

# Single Drop Drying at High Temperatures

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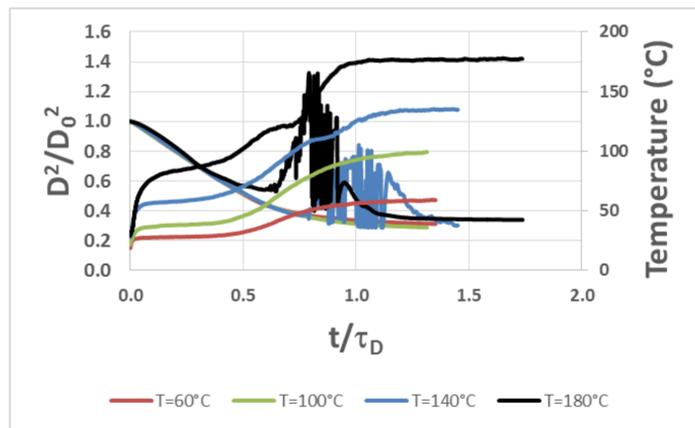
This project seeks to develop experimental and modelling methods that enable dried particle structure, properties and drying rate to be predicted based on droplet drying history. The project will focus on effects driven by boiling and look to develop material independent models which capture behaviors of industrial interest. In particular it will look to address key limitations in current understanding: 1> the impact of a non-isothermal drying history on particle structure and consequently drying rate; 2> improved measurements of material properties under the non-equilibrium conditions experienced during drying; 3> extension of models to include the mechanics of structure formation. A key goal is the development of a regime map which links material properties and drying conditions to morphology.

**Filament rig – allows quantitative analysis of drying kinetics**  
**Not all puffing is equal** – material property evolution during drying drives puffing and final morphology and size

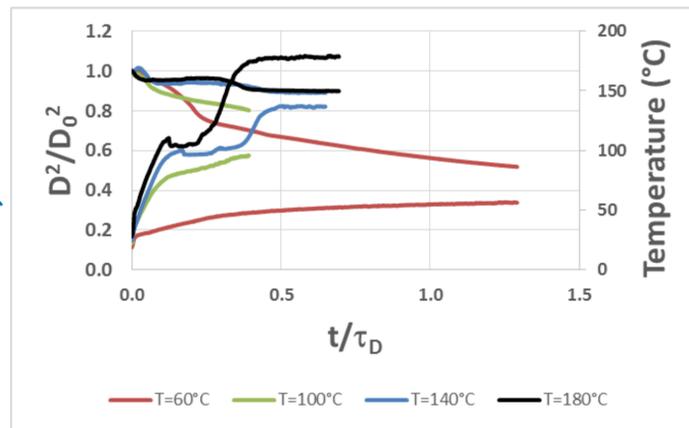
**Modelling** - expansion of the bubble within a droplet  
 - models (no drying) established  
 - off-set bubble expansion drives bubble motion

## Drying kinetics and size evolution

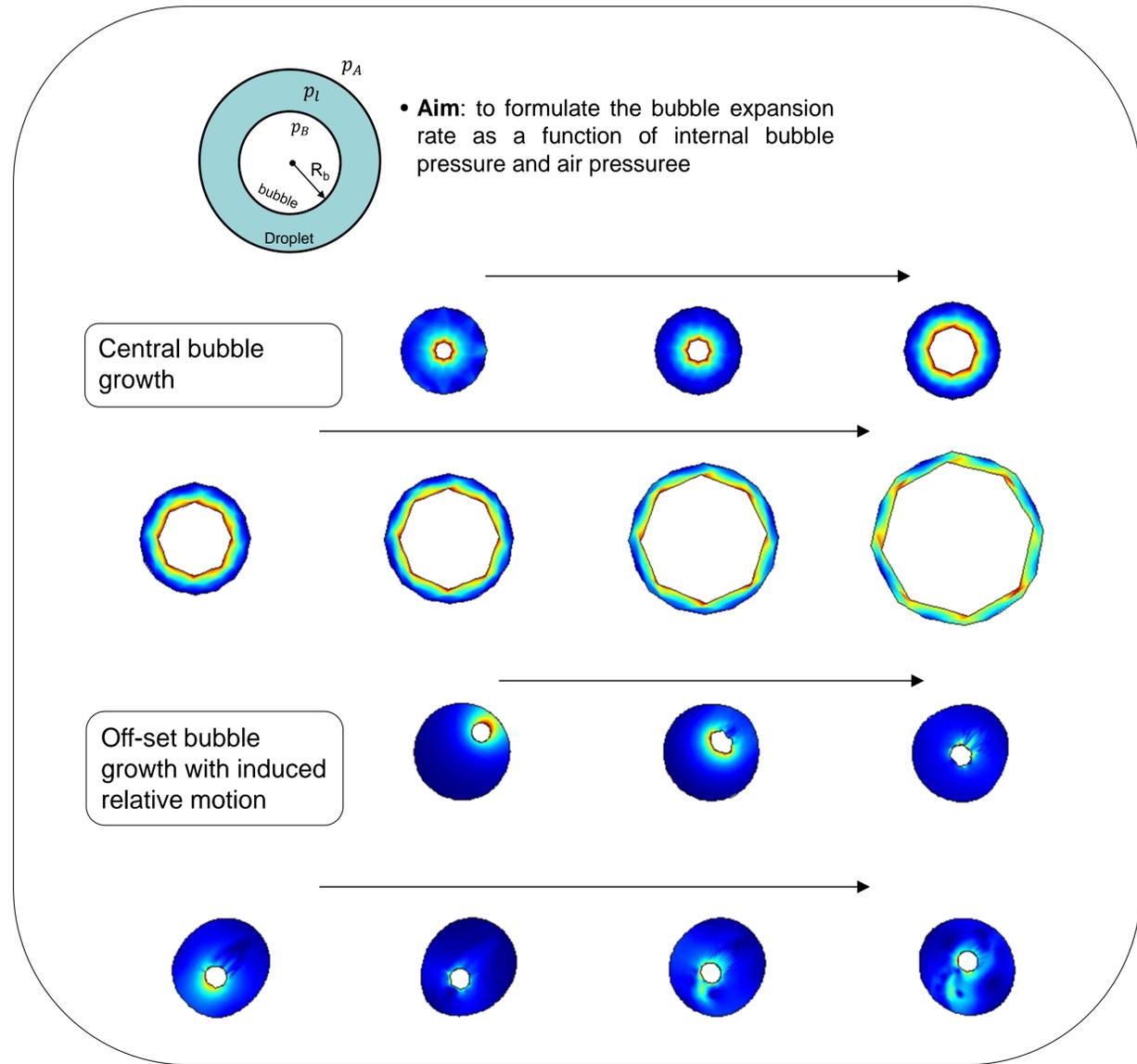
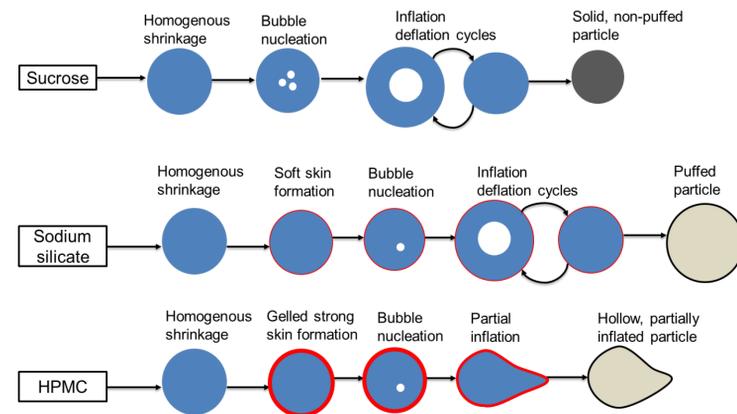
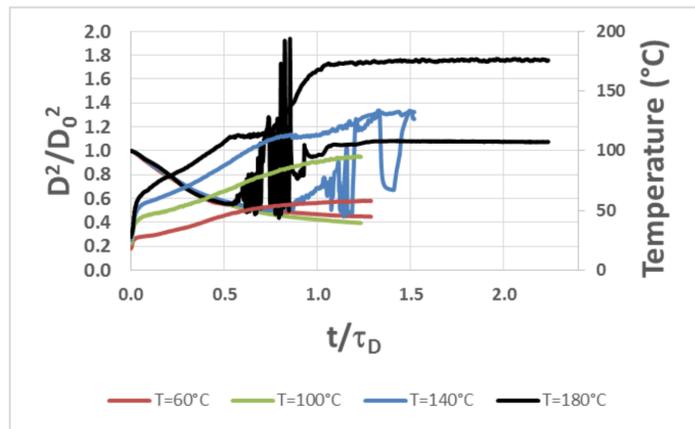
Sucrose, 15%



HPMC, 15%



Silicate, 15%



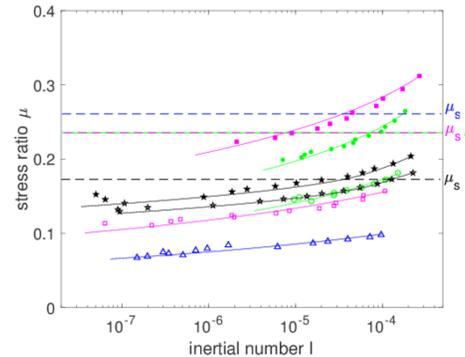
# Nonlocal Rheology of Intermediate Granular Flows: Particle Shape and Size Distributions

Karen Daniels, Zhu Tang  
Dept. of Physics, NC State University

Our research aims are to connect grain-scale parameters to macroscale behaviors within a sheared granular material, through the use of nonlocal rheologies. We aim to answer 3 questions: (Q1) What do the flow field and fluidity field look like for real experiments? (Q2) How do the empirically-measured material properties and cooperativity length vary as we change particle shape and size and distributions in a controlled way? (Q3) Can the fluctuations in local forces (via force chains breaking/forming) account for the non-local contribution to the fluidity? We will perform experiments in a quasi-2D annular shear cell, in which tracking the locations and velocities of individual particles is possible. This will allow for direct tests of competing nonlocal theories which so far have seen little experimental validation.



Top view of apparatus, with leaf springs around the outer confining wall. The inner disk rotates, shearing the granular material. The amount of deformation of the leaf springs measures the confining pressure on the granular material [1]. The shear stress is measured via the torque required to rotate the inner disk, as well as by calibrated measurements of the deformation of the outer leaf springs. We track all particle locations via the holes in the centers of each.



We have conducted experiments on the laser-cut particles and find that the resulting flows can successfully be modeled using nonlocal rheology [1,2]. We find that it is possible to conduct experiments under one set of flow conditions, and then use the same fit parameters to model the same particles until new flow conditions. Legend: acrylic circles (green circles), ellipses (magenta squares), pentagons (black stars), and original photoelastic circles/ellipses (blue triangles) at both higher (solid symbols) and lower (open symbols) pressures. Dashed lines:  $\mu_s$  for each shape. Solid lines: nonlocal rheology model results.

	Vishay circles/ellipses	acrylic ellipses	acrylic circles	acrylic pentagons
$\mu_s$	$0.26 \pm 0.02$	$0.24 \pm 0.02$	$0.24 \pm 0.02$	$0.17 \pm 0.01$
$b$	$1.1 \pm 0.3$	$1.1 \pm 0.5$	$1.1 \pm 0.6$	$1.1 \pm 0.6$
$A$	$0.402 \pm 0.003$	$0.231 \pm 0.003$	$0.280 \pm 0.003$	$0.101 \pm 0.001$

This chart shows the 3 nonlocal fit parameters determined for each set of particles. We find that the yield stress ratio  $\mu_s$  (determined by slow-shear experiments) is shape-dependent for same material, the local parameter  $b$  is insensitive to material and shape, and the nonlocal parameter  $A$  is sensitive to both material and shape.

**Open Questions:** In order to make nonlocal rheology easy to use in the largest variety of conditions, two things are required.

- To better-understand (rather than measure directly) the appropriate boundary conditions to allow for prediction without first conducting experiments.
- Conduct experiments using systematic variations in particle properties in order to provide predictions for each parameter.
- We have uncovered some interesting observations relating force chain fluctuations to the location of  $\mu_s$  in the experiment; relating that quantity of the physics of phase transitions (i.e. as a susceptibility) would be interesting.

[1] Tang, Brzinski, Shearer, Daniels. "Nonlocal rheology of dense granular flow in annular shear experiments." *Soft Matter*. 14, 3040-3048 (2018).

[2] Kamrin & Koval. "Nonlocal Constitutive Relation for Steady Granular Flow." *Physical Review Letters*. 108, 178301 (2012)

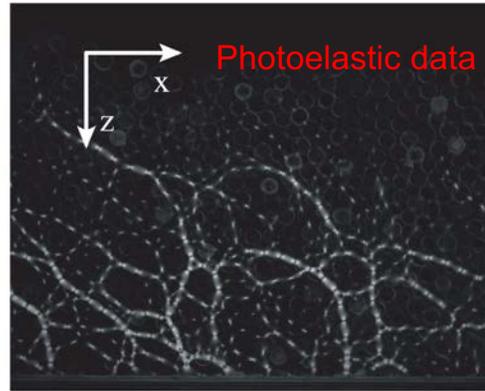
[3] Bouzid, Trulsson, Claudin, Clément, Andreotti, "Nonlocal rheology of granular flows across yield conditions." *Physical Review Letters*. 111, 238301 (2013)

# Non-local effects in intermediate flows

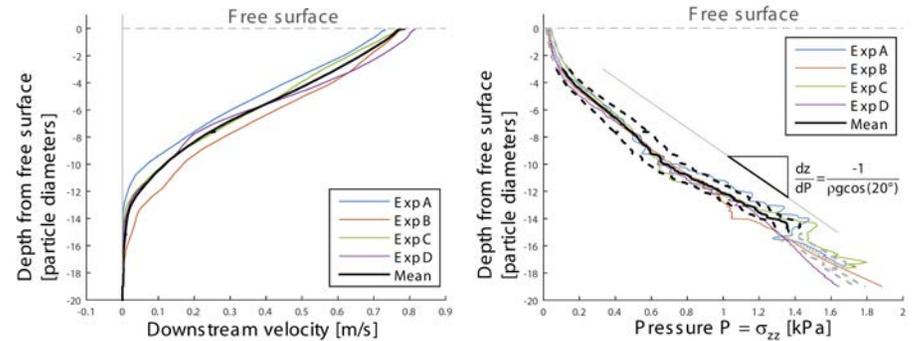
Nathalie Vriend and Karen Daniels

DAMTP, University of Cambridge, UK and Dept. of Physics, North Carolina State University, USA

The aim of this collaboration is to perform tests of two nonlocal rheologies using a faster flow (intermediate flow:  $I \sim 0.25$ ) than is available in the annular Couette cell at NC State. The lab at Cambridge has an existing chute-flow apparatus and imaging system which has been slightly adapted for this research. Identical custom-made 2D photoelastic particles allow for the direct measurement of the contact forces on each particle, combined with particle tracking analysis for dynamical properties. Contact-force measurements can be time-averaged and coarse-grained to provide the continuum stress fields at the boundaries of the materials to test the rheologies. We obtain continuum fields, as a function of depth  $z$ , for the velocity, and normal and shear stresses. From the fields, we are able to calculate the stress ratio, granular fluidity, fluctuations in light intensity and decorrelation time, which can be analyzed to reveal the underlying physics behavior.

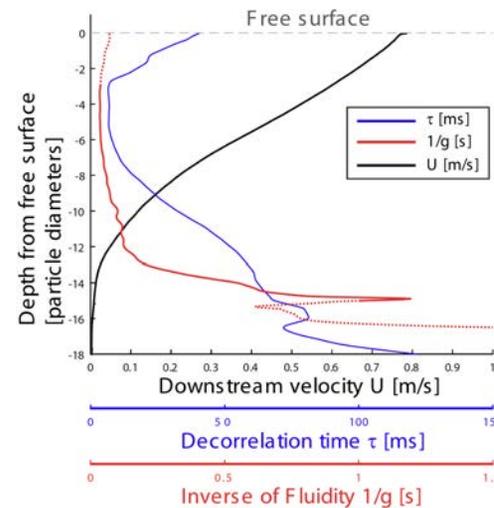
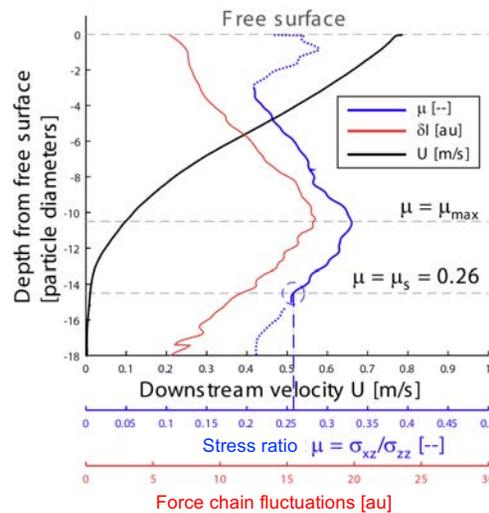


## Kinetic (velocity) and dynamic (stress/forces) information



→ Essential ingredients for rheology:  $I = \frac{\dot{\gamma}d}{\sqrt{P/\rho}} \approx 0.25$

Strong correlation between stress ratio  $\mu$  and force chain fluctuations



Strong correlation between decorrelation time  $\tau$  and the inverse of the fluidity  $g$

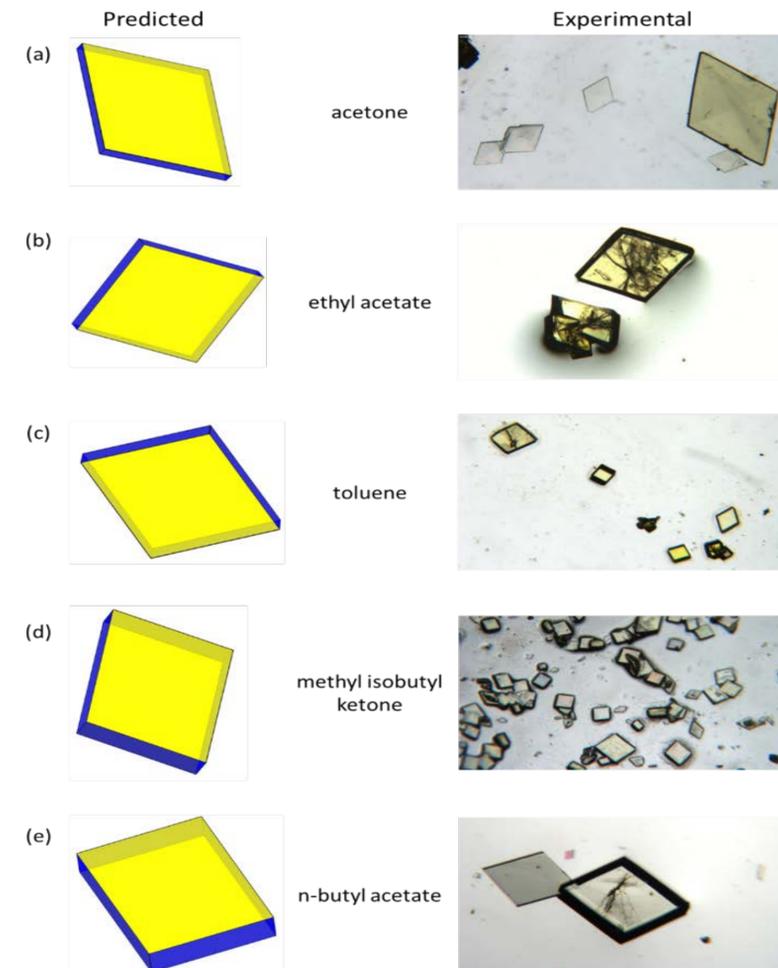
Develop a practical engineering tool for predicting the relative growth rates (growth kinetics) and morphology of solution-grown faceted crystals, including the effects of solvent, and impurities/additives.

Our approach is to leverage six years of research & development building our crystal design software tool called ADDICT.

We have just completed a total re-write of ADDICT tool to make it applicable to a much wider selection of growth units (all developed in Carl Tilbury's doctoral dissertation, 2017) and crystal forms.

We will spend the next year testing ADDICT for a wide variety of complex crystalline forms, and for crystals that exhibit supersaturation-dependent morphologies. We will then start to extend the models in the "growth engine" to encompass new types of materials, such as solvates, cocrystals and organic salts.

## Olanzapine Grown from a Variety of Solvents



# Mixing Rules for Powder Mixing (Phase 1): A Positron Emission Particle Tracking Investigation of a Binary Mixture

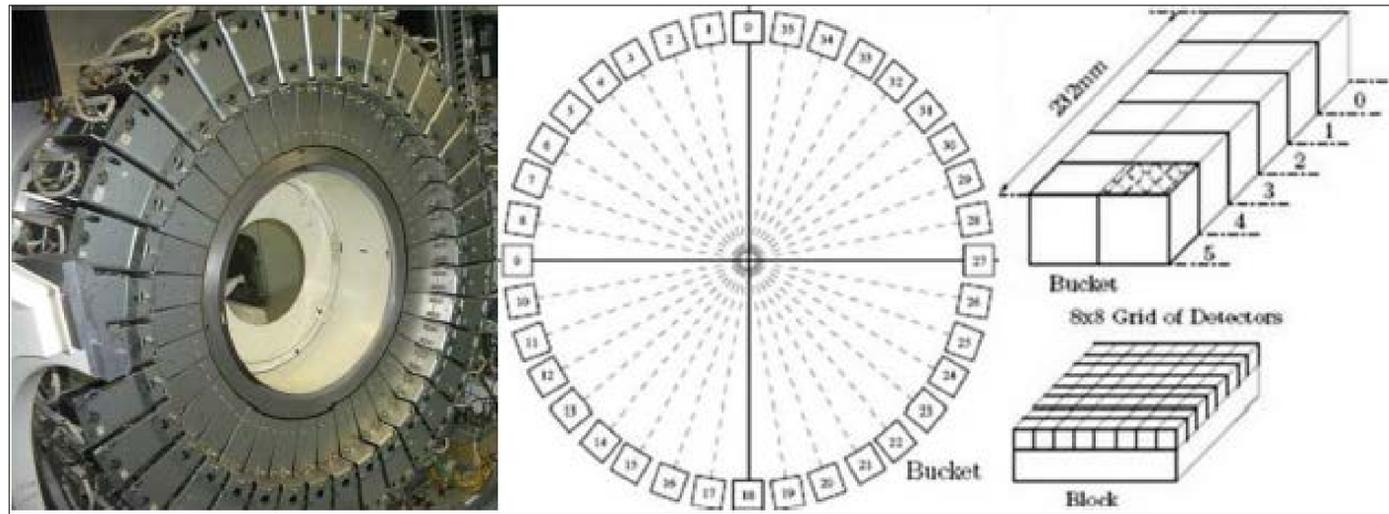
Indresan Govender<sup>1,2</sup>, Suren Moodley<sup>1</sup>, Marcelle Pillay<sup>1</sup>, Malcom Rengasamy<sup>1</sup>

<sup>1</sup>Chemical Engineering, University of KwaZulu-Natal, Glenwood, Durban, South Africa, 4041

<sup>2</sup>Chemical Engineering, University of Cape Town, Rondebosch, South Africa, 7701

Positron Emission Particle Tracking measurements are conducted on a binary mixture (by size) of plastic beads flowing in batch mode within a rotating drum system fitted with lifter bars. The resulting 3D trajectory data constitutes the main ingredients for determining mixing proxies: shear rate, energy fluctuation, probability distribution, and Péclet number. A detailed analysis of the 28 operating configurations will constitute the major part of the next phase in the project.

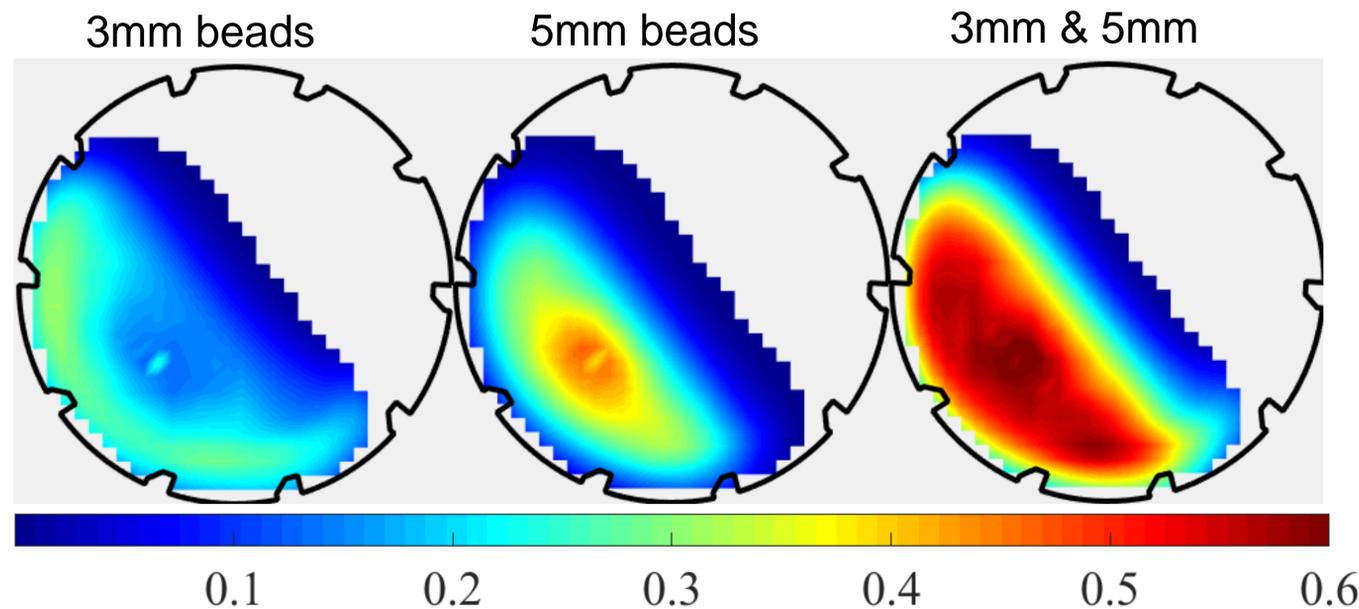
Highest resolution PEPT scanner in the world!



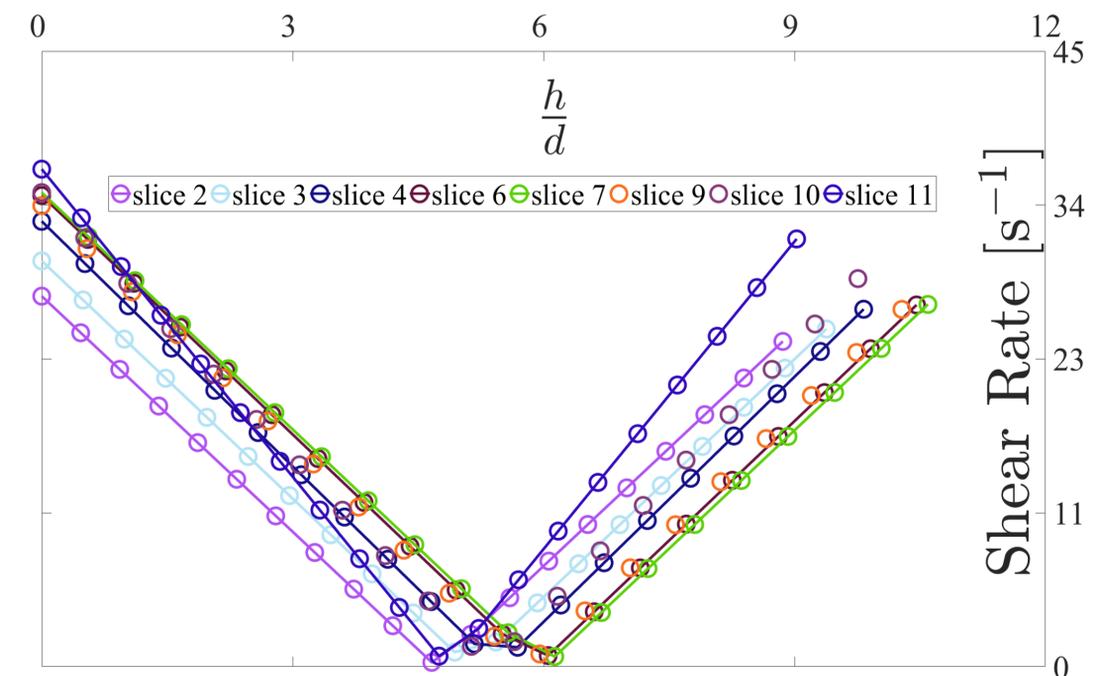
Rotating drum system used in PEPT experiment



Typical PEPT data analysis: fill fraction = 0.4; equal-mass mixture of 3mm & 5mm plastic beads; drum speed = 60% of critical speed (73 RPM)



Solids fraction distribution depicts *exactly* the opposite behavior to Kinetic Stress Theory (KST) at 60% of critical speed. Subsequent analysis performed along depth profiles from free surface.



Shear rate variation with bed depth ( $h/d$ ). Implies differences in local velocity fluctuations which ultimately drive a large particle towards regions of greater fluctuations

# 3D printing "Perfect Particles"

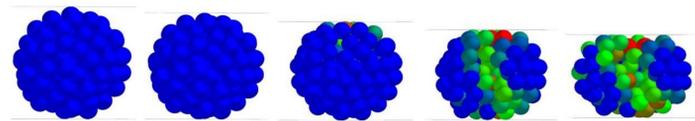
Ruihuan Ge, Mojtaba Ghadiri, Karen Hapgood  
Monash University, Leeds University & Deakin University



3D printed agglomerates with defined and tuneable properties are required to advance our understanding of a range of particle processes. Several agglomerate designed underwent breakage testing and demonstrated excellent experimental reproducibility. Macroscopic agglomerate breakage behavior was predicted by DEM simulations using the TBBM contact model. However, DEM initially underestimated the quantitative compressive loads for spherical random agglomerates. By using FEM simulations the limit of linear elastic deformation was determined, & the DEM simulations (& TBBM bond model) were valid over this small deformation range. The second stage of the project extends the idea of using 3D printing to generate a range of physical particles from the *in silico* equivalents in DEM simulation software to conduct experiments that cannot be done in any other way – particularly varying agglomerate sizes, shapes and density.

## Agglomerate breakage experiments & DEM

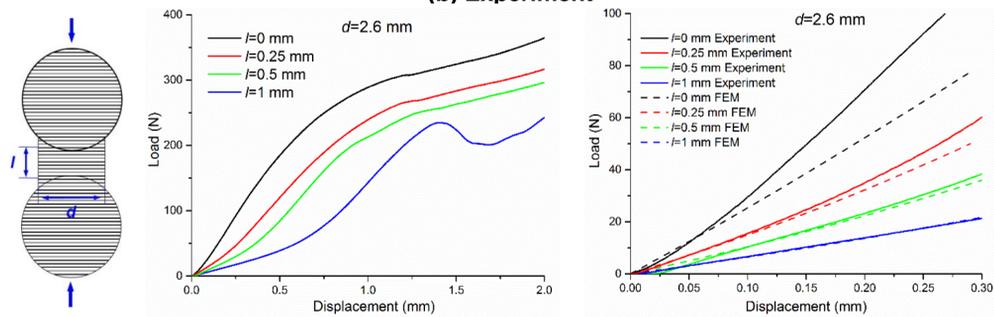
Random spherical agglomerate ( $\epsilon=44\%$ )



(a) Simulation

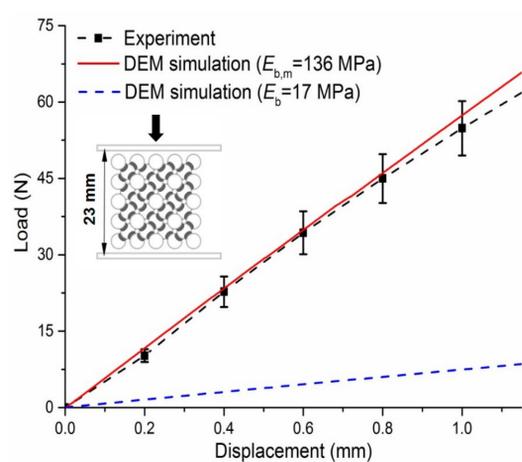


(b) Experiment

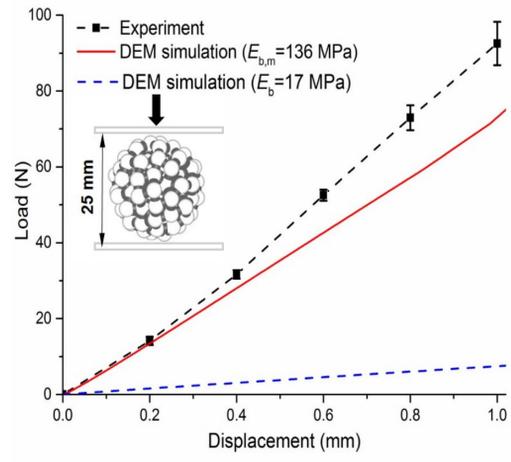


(a) Experimental results

(b) FEM vs Experiment



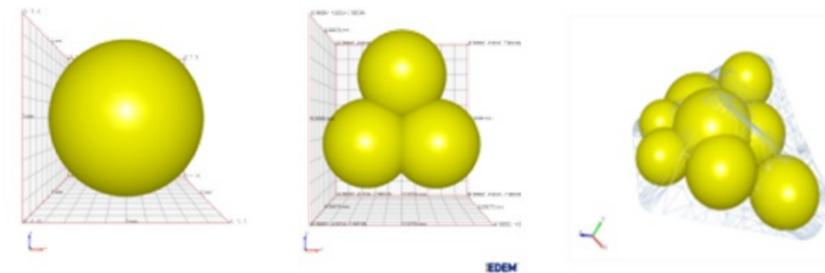
(a) Cubic tetrahedral structure



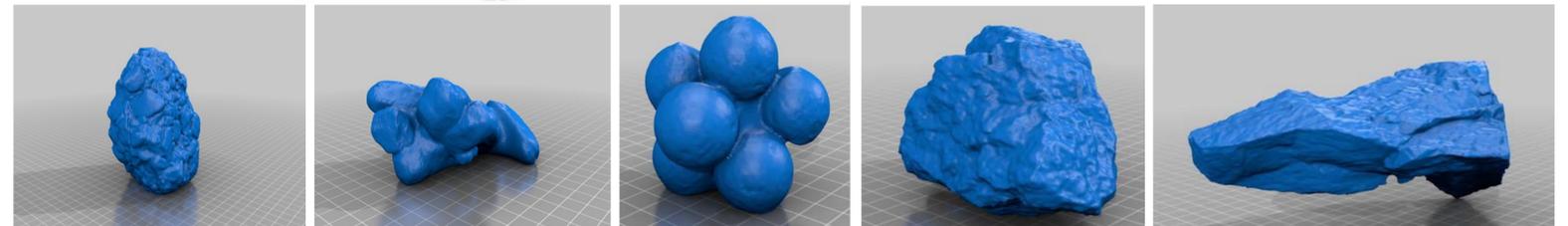
(b) Spherical random structure ( $\epsilon=49\%$ )

## New uses for 3D printed particles: Flow of irregular particles

- Flow of irregular shaped particles. Testing of original shape and "equivalent" DEM shape in simple flow – how many spheres are required?



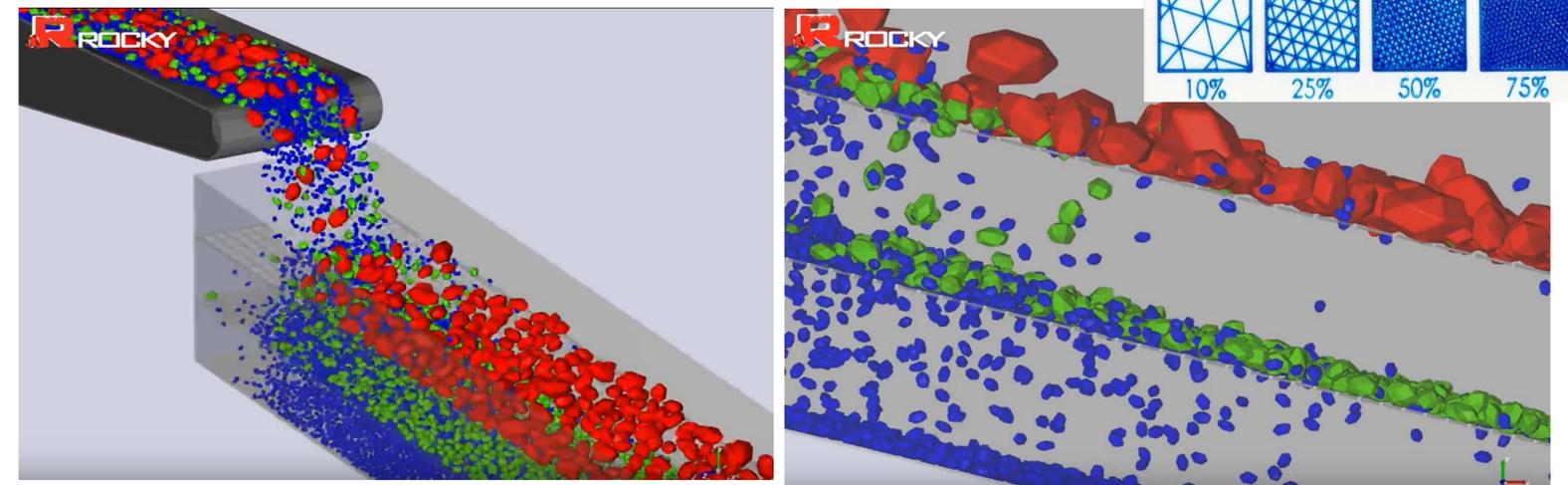
**EDEM™ Pro-Tip:**  
If it doesn't have shape,  
then it's probably wrong



COD Chert-pebble Breccia by geofablab is licensed under the Creative Commons - Attribution license.

Hi Res Rocks! (3D scan) by NeverDun is licensed under the Creative Commons - Attribution license

- Use 3D printing colours for size and/or density

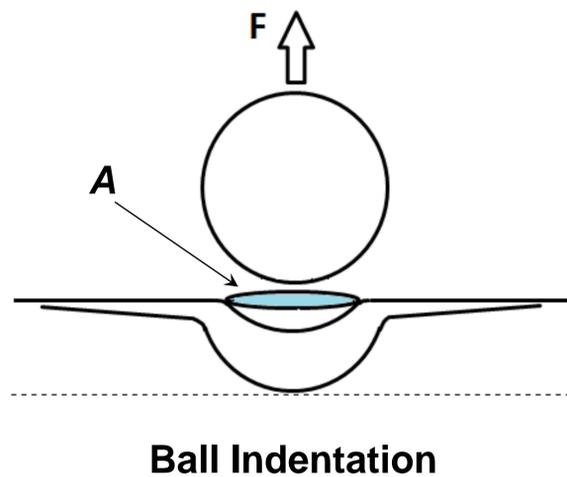


# Flowability Assessment of Weakly Consolidated Powders

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<sup>1</sup>Department of Chemical and Process Engineering, University of Surrey, <sup>2</sup>Institute of Particle Science & Engineering, University of Leeds

Measurement of unconfined yield strength of powders can be made with a variety of commercially available shear testing devices. Traditional flowability measurement devices have a number of shortcomings, e.g. reproducibility of unconfined yield strength is greatly reduced at low stresses, sometimes measurement is inconsistent with observed behaviour, or materials found to be cohesionless may still have practical differences. Generally the onset of flow is measured, which may not be a complete flow description. IFPRI seek to develop a theoretical understanding of flow of weakly consolidated and weakly cohesive powders. The ball indentation method is applied to establish powder flow behaviour at low stresses. Indentation measurements are carried out on vertically consolidated beds and sheared beds (critically consolidated) at the same major principal stress as shear cell and uniaxial compression measurements, in order to compare flowability measurements and determine constraint factor.



$$H = F_{max} / A \quad A = \pi(2Rh - h^2)$$

$$H = C \cdot \sigma_c$$

$H$  = hardness

$F_{max}$  = maximum force

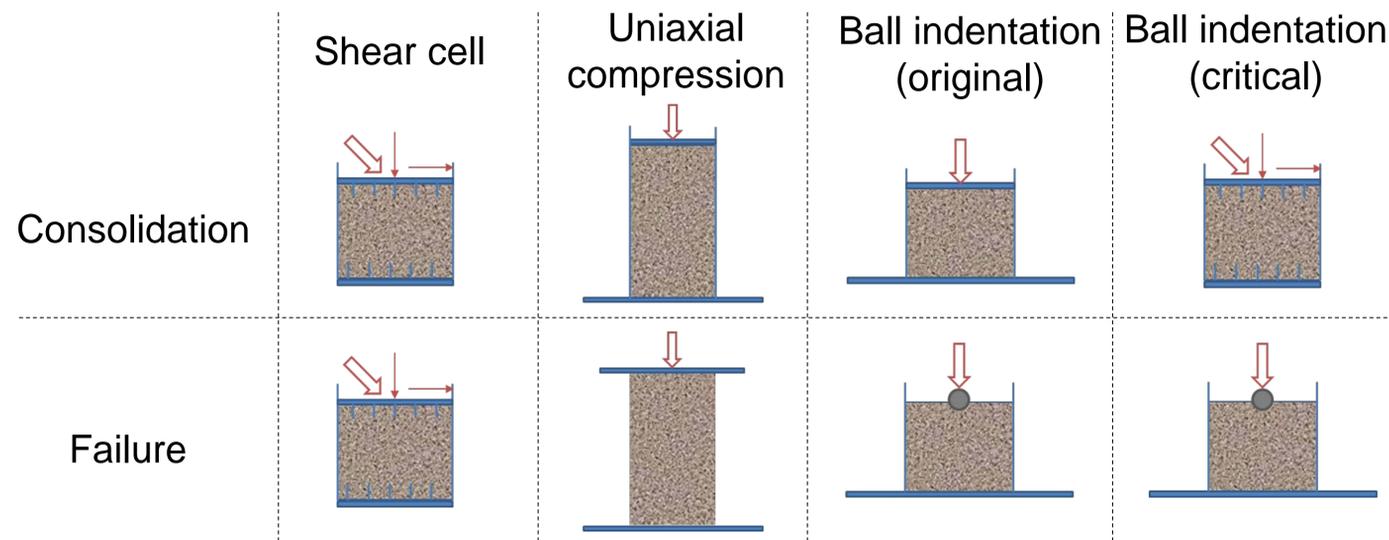
$A$  = projected area of impression

$R$  = indenter radius

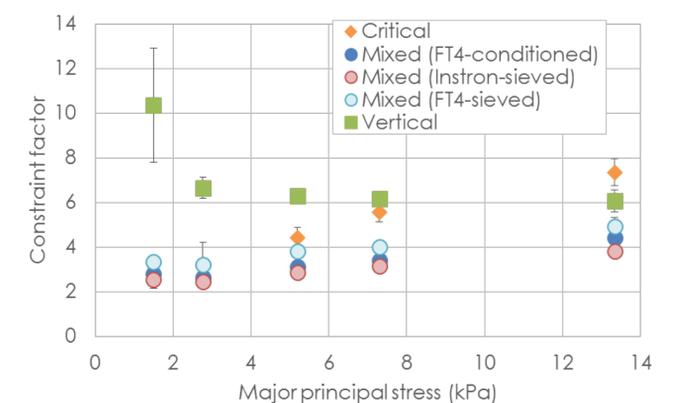
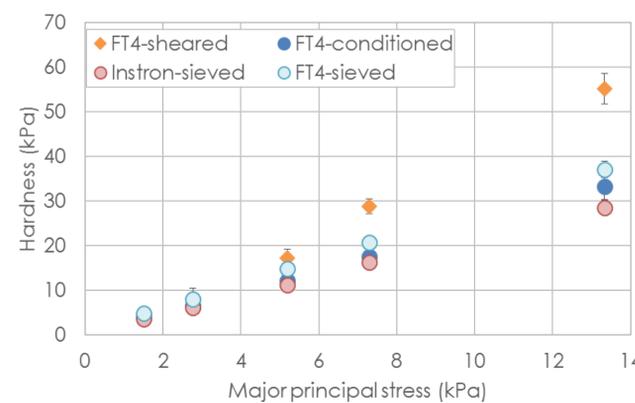
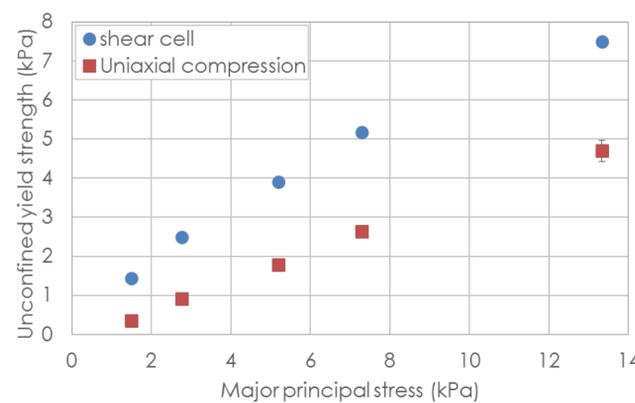
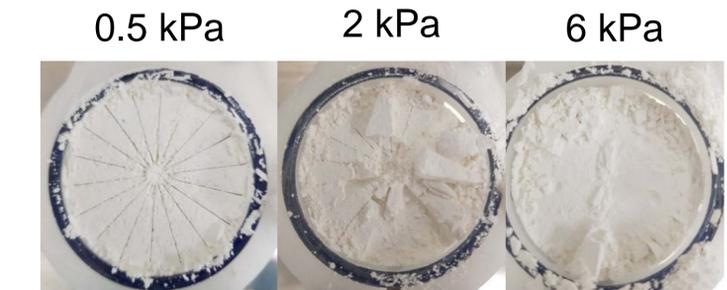
$h$  = penetration depth

$C$  = constraint factor

$\sigma_c$  = unconfined yield stress



Method	Indentation consolidation	Unconfined yield strength
Mixed	Vertical	Shear cell
Vertical	Vertical	Uniaxial compression
Critical	Critical (shear cell)	Shear cell

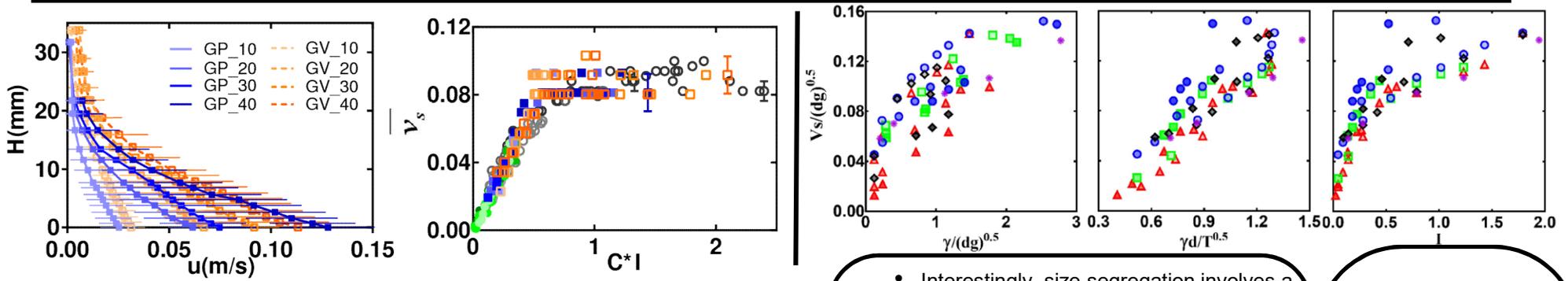


- Critically consolidated bed preparation for indentation measurement is challenging
- Unconfined yield strength measured by the uniaxial compression method is less than that determined in the shear cell, particularly at lower stresses
- Constraint factor determined by the vertical method is almost independent of consolidation stress in the reliable range (> 3 kPa)
- Mixed and vertical methods exhibit an increase in constraint factor with applied stress

# Quantitative Prediction of Segregation at Process Scale

Joseph J. McCarthy  
University of Pittsburgh

- Particle segregation is a problem for a wide range of industries
- Segregation rate models hold promise for scale-up via continuum-level analysis (via device-specific transport equations), **however**
  - Experimental validation of models is extremely difficult
  - Models often focus on simplified (binary) systems (size or shape segregation only)
- Two methods of combating experimental difficulties are to
  - exploit competing time-scales via flow perturbations
  - Examine purposefully inhomogeneous flows for rapid state explorations
- Easier validation allows exploration of more complex segregation mechanisms/problems (multi-modal, cohesive, shape, etc.)



**1**

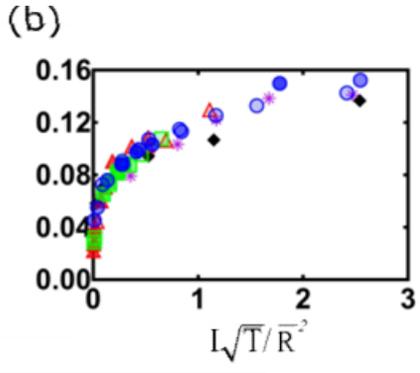
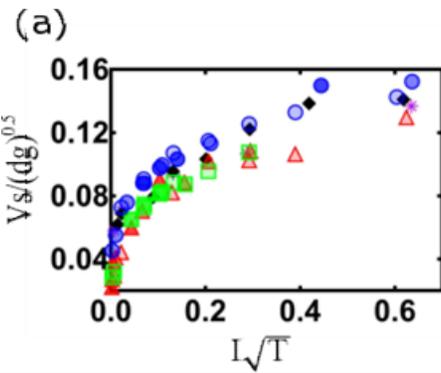
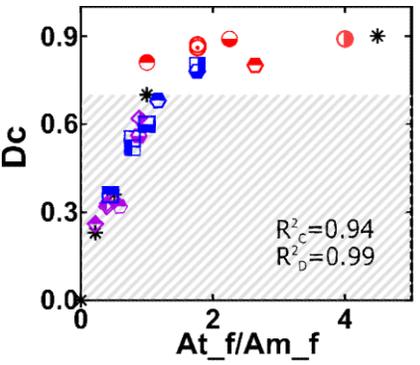
- Experiments using inhomogeneous shear flows allow a wide range of (shear) conditions to be explored simultaneously
- Our results support our novel saturating segregation model for density segregation

**2**

- Interestingly, size segregation involves a more complex interplay between segregation and rheology
- Simply using the inertia number,  $I$ , is insufficient

**3**

- Instead, one must combine both the inertia number and the granular temperature to scale the results
- In other words, one needs to create voids, but also explore sufficient space to find them
- The size ratio scales as the square due to the fact that the hole size must match the projected area



**4**

- A new shape definition allows us to collapse results from disks to cylinders into one curve, based on a ratio of areas (similar to size segregation)
- Note that disks often “roll” down surfaces

# A Holistic Approach for the Model-based Control of Crystal Size, Shape and Purity in Integrated Batch and Continuous Crystallization - Wet Milling Systems

Botond Szilagyi, Kanjakha Pal, Zoltan K. Nagy

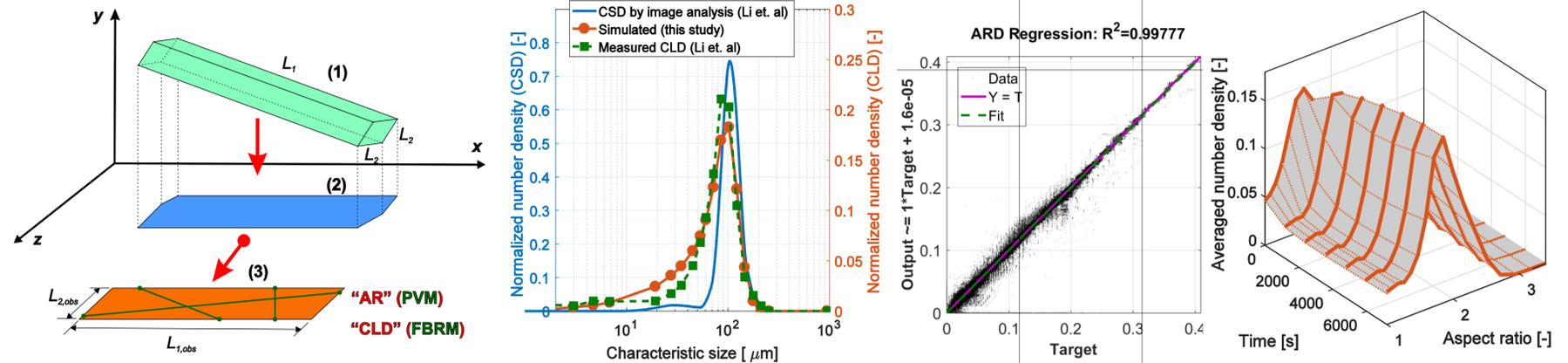
Purdue University, Davidson School, of Chemical Engineering, West Lafayette, US

## Goals

1. Integrated crystallizer-wet mill models for batch and continuous operation with 1D and 2D PBM, solved with and without GPU acceleration
2. FBRM and PVM soft sensors applying backward and forward transformation for 1D and 2D crystals
3. 2D PBM development for the system configurations with and without impurity model
4. Model Discrimination Framework and Iterative Model-based Experimental Design (IMED)
5. Development of the estimation and 1D and 2D PBM and MOO based NMPC and validation via simulation for the batch and the continuous systems

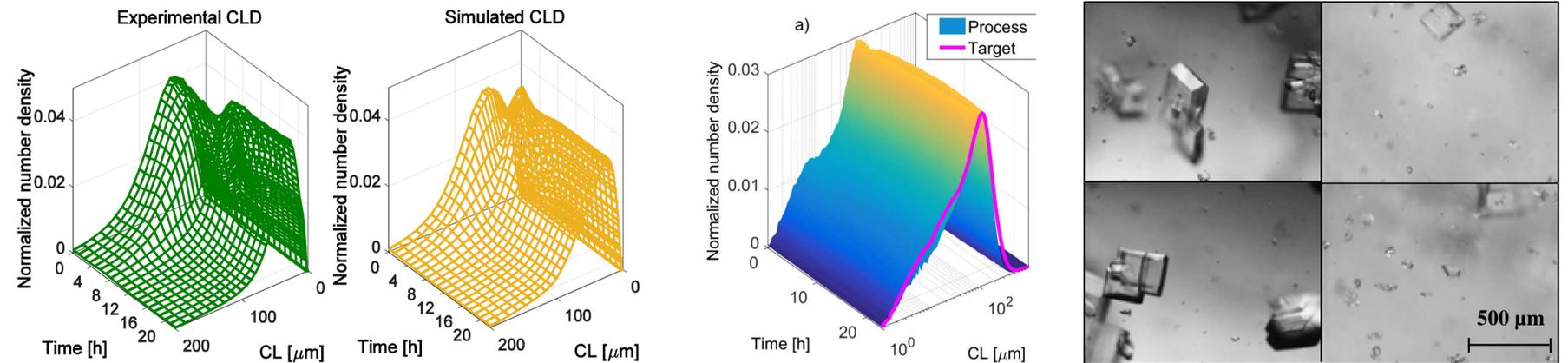
## Soft sensor

- Soft sensor based on improved geometrical model: mapping **all** possible chord lengths and aspect ratios of **all** possible projections – off-line, **grid dependent**
- Weighted summing of individual crystal's CLDs and ARDs to approximate the most likely CLD and ARD of a population of crystals
- ANN for learning the geometrical model output: efficient memory and grid independent. Enables the transformation on **arbitrary FVM grids**.



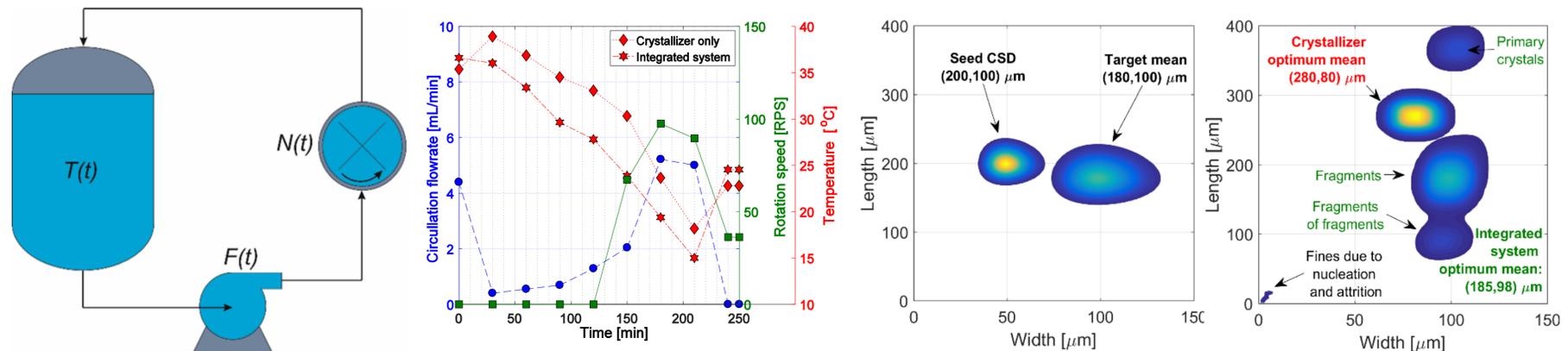
## CLD based NMPC

- Parameter estimation of seeded cooling batch crystallization of L-ascorbic acid based on concentration and **CLD measurements** using the CSD to CLD forward transformation
- **Implementation** of an adaptive nonlinear model predictive **control** involving high fidelity full population balance models (solved via the CrySiV function) based on concentration and **CLD feedback** information



## Integrated system

- Integrated crystallizer – external wet mill system for simultaneous crystal **size and shape optimization**
- **Considered mechanisms**: nucleation, growth and dissolution in wet-mill, nucleation, growth, dissolution, fragmentation, attrition and energy balance in wet-mill
- Improved attainable size and shape domain by compared to the crystallizer only configuration
- **Dynamic optimization** revealed unexpected optimal operation



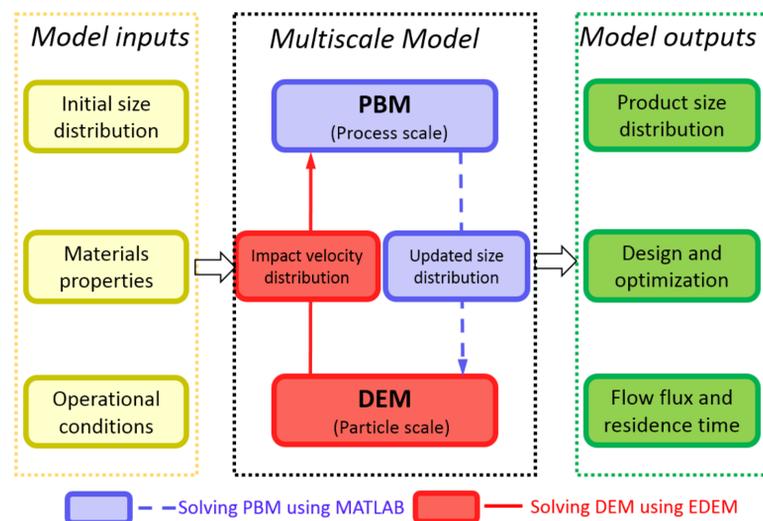
# Milling and material grindability: modelling, measurement and mill fingerprinting

J.Y. Ooi, X.Z. Chen, L.G. Wang, J.F. Chen\*, J. Sun  
University of Edinburgh, Scotland, UK; \*Queen's University Belfast, UK

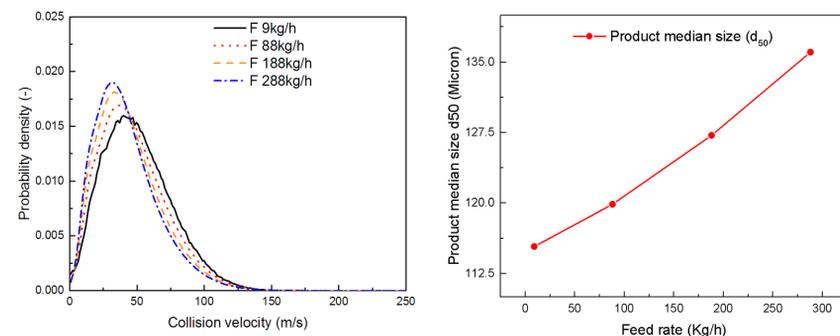
Milling is a common industrial operation for particle size reduction that is highly inefficient. The goal of this project is to develop a generic methodology to link material grindability with particle dynamics in a mill, involving:

- Computational modelling and experiments to characterise the milling function
- Developing “grindability” tests to measure the comminution characteristics of particulates
- Hierarchical verification and validation leading to robust evaluation of milling performance

## DEM-PBM coupling for pin mill

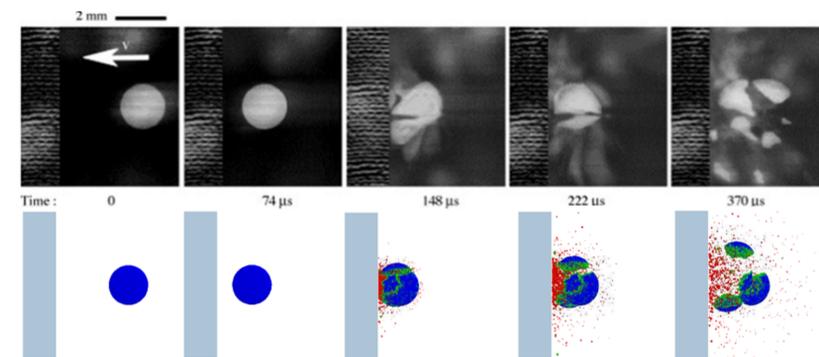


## High feed rate prediction for the pin mill

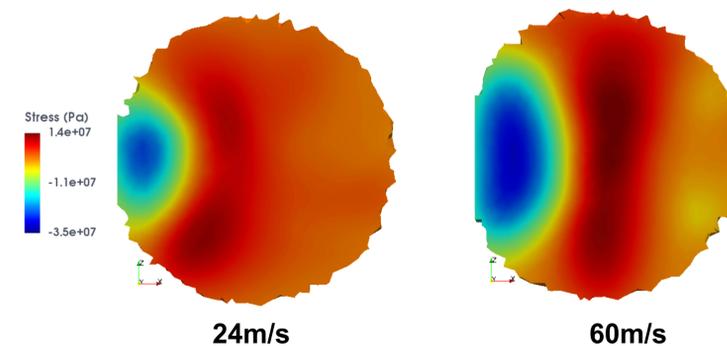


Increasing the feed rate of the pin mill from 9kg/h to 288kg/h, the model predicts a decrease of the average impact velocity by **14%**, leading to an increase of product median particle size ( $d_{50}$ ) by **19%**.

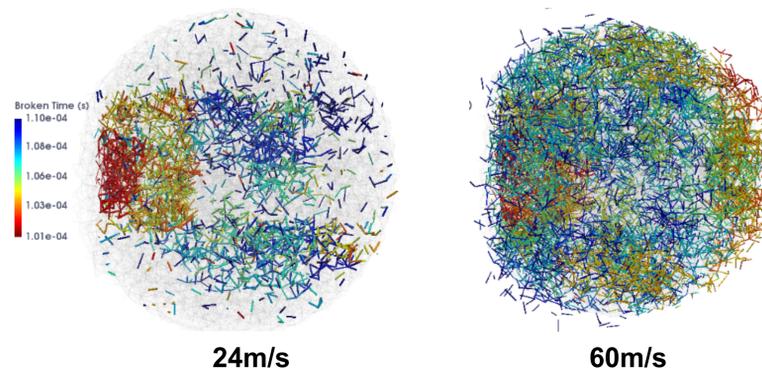
## Bonded DEM simulations of particle impact



Comparisons between simulations and the experiment of Antonyuk *et al* 2006 (23 m/s)

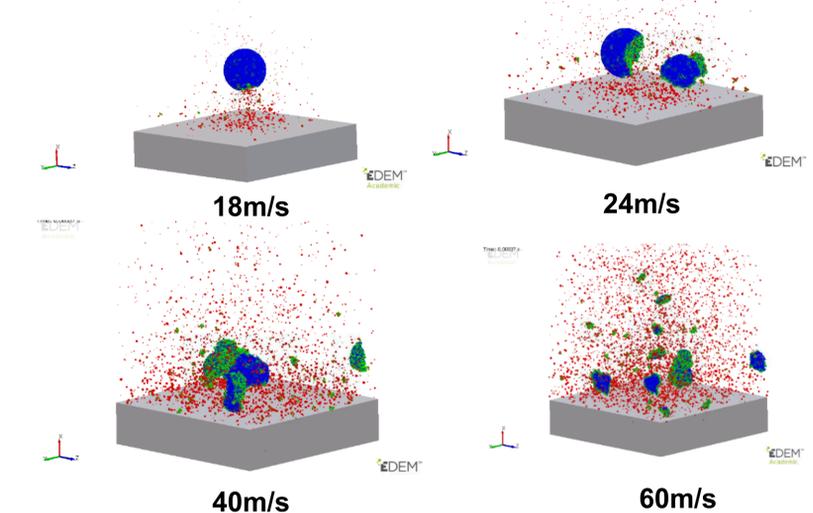


Stress distribution on a diametral slice  
Red: tension; Blue: compression



Micro-crack propagation.  
Red: early time; Blue: later time

## Bonded DEM predictions at increasing velocities



## Significance from observations

- DEM-PBM coupling predicts a 19% increase of milling median size when the feed rate increases from 9kg/h to 288kg/h
- Bond DEM simulations show good agreement with experiment observations and were used to predict the breakage pattern at high impact velocities.
- Higher impact velocity generates a stronger tensile zone leading to more drastic damages

## Next steps

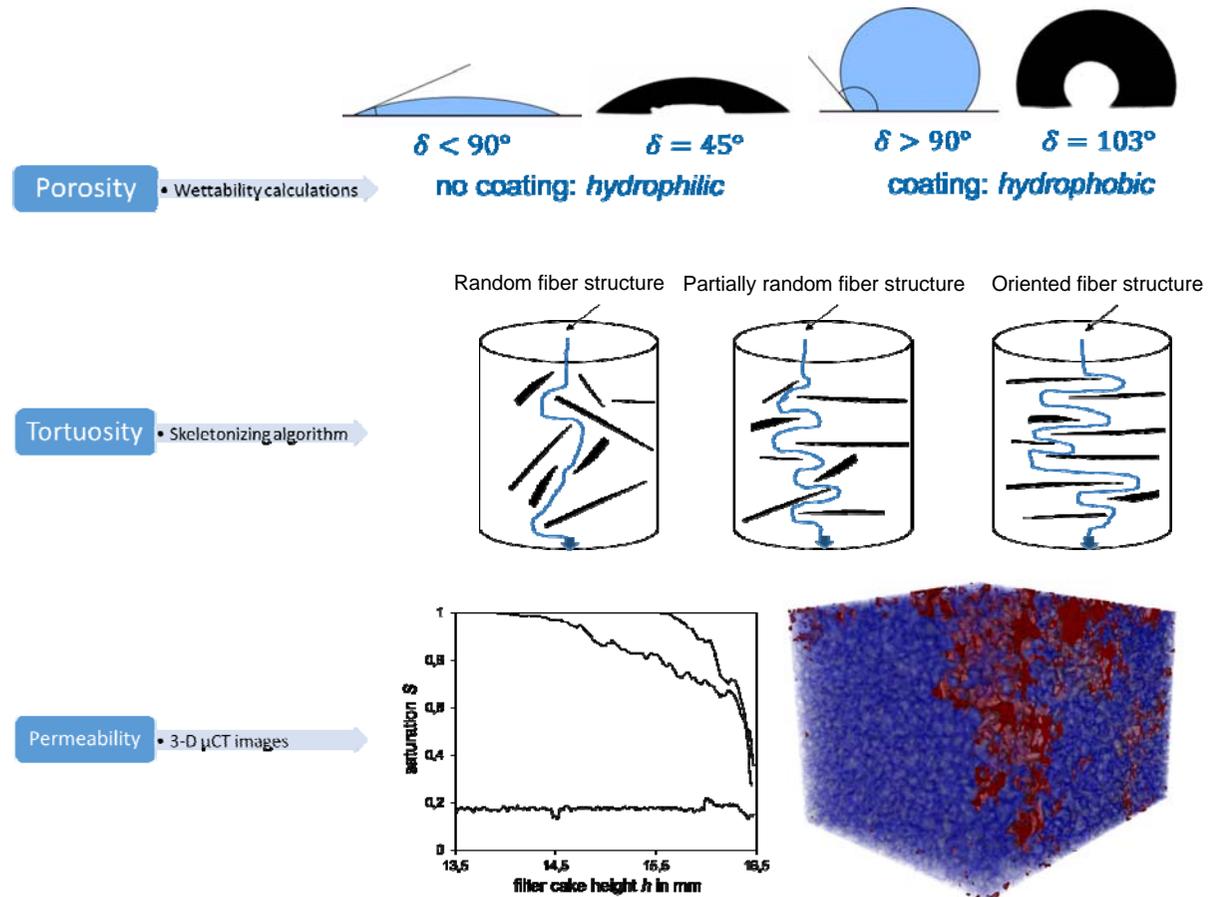
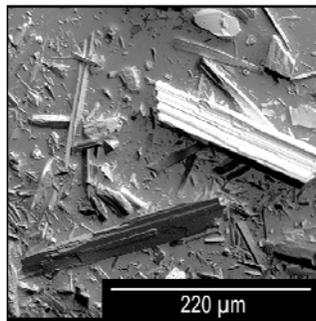
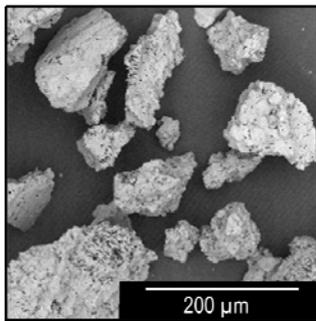
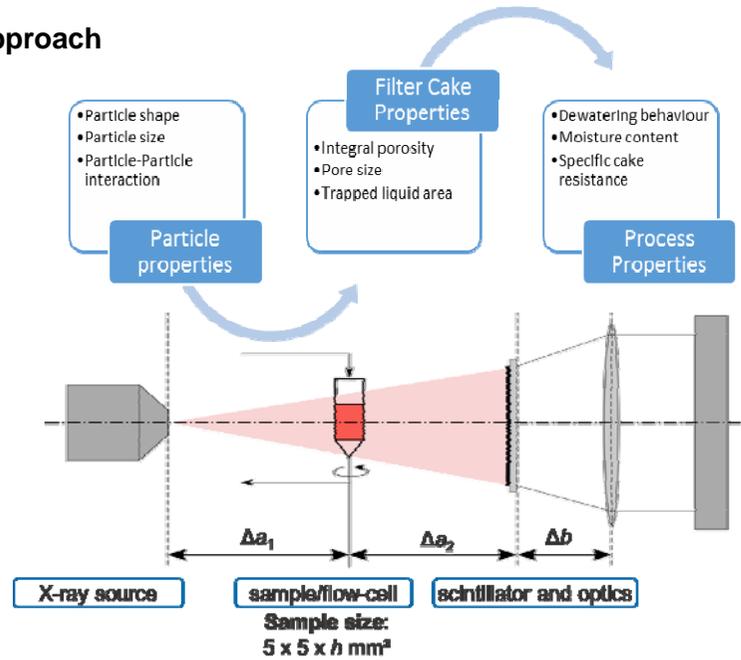
- Utilize bond DEM simulations to reveal the failure mechanisms and inform predictions at mill scale
- Refine the DEM-PBM coupling method to include more physics
- Extend the coupling strategy for other systems

# DETAILED INSIGHT INTO MICROSCOPIC FILTER CAKE PHENOMENA USING 3D-TOMOGRAPHY

Mashia Mohammadfoghi, Erik Löwer, Thomas Leißner, Urs A. Peuker  
TU Bergakademie Freiberg

Phenomenological filtration experiments has been carried out to investigate the particle-particle interaction and its effect on the cake structure and flow during the filtration process. To get a conceptual understanding of particle shape influencing the cake structure, we selected needle-like particle shape that has been used widely in industry. Needle-like particles has a broad application in daily life; from Pharma industry (metformin) to Machine industry (Wollastonite). The objective of this research is to show quantitatively the dependency of permeability, porosity and tortuosity of the filter cake from the particle properties. One of the steps is to calculate on the basis of 3D-tomography measurements the path length ratio (PLR). As the shape of the particles, the packing and the angularity are the most important parameters affecting tortuosity, we considered three particle arrangements scenarios occurring in the cake structure.

## Approach

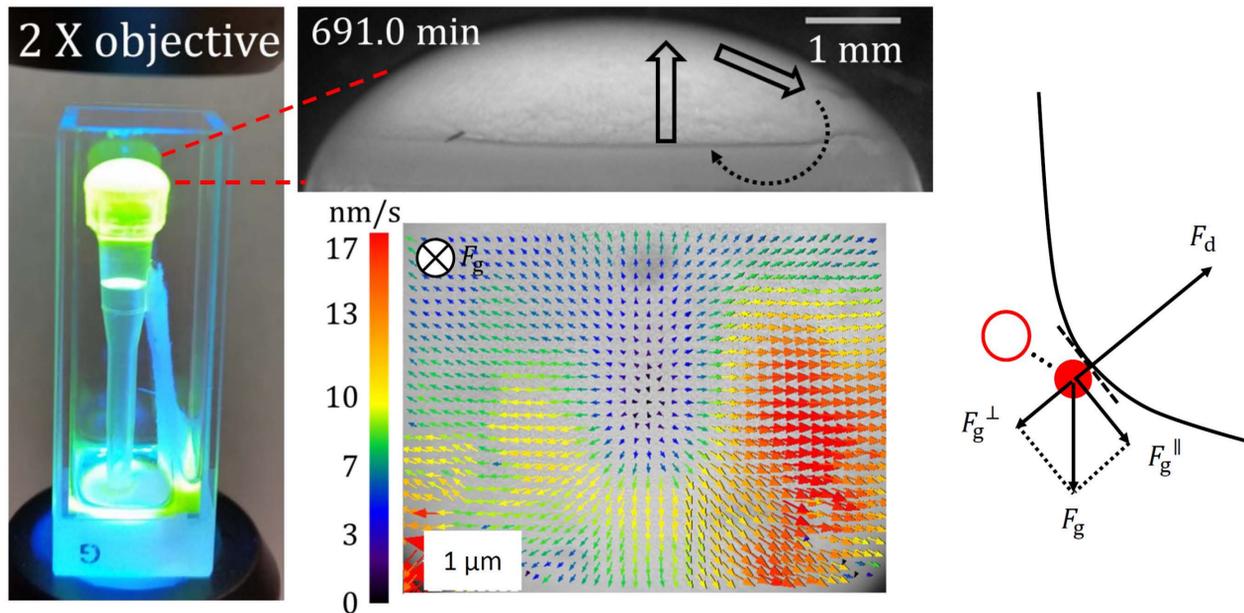


# The Stability of Colloidal Gels: Meniscus Effects, Hydrodynamics, and a Two-Component System

Xuemao Zhou, Joost de Graaf, Michiel Hermes, Yujie Jiang, John Royer, Wilson Poon  
 SUPA and School of Physics & Astronomy, The University of Edinburgh, United Kingdom

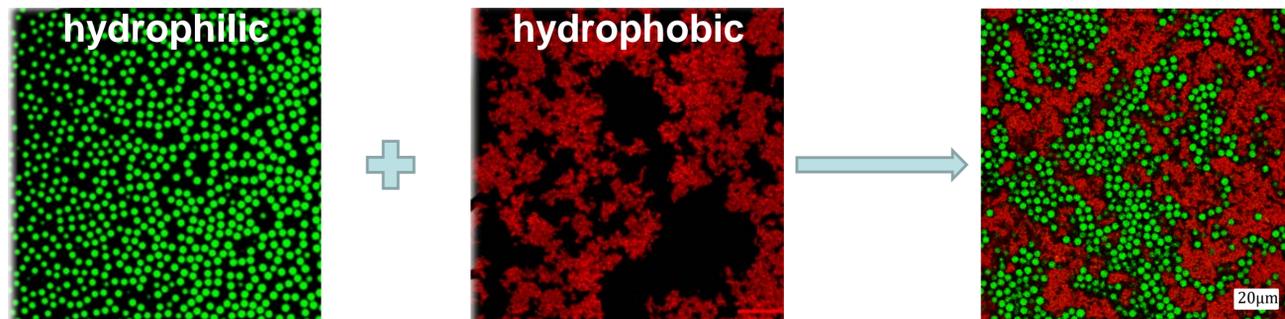
Our goal is to understand the long-term stability of colloidal gels. We previously identified a key role for the meniscus, where dense debris forms and falls to triggering rapid collapse [1]. We have now explored *how* the meniscus plays this role using a bespoke apparatus. Curvature of *either sign* at the meniscus leads to gravity-driven tangential shear, resulting in debris-triggered collapse. Our simulations of the interplay between hydrodynamics and gravity have also advanced. Eliminating the effect of debris and rising fluid droplets, we find that when there is no pre-existing system-spanning cluster ( $\phi < 0.1$ ), fluid backflow speeds up sedimentation, while for  $\phi > 0.1$ , the mechanical strength of a pre-existing percolating cluster prevents such acceleration. Finally, we have started experiments with a binary system comprising a colloidal gel of attractive small particles, whose yield stress enables larger repulsive granular particles to resist sedimentation. We find that the larger particles qualitatively change how the background gel breaks and rejuvenates under shear.

**Gel meniscus curvature of either sign generates debris and rapid collapse**



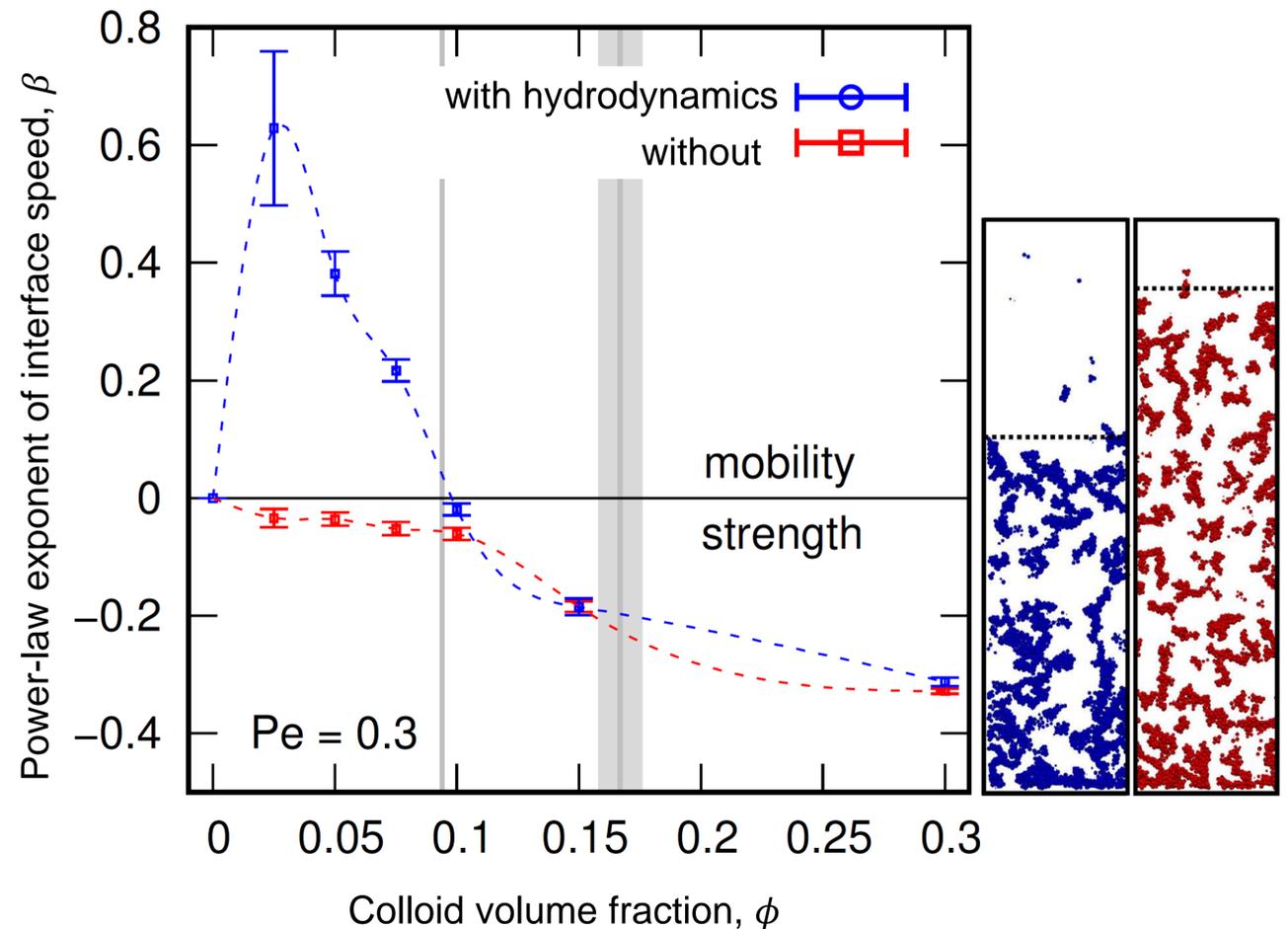
(Left) Varying the curvature of gel meniscus by controlled filling. (Mid-top) Side view. (Mid-bottom) PIV velocity map of top view. (Right) Force balance on a particle at a concave meniscus. The weight component  $\perp$  the interface is balanced by depletion attraction; but an unbalanced  $\parallel$  component remains.

**A binary model: grains (red) in a gel matrix of attractive colloids (green)**



Small ( $0.5 \mu\text{m}$  hydrophobic silica) + Large ( $4 \mu\text{m}$  charge-stabilised silica)  
 = large particles embedded in matrix of a small-particle gel

**LB simulations suggest fundamental difference between  $\phi < 0.1$  and  $\phi > 0.1$ ; a system-spanning cluster pre-exists in the latter case**



(Left) The power-law exponent of the initial interface speed  $v \propto t^\beta$  vs.  $\phi$  at  $\Delta U = 10k_B T$  showing two, accelerating ( $\beta > 0$ ) and decelerating ( $\beta < 0$ ), regimes when hydrodynamics is included. (Right) Equal-time snapshots of a slice of a sedimenting gel with and without hydrodynamic interactions.

# Self-Assembled Monolayers as Nucleating Surfaces to Study Early Formation Pathways of Crystal Polymorphs

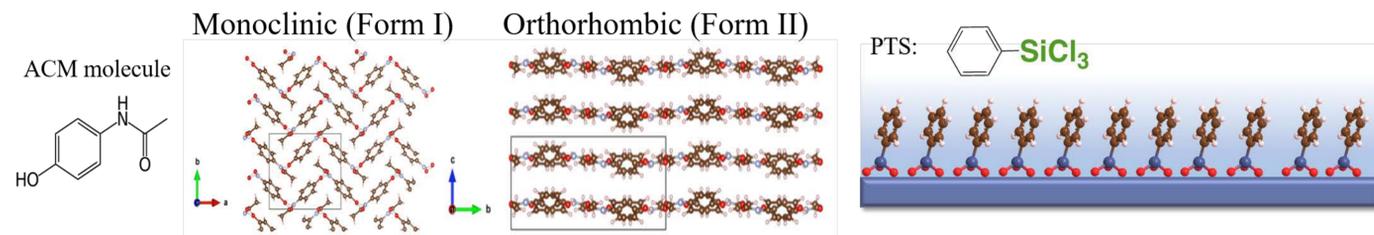
Jiazhen Xu<sup>1</sup>, Ethan M. Susca<sup>1</sup>, Detlef M. Smilgies<sup>2</sup>, Lara A. Estroff<sup>1</sup>, Ulrich B. Wiesner<sup>1</sup>

<sup>1</sup>Department of Materials Science and Engineering, <sup>2</sup>Cornell High Energy Synchrotron Source, Cornell University, Ithaca, 14853

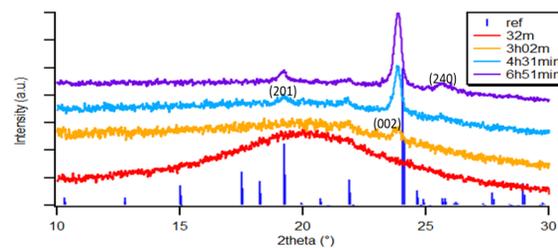
High level objectives of this project are to identify appropriate model system(s) to study, adapt and apply characterization techniques to describe early particle formation stages and to collect data that is relevant for the development of molecular dynamic simulation or other computational physics models. The understanding and control of crystallographic polymorphism and crystal habit of organic compounds is technologically important to a number of industries. In previous work, we have developed a system in which the polymorph selectivity of a paradigm pharmaceutical compound acetaminophen (ACM) is a result of the combination of self-assembled monolayer (SAM) modified substrate surface chemistries and the choice of solvent system. Our current goal is to study the early stages of acetaminophen crystal growth on SAMs with polymorph selectivity by using time-resolved *in situ* synchrotron x-ray scattering experiments.

## Investigated Drug: Acetaminophen (ACM)

### Phenyl trichloro silane (PTS) SAMs as model hydrophobic surface

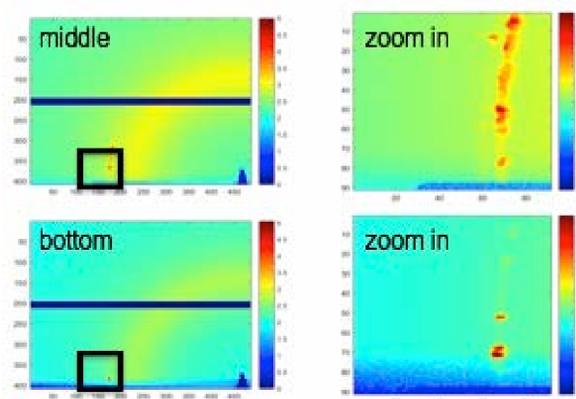
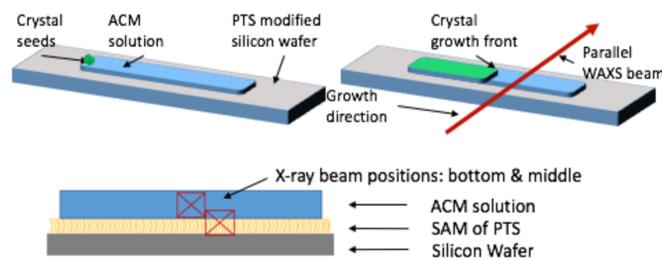


### *In situ* GADDs: Spontaneous nucleation & growth of form II:



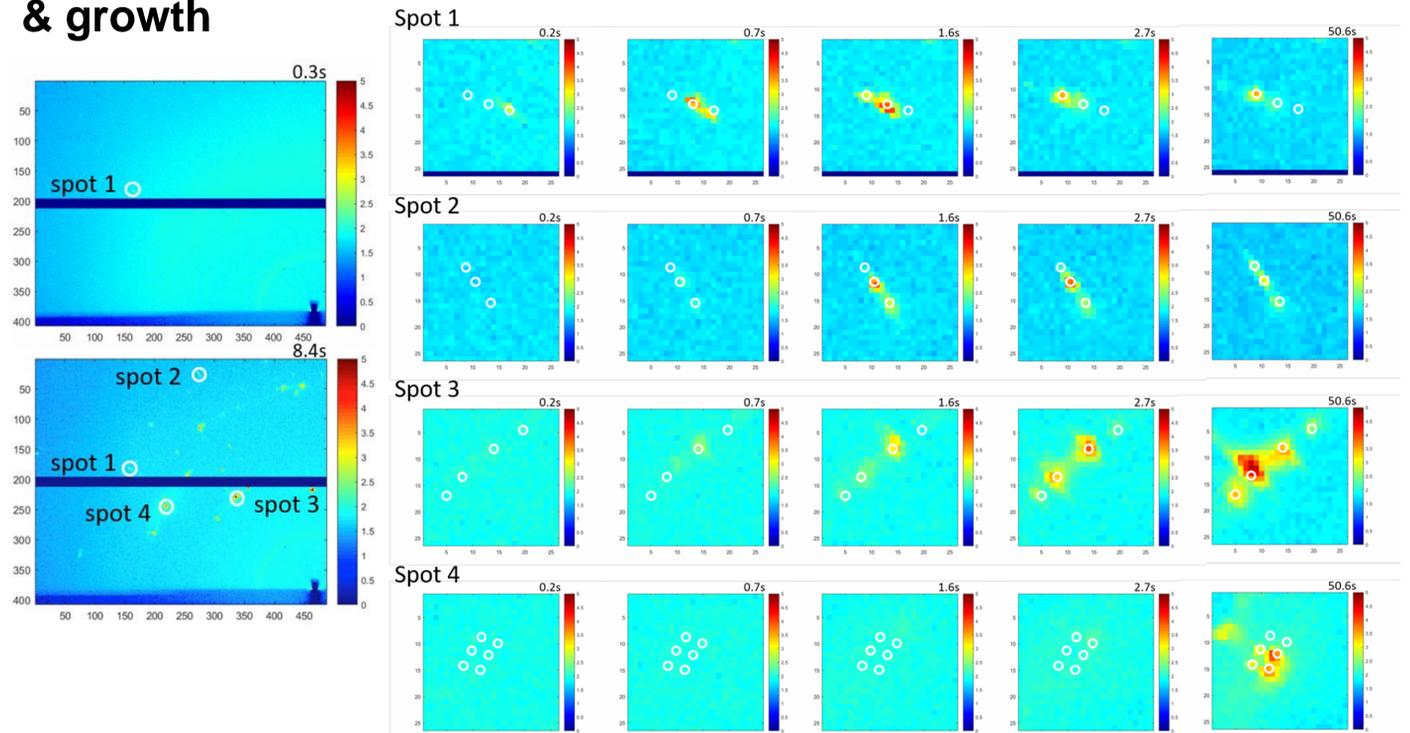
- Highly viscous solution retard crystallization for a long time before (002) reflex occurs first, followed by other peaks.

### *In situ* synchrotron WAXS: Form II from seeded nucleation:



- Wider azimuthal spread of signal suggests crystals grow up from substrate – solution interface

### *In situ* synchrotron WAXS: Form I from spontaneous nucleation & growth



- Early time evolution of first diffraction spot shows unusual shift along q direction between 3 distinct positions not seen for other spots, therefore hinting at possible early structural transformation (versus simple rotation).

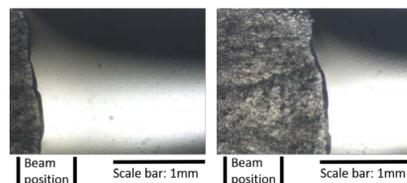
### Summary

- Time-resolved *in situ* synchrotron work provides first insights into early ACM crystal formation stages
- Results confirm nucleation at substrate-solution interface and reveal interesting early structural transformations, warranting further in-depth studies

### Future directions:

- Continuing with synchrotron based GIWAXS experiments
- Introducing blade coating as an alternative method
- Introducing other model systems: e.g. 5-methyl-2-[(2-nitrophenyl)amino]-3-thiophenecarbonitrile (ROY)

optical micrographs



# Gravity and suction die filling of cohesive powders

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The primary goal of this research project is the investigation of die filling behavior of cohesive pharmaceutical powders. The objectives include:

- ❑ To investigate gravity die filling of common pharmaceutical excipients, using linear and rotary die filling devices.
- ❑ To explore suction die filling of common pharmaceutical excipients, using linear die filling device.
- ❑ To compare die filling mechanisms in suction and gravity filling and examine potential correlations between powder properties and the die filling efficiency.

- ❑ Two die filling systems were used to assess powder die filling mechanism and efficiency: a linear device and a rotary system (Fig 1 and 2). It was demonstrated that the die filling efficiency is higher with the rotary system (Fig. 3).
- ❑ A series of powder characterisation techniques were carried out, including particle size distribution, morphology, flow index, air permeability, shear cell analysis. The results were compared with the powder performance in die filling tests on the rotary device (Fig. 4)
- ❑ The linear die filling system was equipped with a suction filling mechanism. Suction filling was investigated for several powders and the results were compared to the gravity filling (Fig.5).



Fig. 1. Rotary die filling system, top view

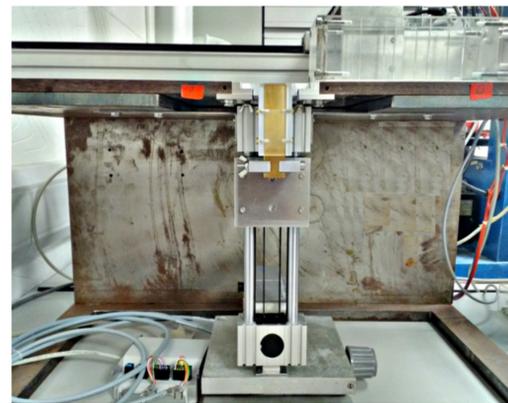


Fig. 2. Linear die filling system

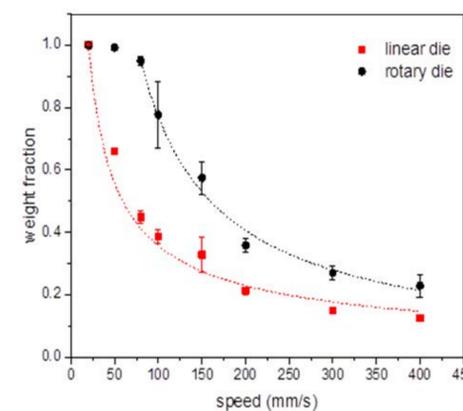


Fig. 3: Comparison of die filling efficiency of mannitol in linear (red line) and rotary (black line) systems.

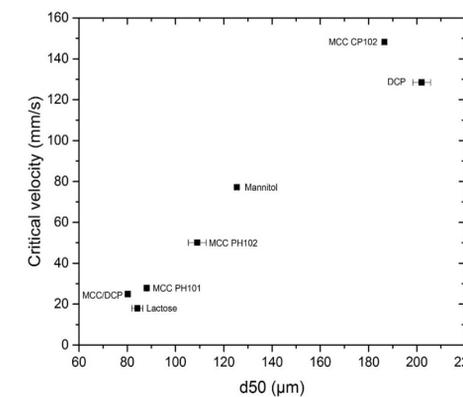


Fig. 4: Correlation between the particle size (d50) and die filling efficiency (fill ratio) for different powders.

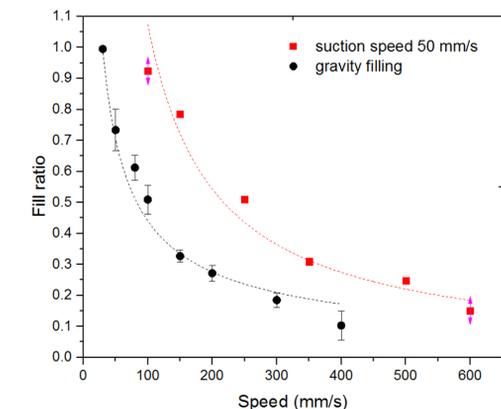


Fig. 5: Comparison of die filling efficiency of MCC PH102 on a linear die filling system: gravity fill (black line) and suction fill (red line)