $p_c = \Pi \left[-\ell^2 \frac{d\Pi}{d\phi} \nabla^2 \phi, \right]$

Round-robin

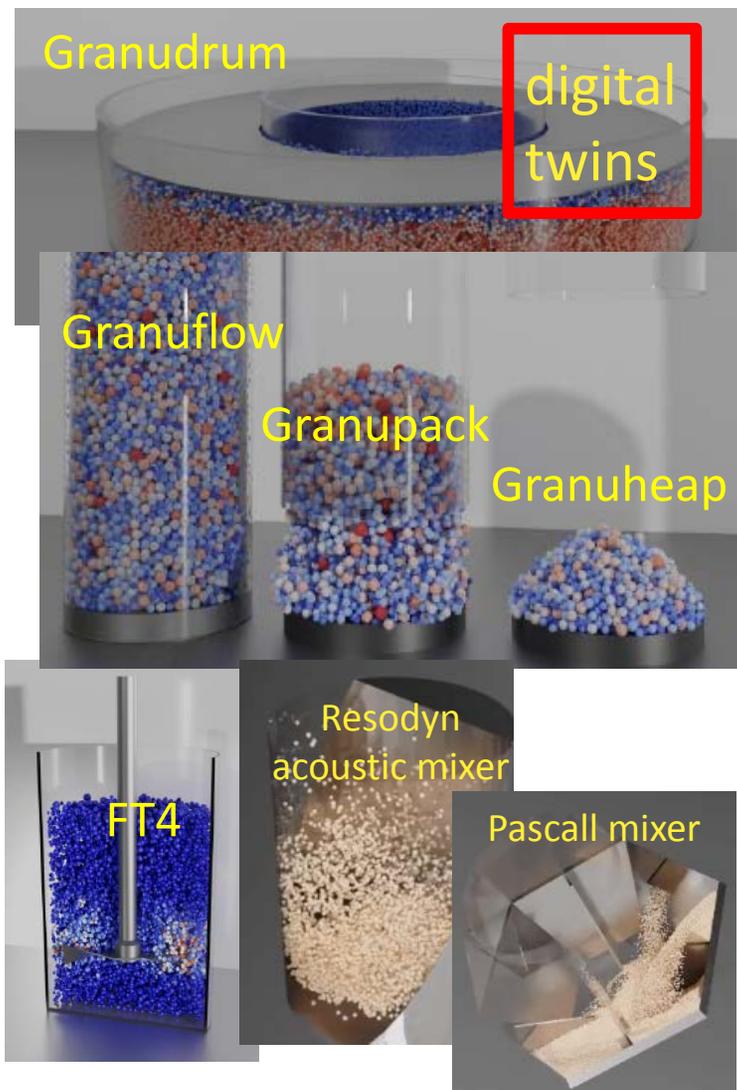
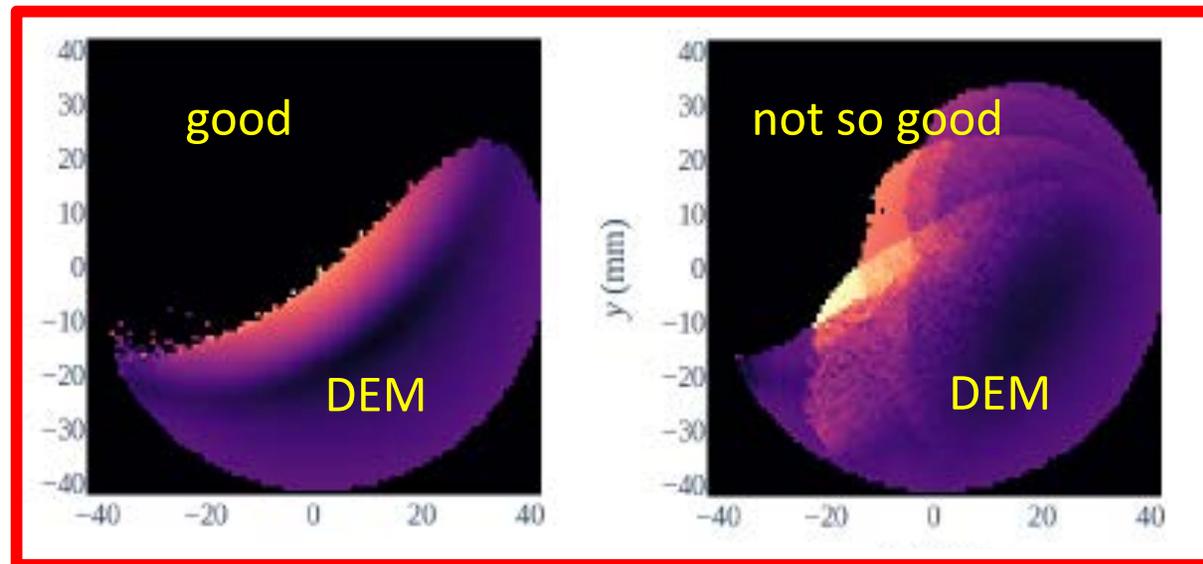
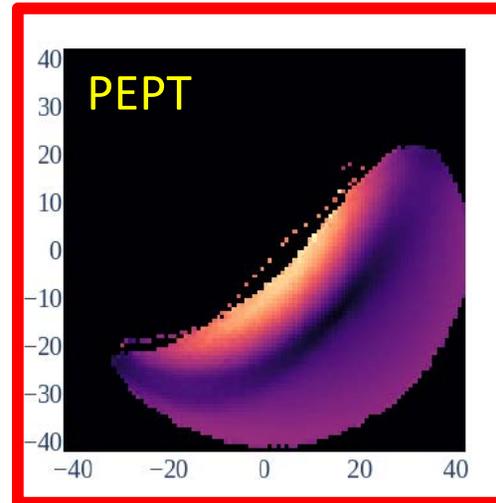
a prolific project

Kit Windows-Yule

Automatic calibration of
DEM parameters
(e.g. restitution matters)

7 powders kinds:
shape, cohesion,
size, mixtures

diverse equipment:
Pascall mixer,
Resodyn acoustic mixer,
Schultze shear tester,
Granutools

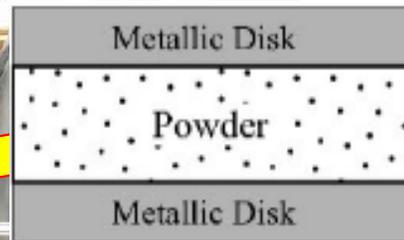
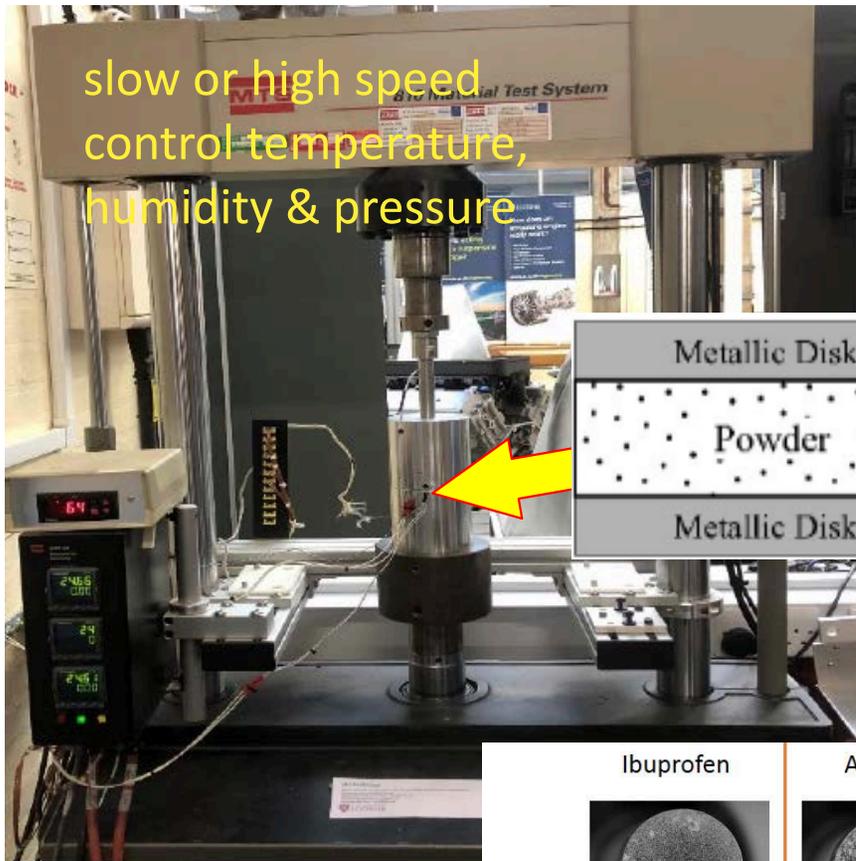


What we learned

powder adhesion metal during compaction

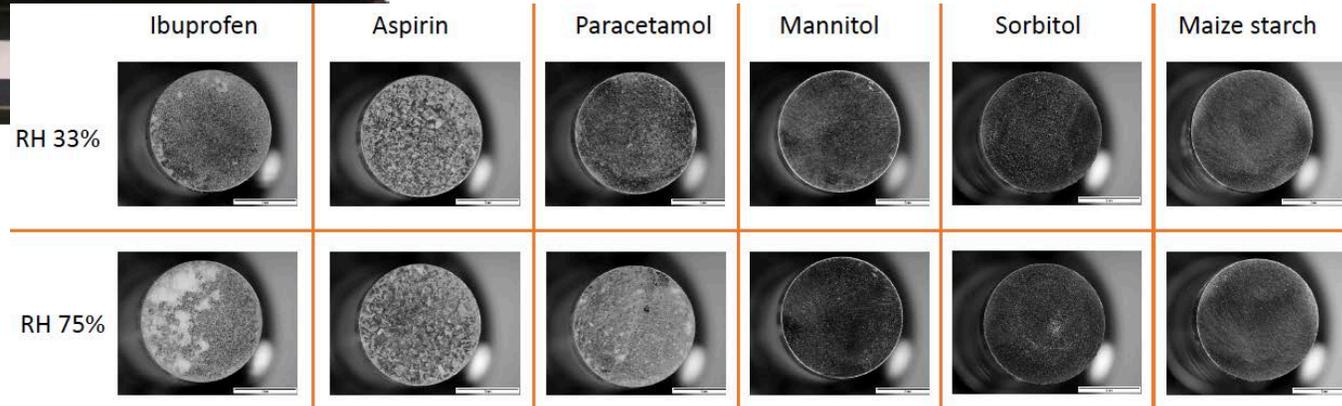
Csaba Sinka

slow or high speed
control temperature,
humidity & pressure



Used Principal Component Analysis to find property combinations associated with sticking of powders already studied

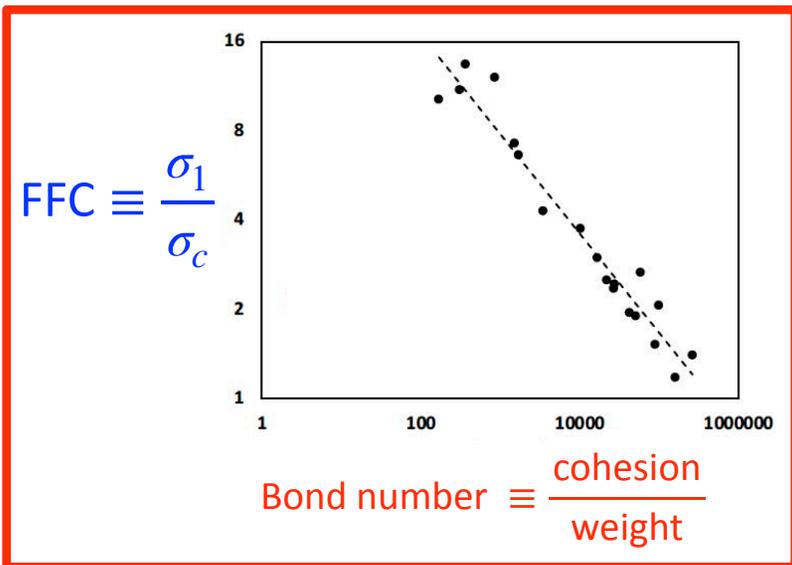
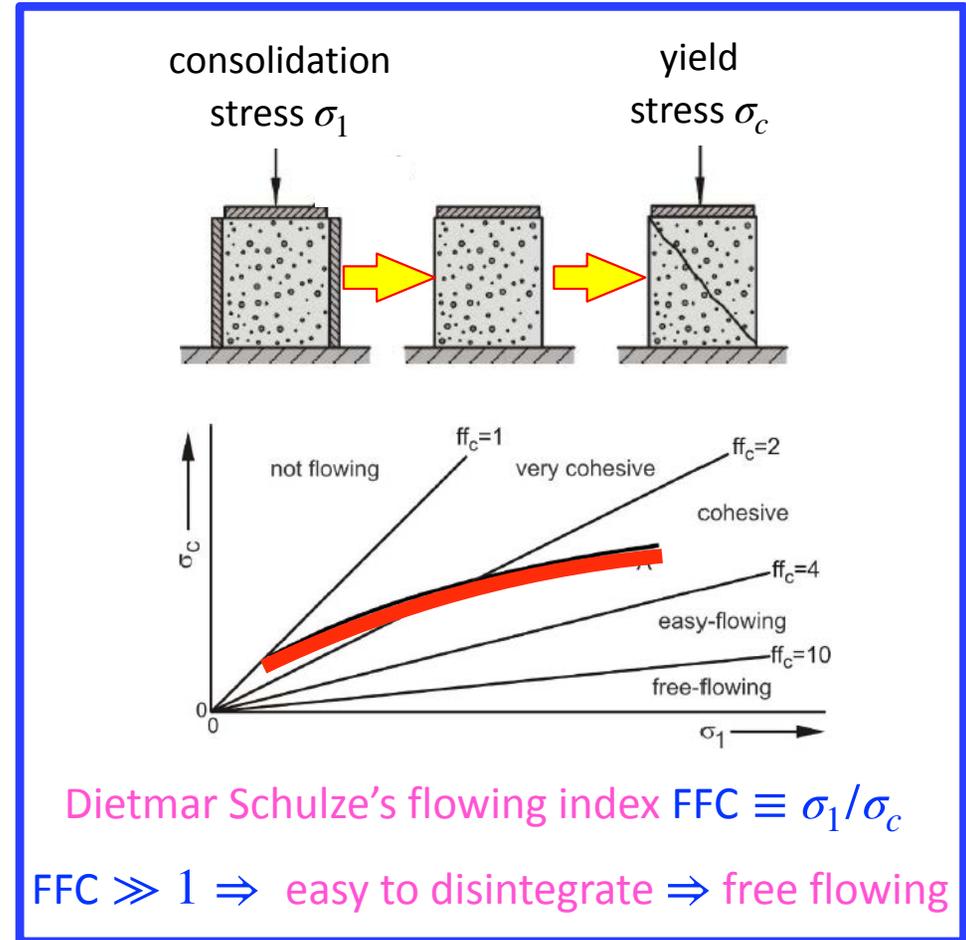
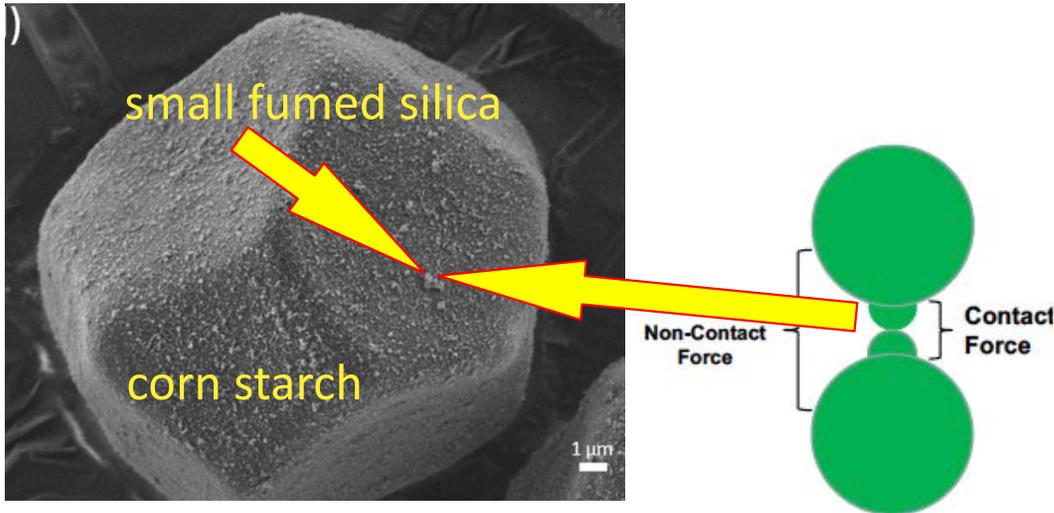
Identified MORDRED chemical descriptors; began correlating with Principal Components to predict sticking for new powders



What we learned

selection of flow aids

Raj Davé

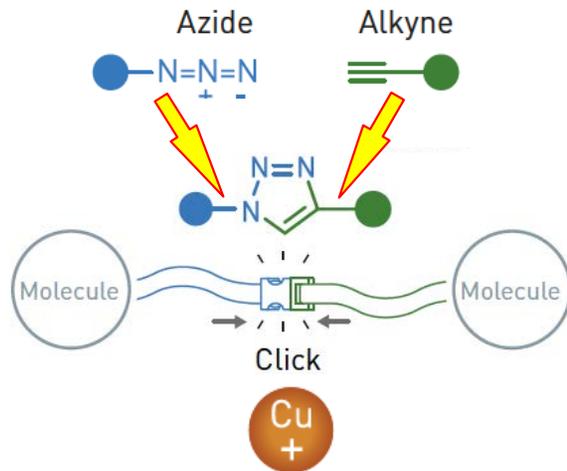


Rough particles do not benefit as much as smooth ones from the presence of small added particles

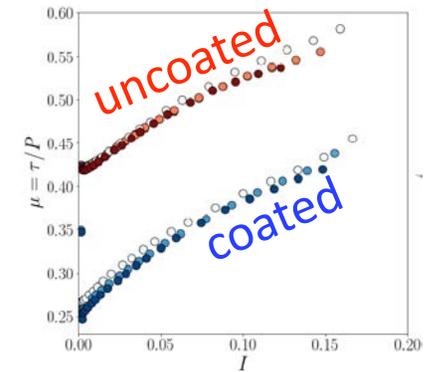
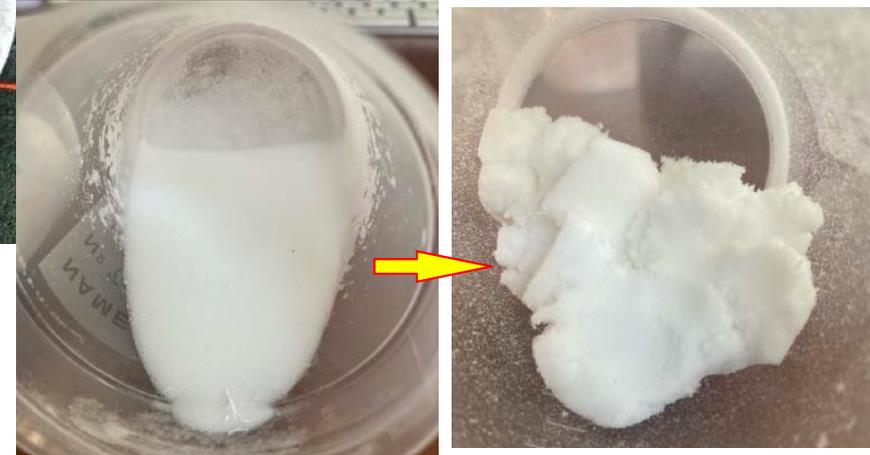
What we learned

controlling particle adhesion in powder flow

Olivier Pouliquen



synthesize and functionalize surface coatings with "click chemistry" to create particles of bespoke adhesion

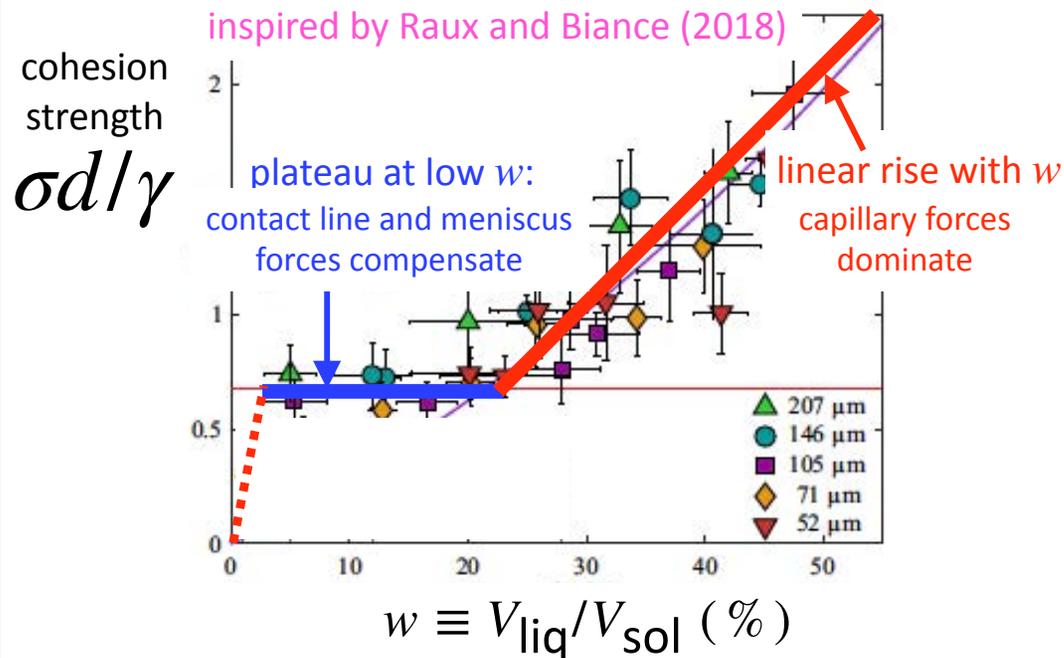
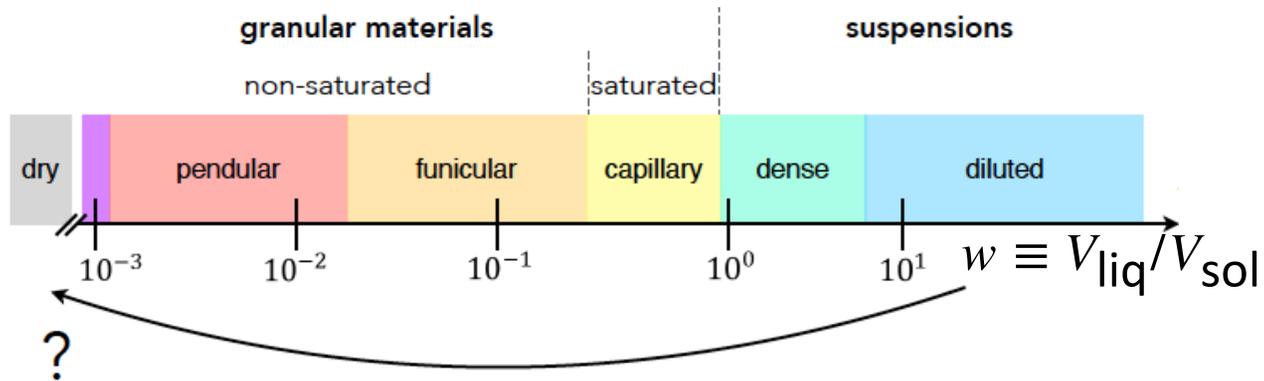


Collaboration with Alban Sauret

Under way: construct a smaller (millimetric) annular shear cell for low confining pressures

What we learned

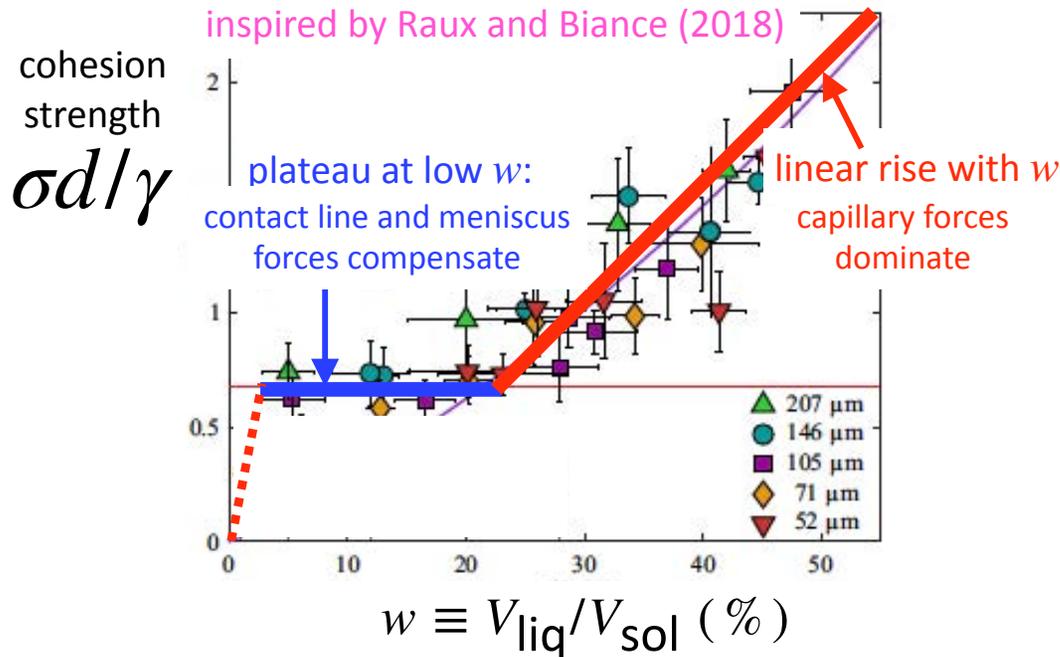
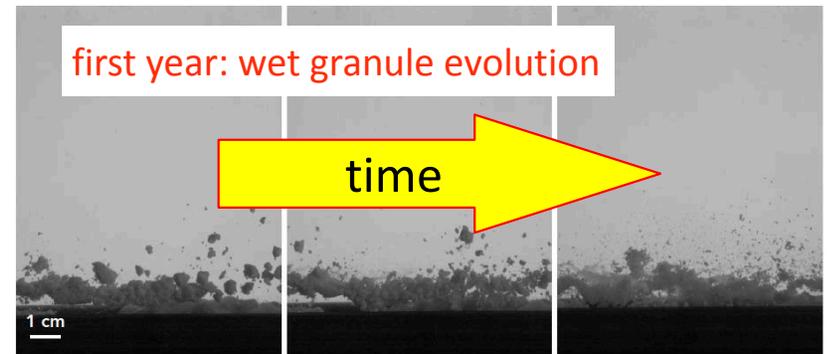
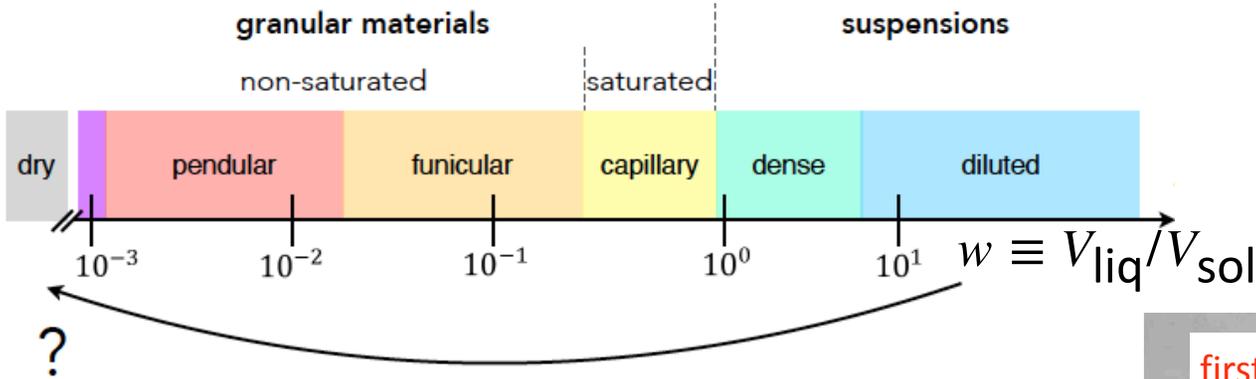
agglomerate formation in drying



What we learned

agglomerate formation in drying

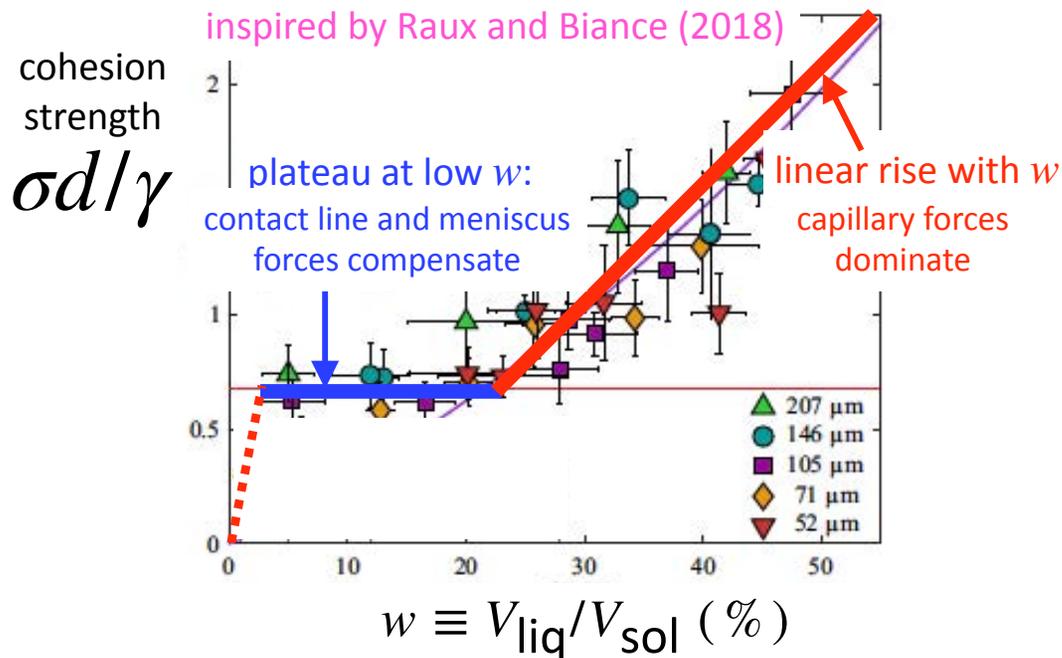
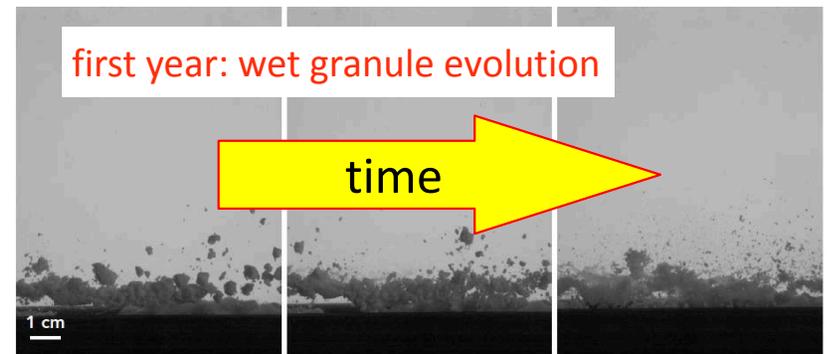
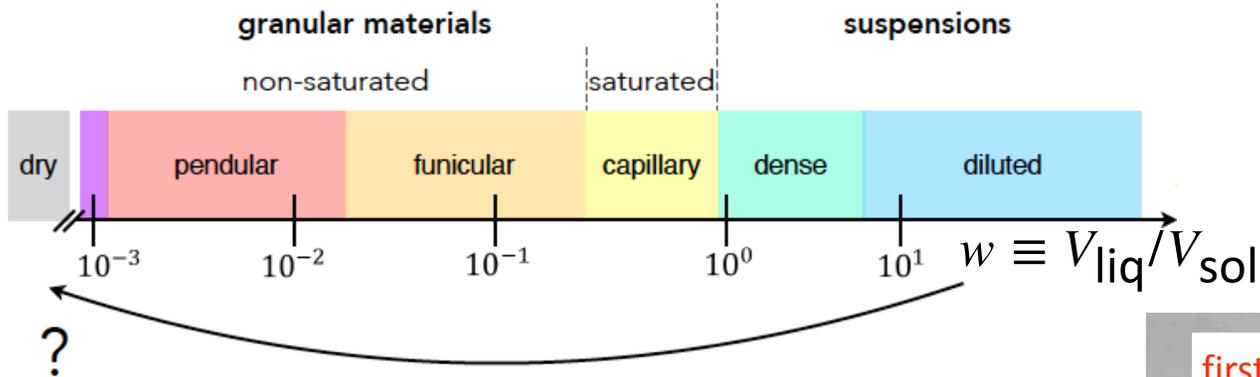
Alban Sauret



What we learned

agglomerate formation in drying

Alban Sauret



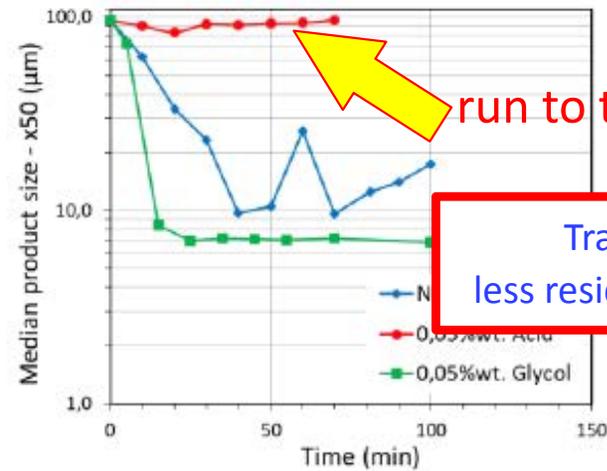
next year: flow drying air and use rotating drum



What we learned

additives in continuous milling and classification

Arno Kwade



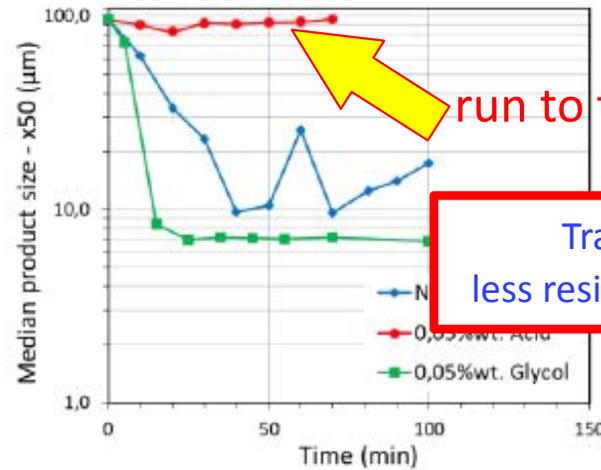
run to the exit

Trade-off of better flowability in mill:
less residence time \Rightarrow particles run to the exit...

What we learned

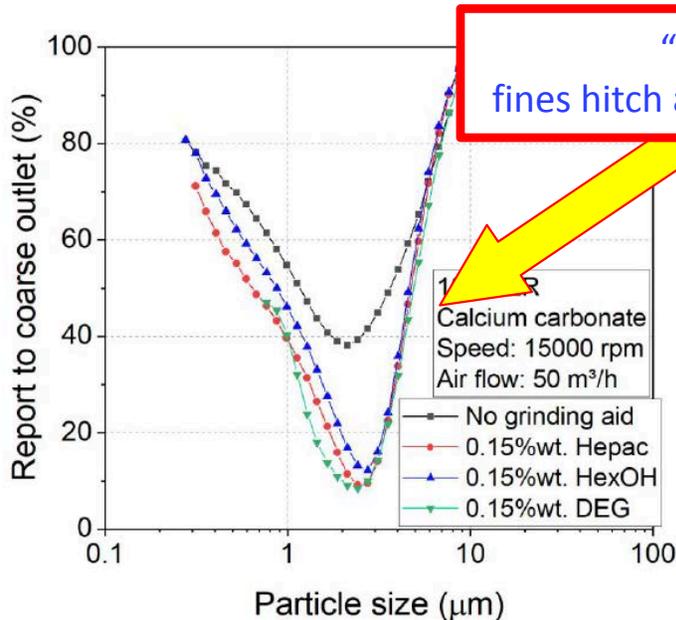
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Arno Kwade



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“fish-hook” cumulative PSD:
fines hitch a ride on coarser particles in classifier

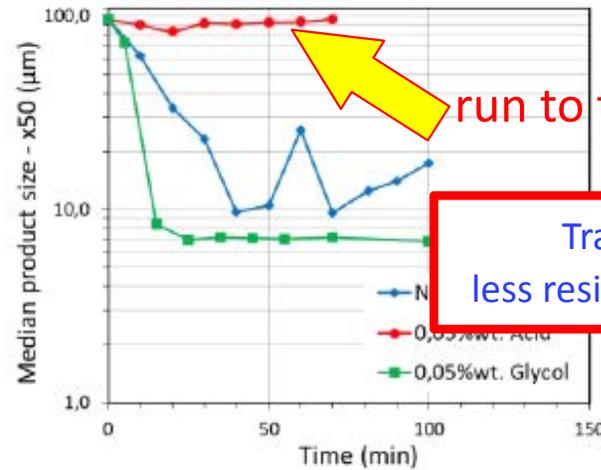
1
Calcium carbonate
Speed: 15000 rpm
Air flow: 50 m³/h

— No grinding aid
— 0.15%wt. Hepac
— 0.15%wt. HexOH
— 0.15%wt. DEG

What we learned

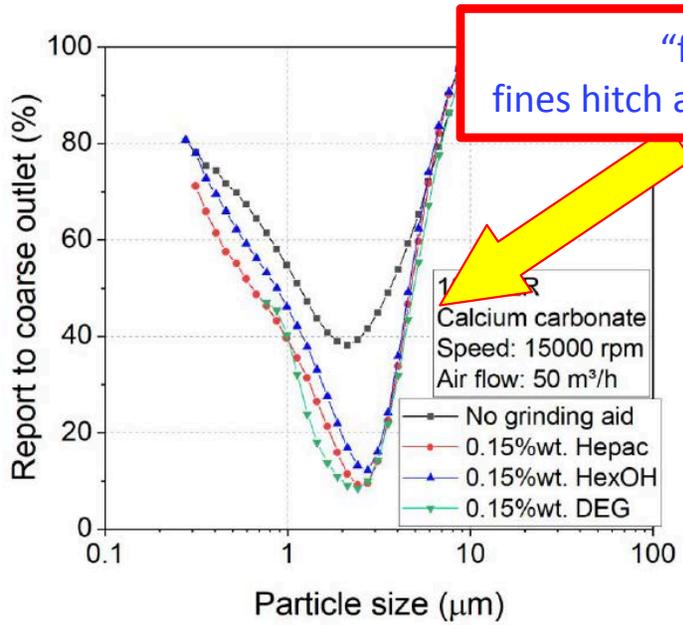
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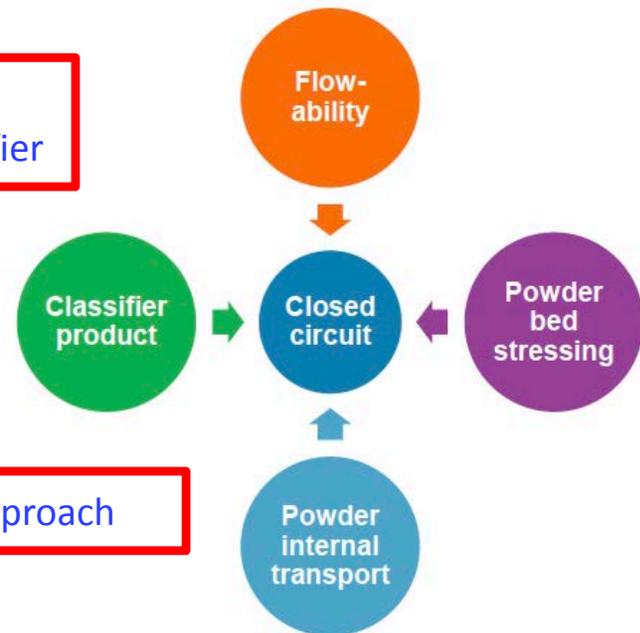


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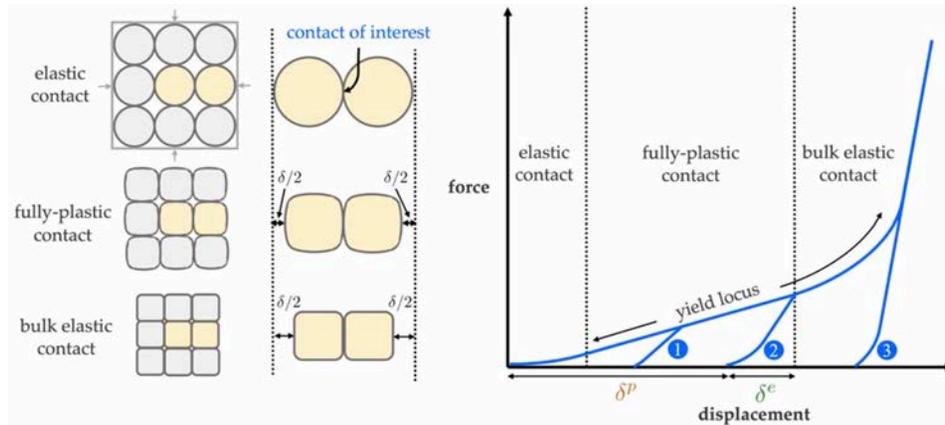


Systems approach

What we learned

air-induced defects in compaction

Ken Kamrin

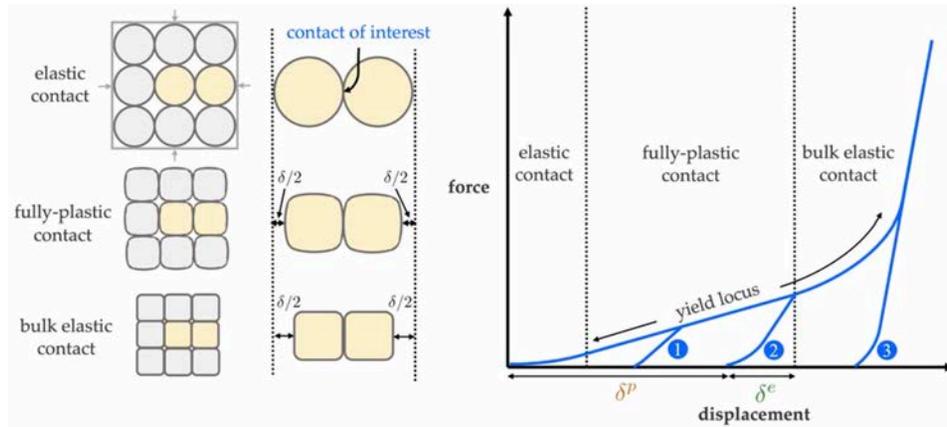


Modeled force-displacement relations and validated against FEM simulations

What we learned

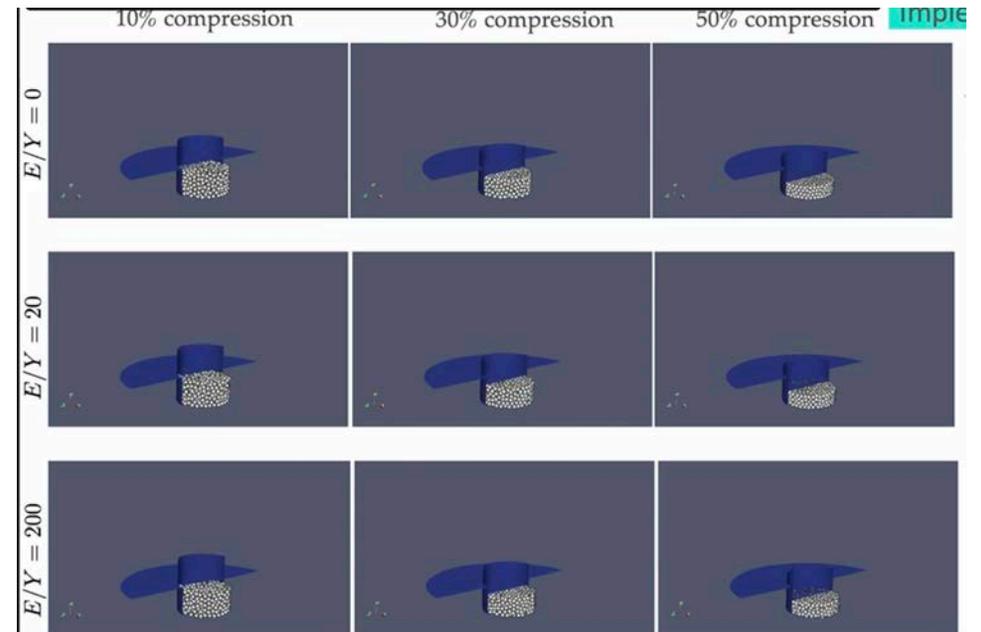
air-induced defects in compaction

Ken Kamrin



Modeled force-displacement relations and validated against FEM simulations

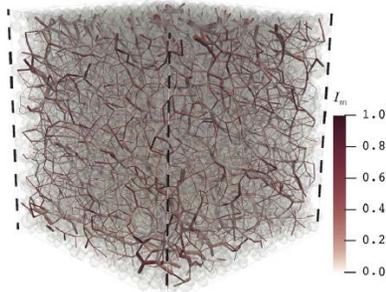
Incorporated the elasto-plastic model in numerical simulations without air



Forward look

recruit scholars of wide scientific bandwidth

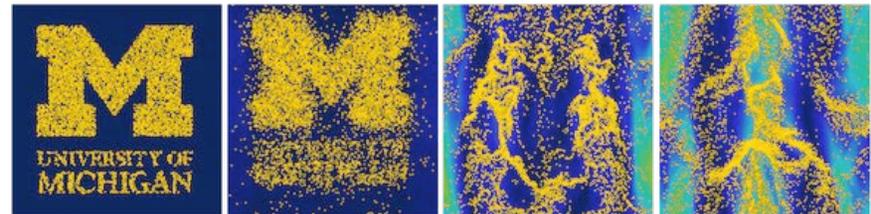
modeling and DEM



Farhang Radjai (Montpellier)

granular materials rheology and fabric

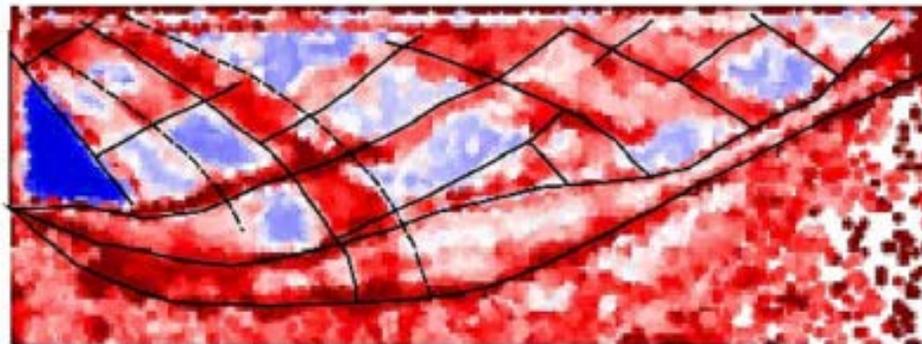
reintroduce gas-solid interactions



Jesse Capecelatro (Michigan):

large-scale numerical simulations

stress localization of granular materials



Antoinette Tordesillas (Melbourne):

analysis of complex localization patterns

Suggested powder flow scientists

Heinrich Jaeger (Chicago): particle charging, granular impacts, dense suspensions.

Anil Misra (U. Kansas): granular theory.

Atieh Moridi (Cornell): thin flow with application to rapid prototyping.

Roberto Zenit (Brown): capillary interactions.

Ecevit Bilgili (NJIT): milling, granulation, extrusion, spray drying.

Paul Umbanhowar (Northwestern): granular physics.

Anthony Thornton (Twente): granular segregation.

Mark Shattuck (CCNY): granular mechanics.

Jean-Christophe Géminard (ENS, Lyon): solid friction, sediment suspensions.

Nico Gray (Manchester): granular flow segregation.

Elisabeth Guazzelli (Paris-Diderot): granular suspensions.

Alexandre Valance (Rennes): granular flows, geophysics

Doug Jerolmack (U. Penn): geophysical debris flow.

Eckart Meiburg (UC Santa Barbara): simulations of cohesive immersed sediments.

Berend van Wachem (Magdeburg): fluidization, gas-solid flows

Hans Kuipers (Eindhoven): gas-solid flows, wet systems