



International Fine Particle Research Institute



3D Printing of Perfect Particles

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IFPRI AGM, May 2020

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IFPRI Project overview Years 1-6

Brief: Design controlled agglomerates with tuneable properties that can be systematically varied to validate models of granule breakage, flow or dissolution

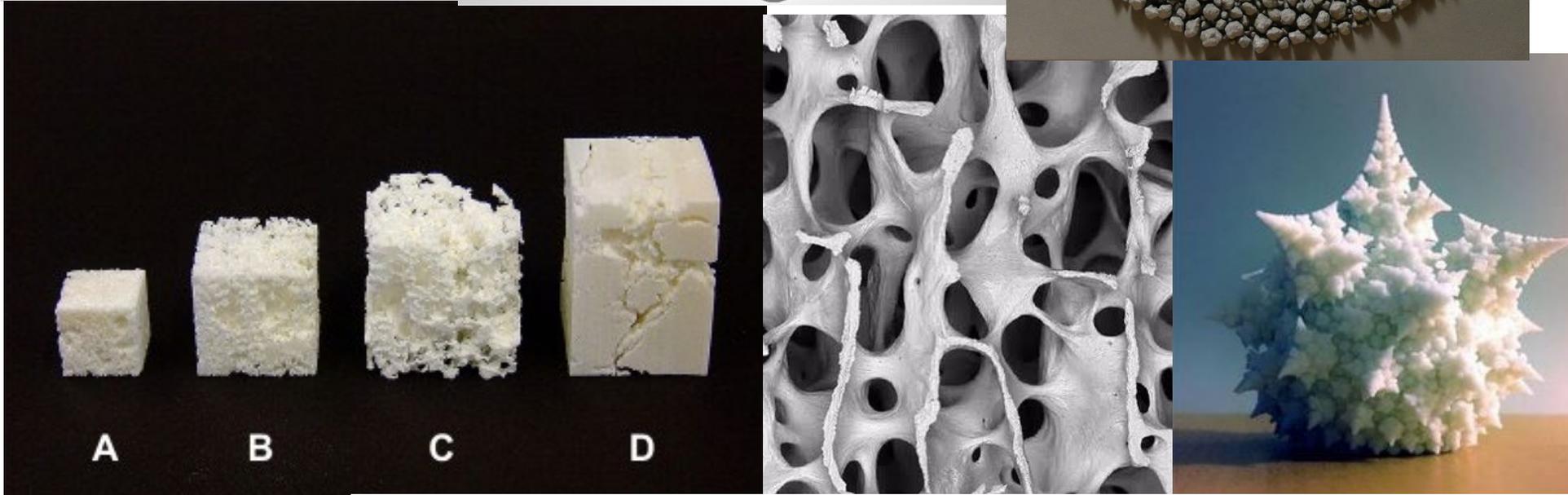
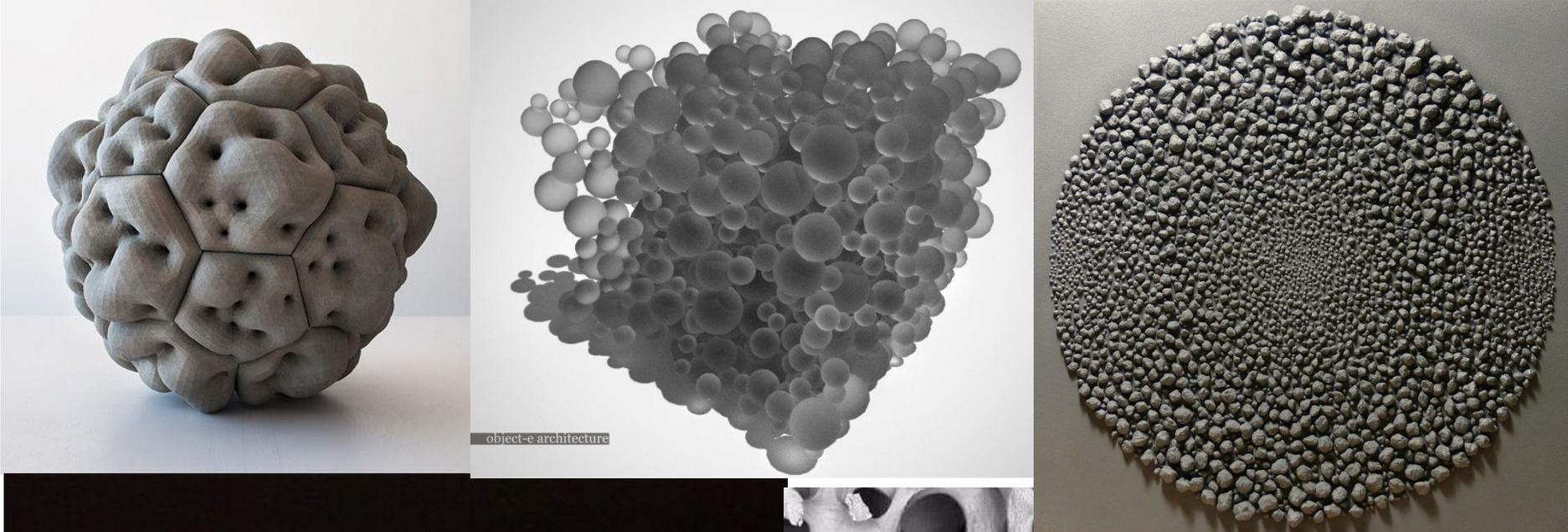
Years 1-3: 3D Printing Tunable Particles

- 3D Printing approach: CAD design and 3D printed agglomerates in a Stratasys polyjet printer, prints multiple materials simultaneously.
- **Printed multiple identical copies of agglomerates, varying geometries and bridge strength**
- **Focus on breakage:** compared quasi-static deformation and breakage of agglomerate under compression
- **Compared to DEM** simulations of an identically structured agglomerate

Years 4-6: 3D Printing Perfect Particles

- 3D Printing Approach: Making the most of disruptive technology in particle technology applications
- Goal: **A suite of designer particles**, agglomerates and substrates, including “tunable” properties,
- Use these “perfect particles” to validate and advance more realistic models of
 - Powder flow and segregation,
 - Agglomerate breakage
 - Wetting and dissolution.

3D print any* agglomerate



** Need to design and remove the support material*

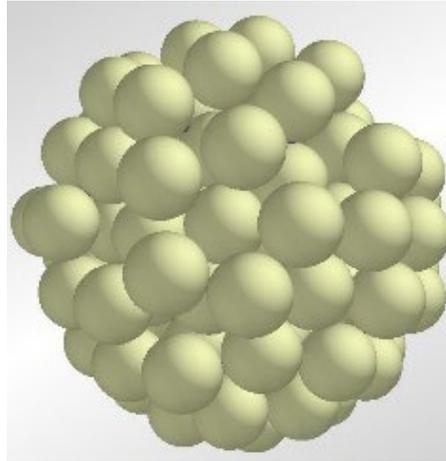
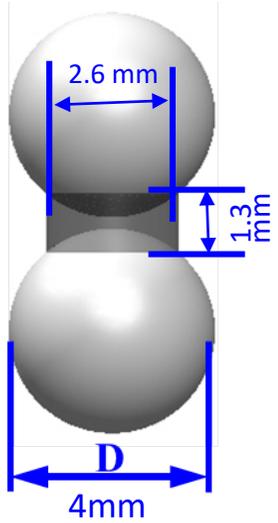
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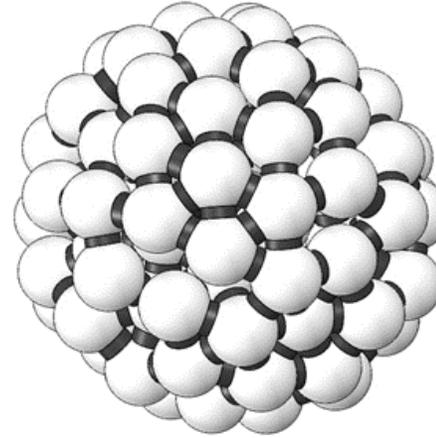
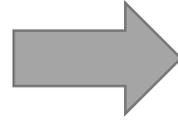
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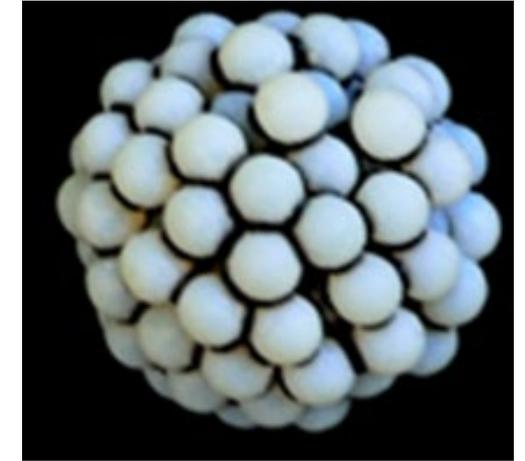
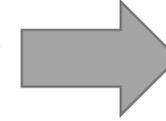
Agglomerate design and printing



Create agglomerate structures in EDEM



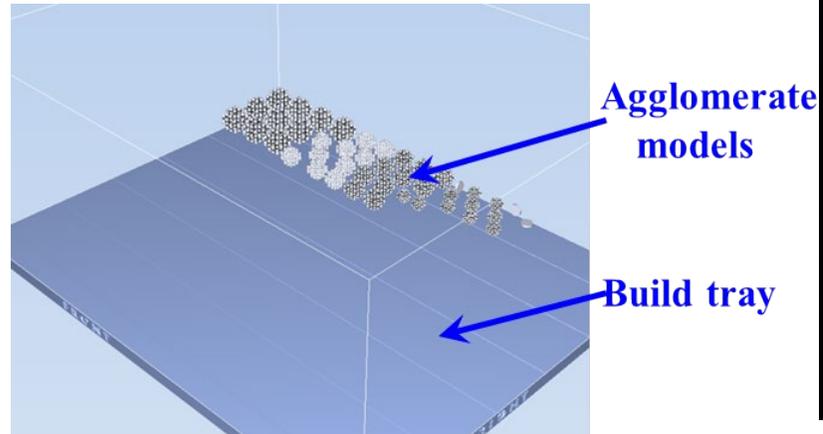
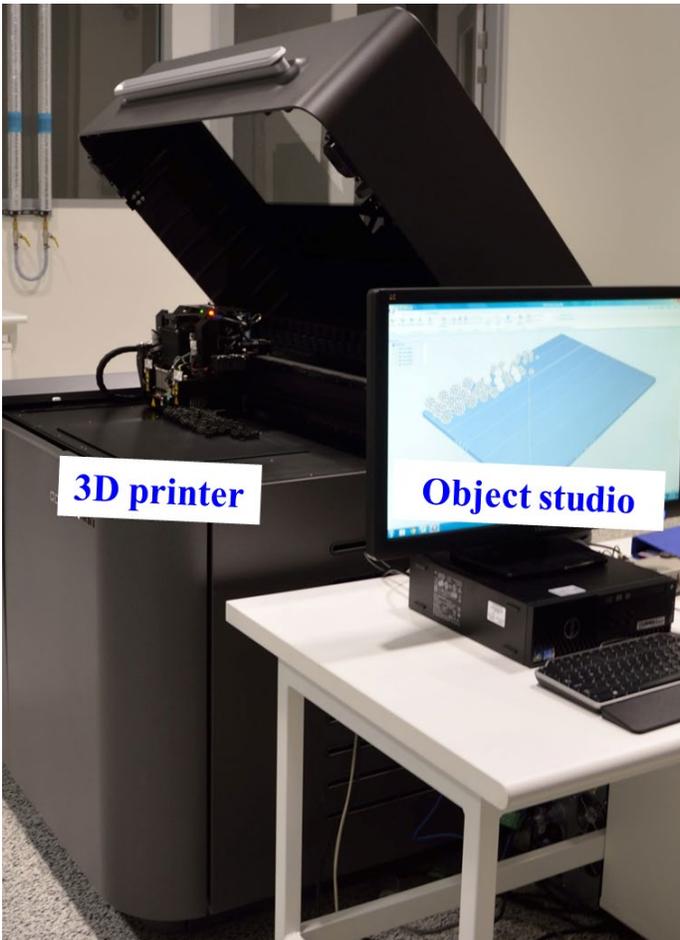
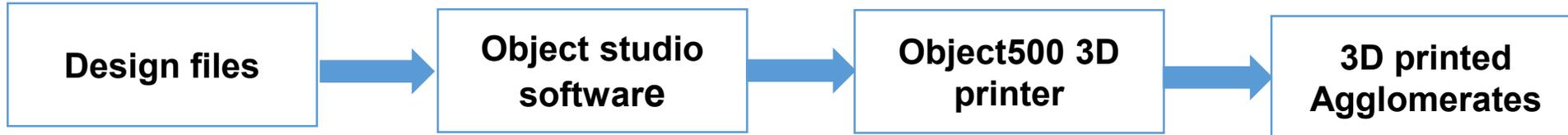
Replicate agglomerates In Solidworks



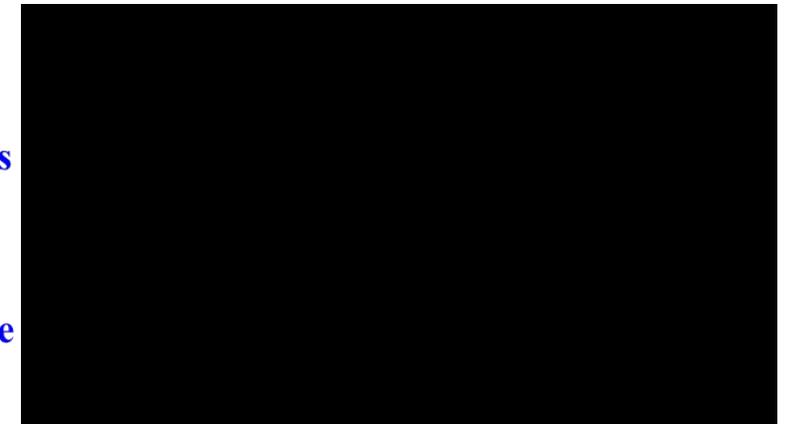
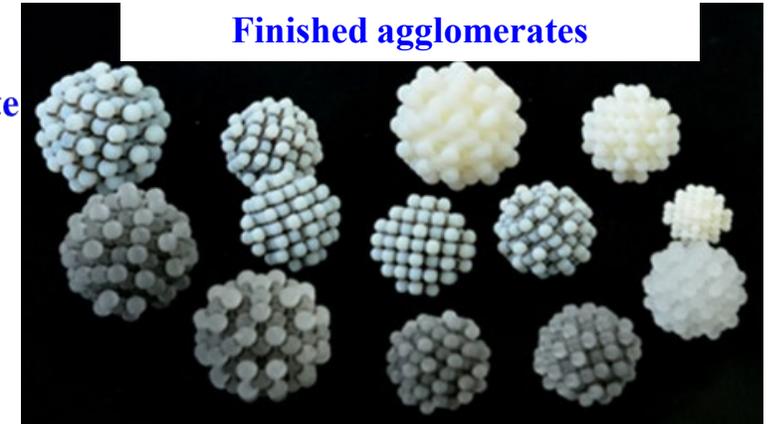
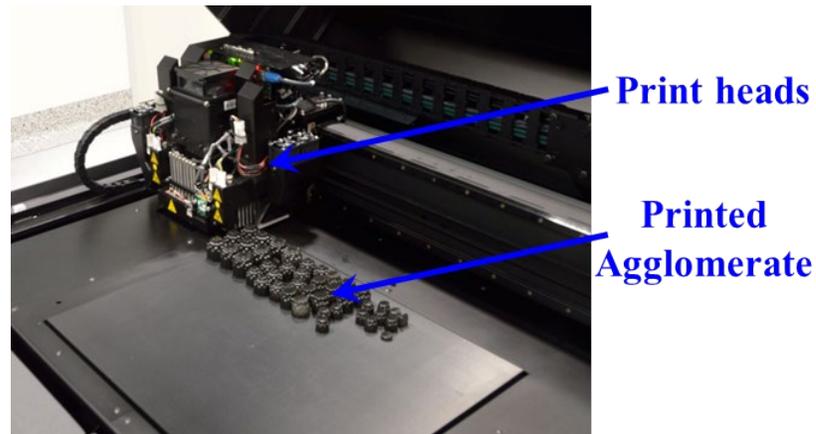
3D printed agglomerates

- Define materials to be used for each particle and bond (rigid or ductile)
- Systematically vary bond strength, geometry, particle size, bond size etc
- Conduct multiple replicate breakage tests
- Print layer orientation can affect results for weaker interparticle bonds

Agglomerate Printing



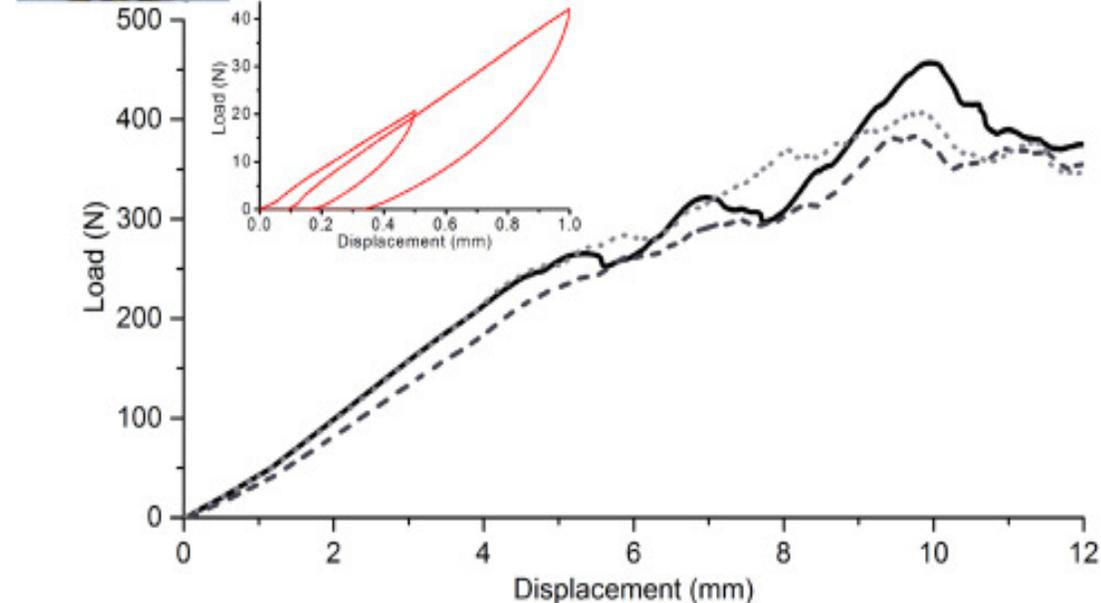
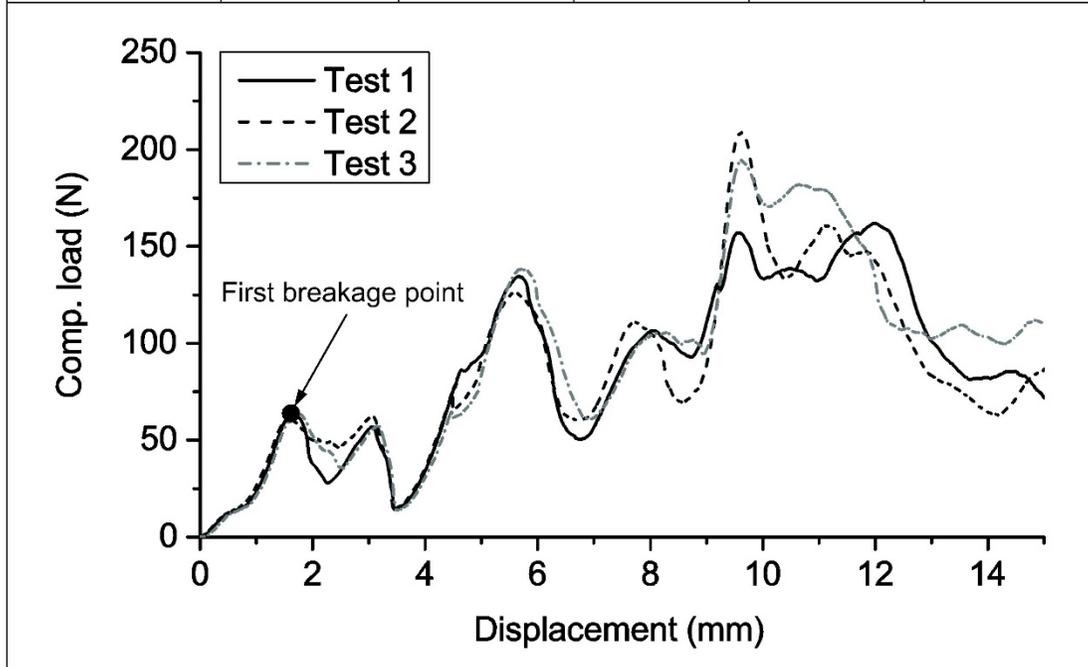
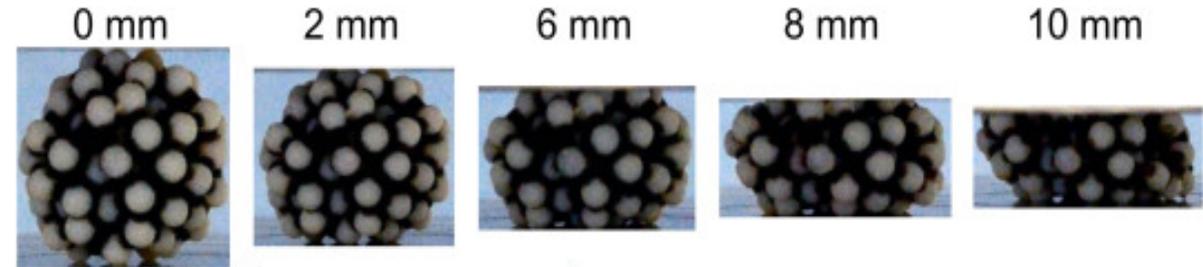
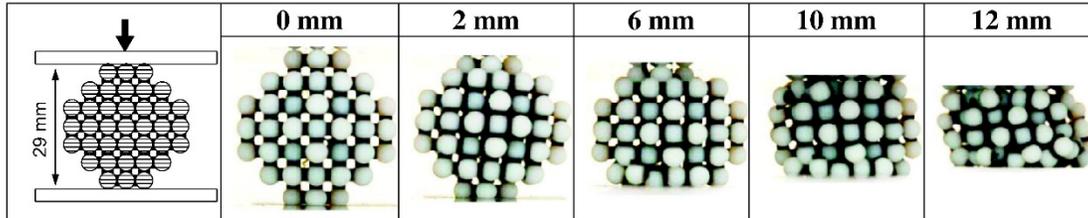
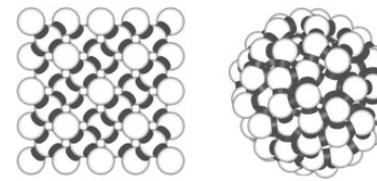
(a) Object studio software



How a Objet500 part is made (YouTube)

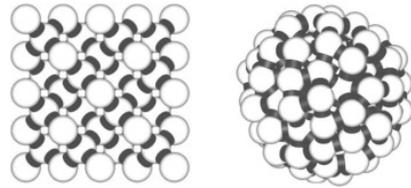
<https://www.youtube.com/watch?v=Apzlk8RJiqs>

Deformation & Breakage

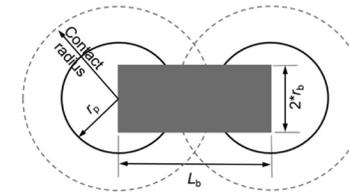


Highly reproducible experimental data for replicates of the same design

Deformation & Breakage

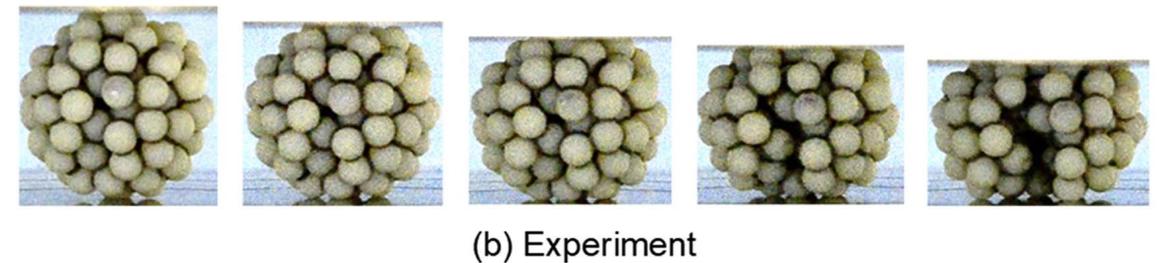
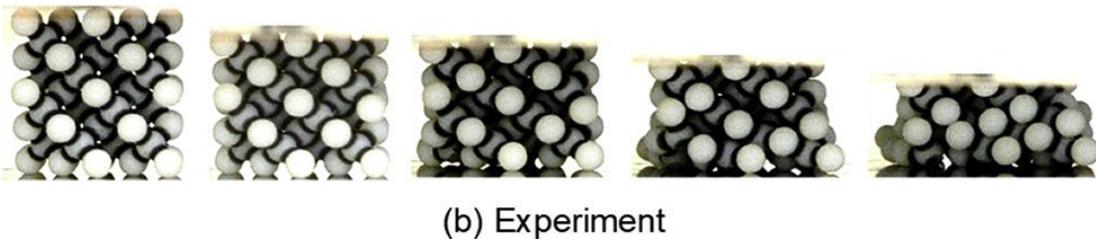
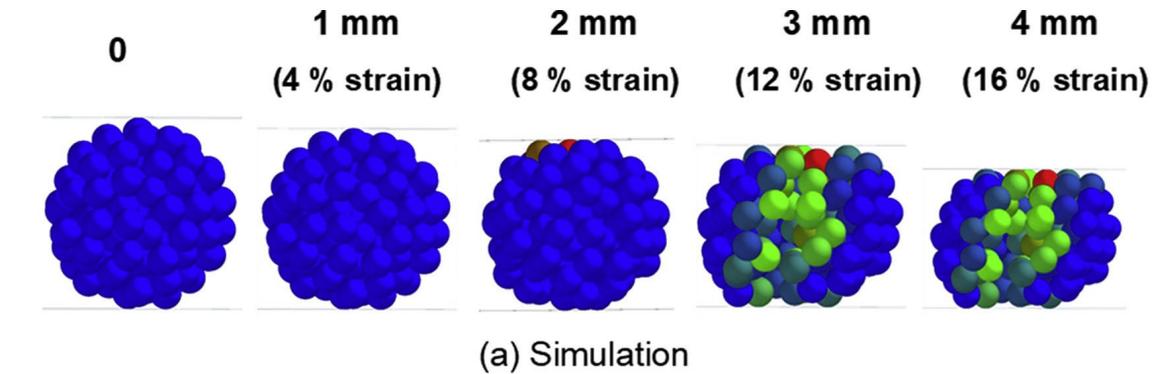
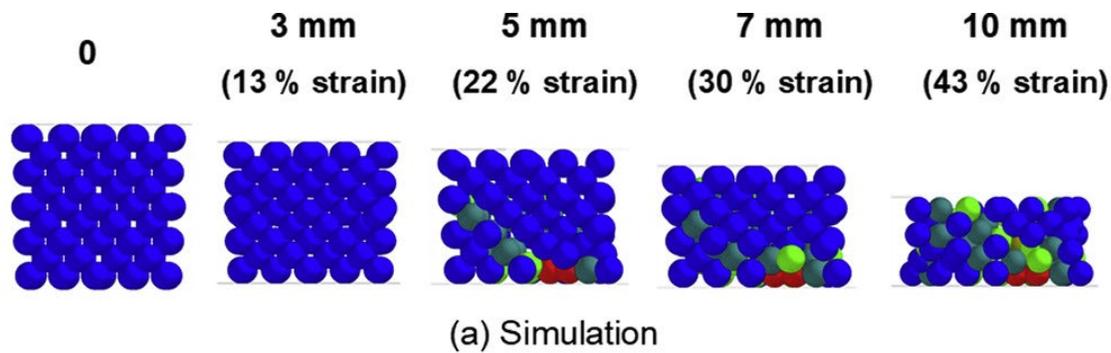


EDEM
TBBM contact model:



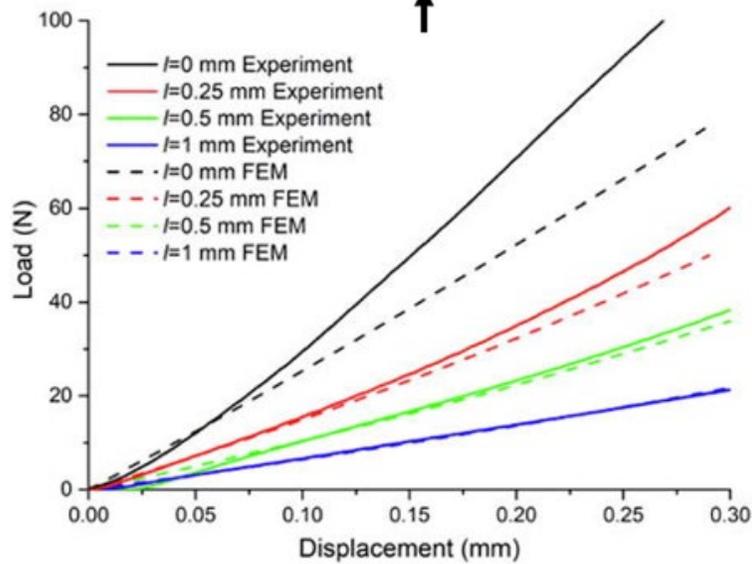
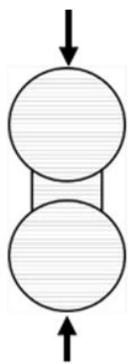
Symmetrical Agglomerate

Random Structure Agglomerate

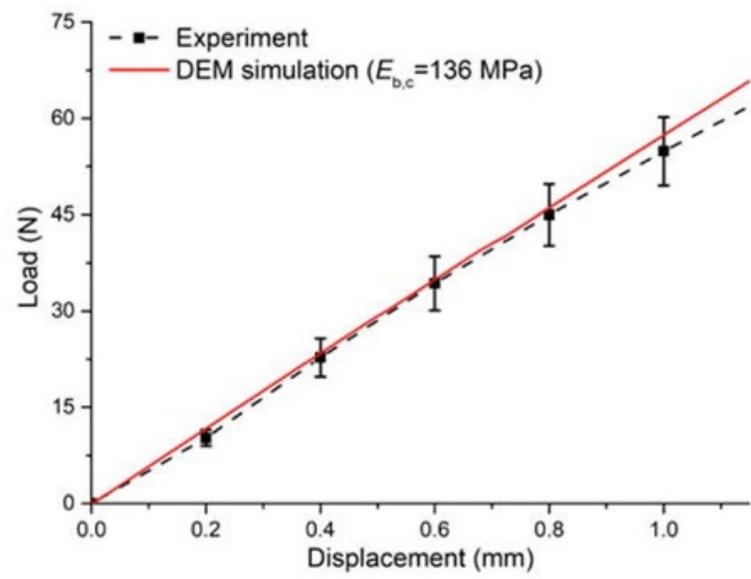
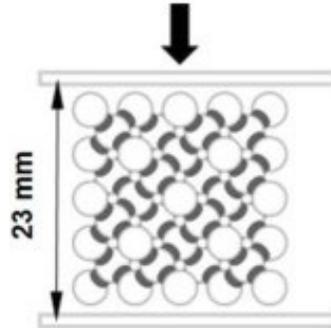


Ge et al (2019). DEM analysis of compression breakage of 3D printed agglomerates with different structures. *Powder Technology*, 356, 1045-1058. doi: <https://doi.org/10.1016/j.powtec.2019.08.113>
 Ge et al. (2020). Deformation of 3D printed agglomerates: Multiscale experimental tests and DEM simulation. *Chemical Engineering Science*, 217, 115526. doi: <https://doi.org/10.1016/j.ces.2020.115526>

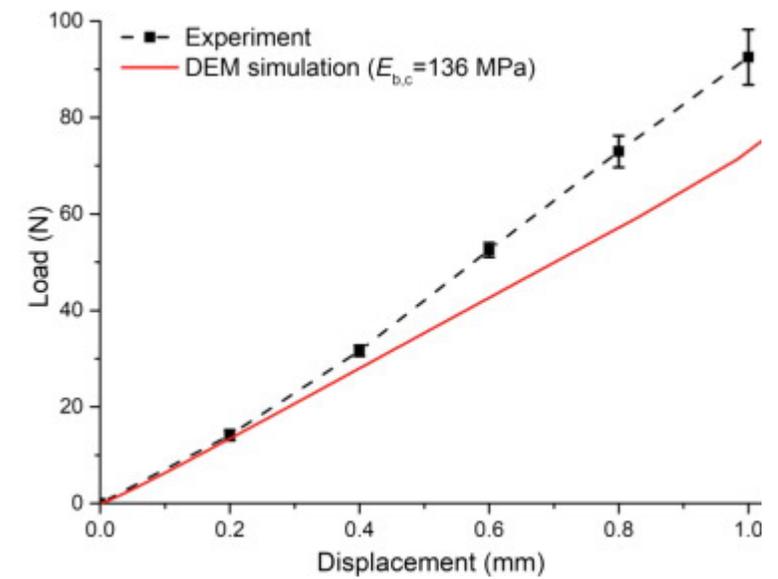
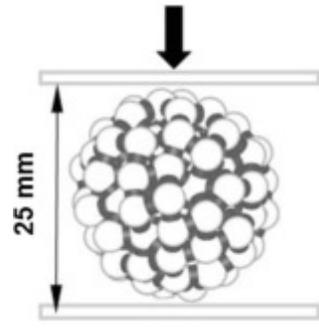
Deformation & Breakage



➤ Doublet scale



➤ Symmetrical Agglomerate



➤ Random structure Agglomerate

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 - Powder flow and segregation,

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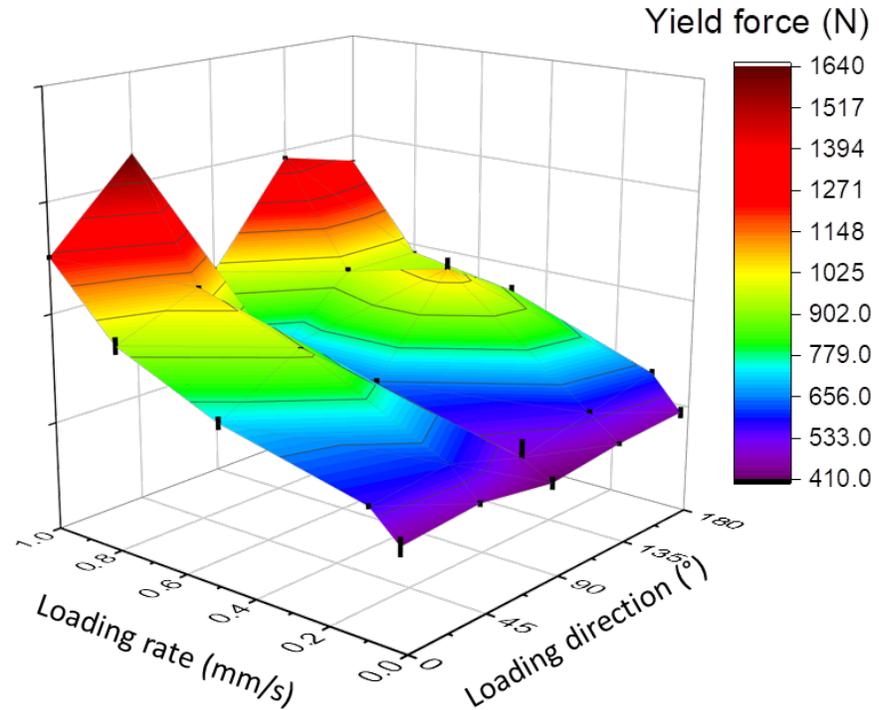
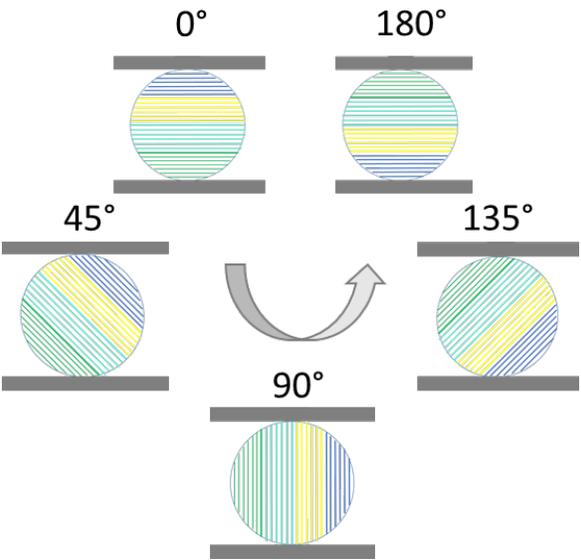
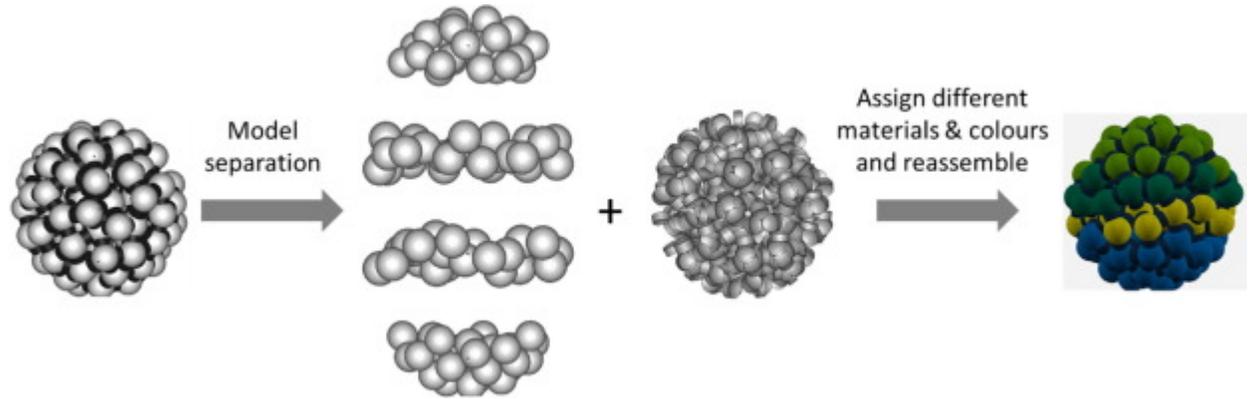
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Years 4-6: 3D Printing Perfect Particles

- Agglomerate Breakage
 1. Agglomerate strength extensions
 2. Tracking of deformation and breakage
 3. Photoelastic stress visualisation
- Agglomerate Dissolution
 4. Liquid imbibition into porous substrates
- Flow & segregation of irregular particles
 5. Flow of irregular particles
 6. Density Segregation
 7. DEM Boundary experiments



1a. Multi-coloured agglomerates

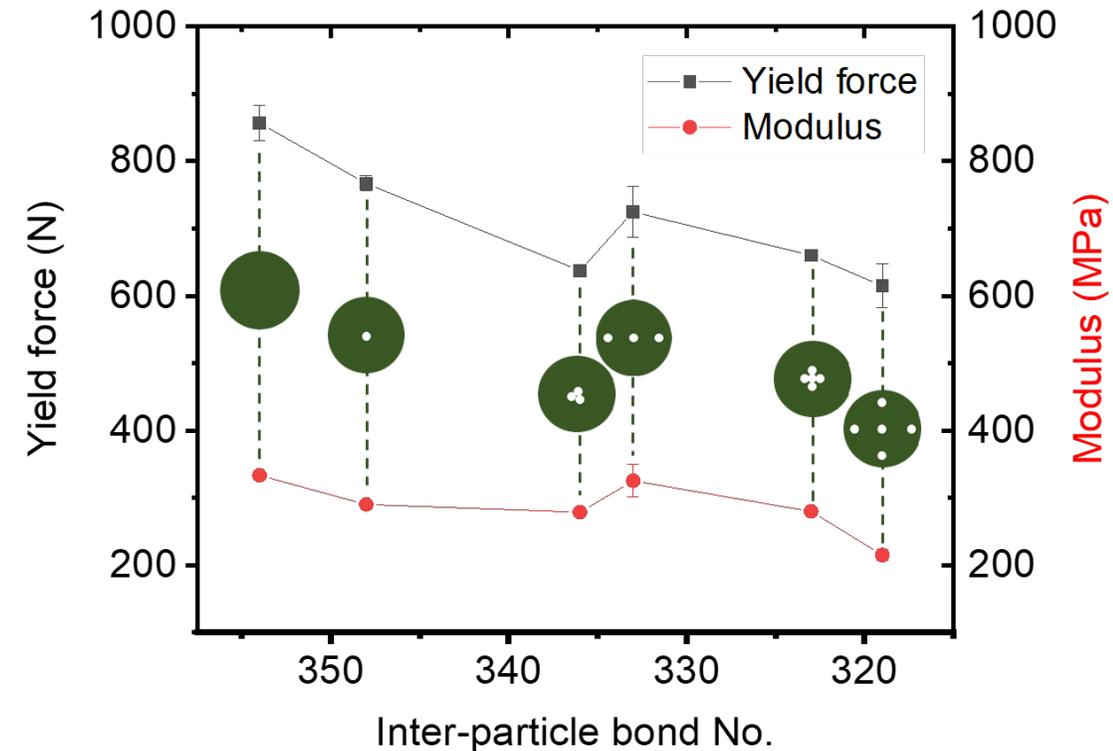
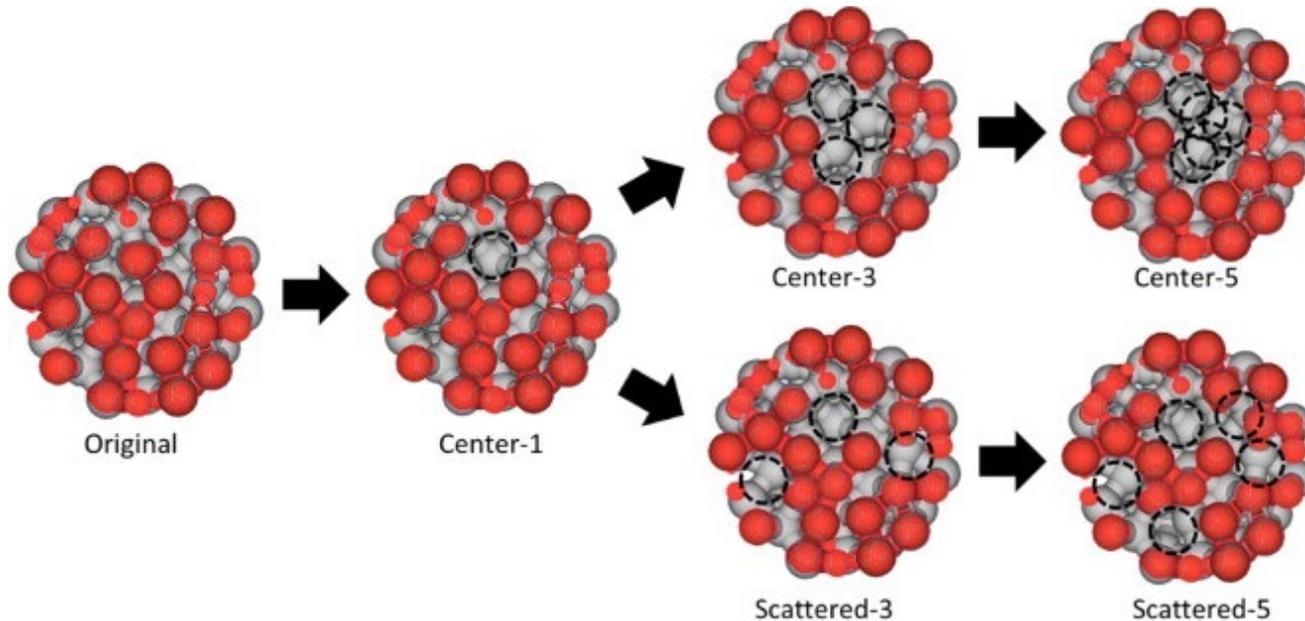


- Compress a single agglomerate at orientations
- Randomly structured bonds
- Loading rate varied
- **Shows a single agglomerate has a range of strengths, depending on orientation.**

Zhang, J., Amini, N., Morton, D. A. V., & Hapgood, K. P. (2020). 3D printing of tuneable agglomerates: Strain distribution and effect of internal flaws. *Advanced Powder Technology*. (in press) doi: <https://doi.org/10.1016/j.apr.2020.04.037>

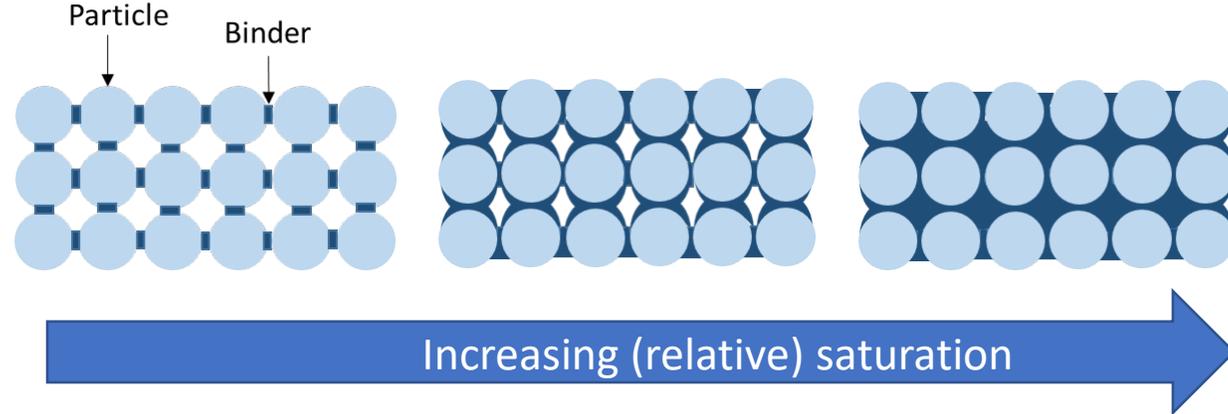
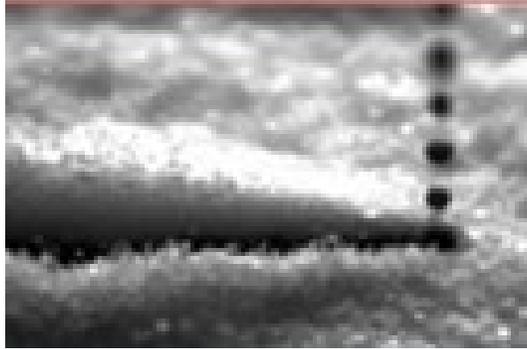
1b. Agglomerates with internal flaws

- Inspired by famous paper by Subero & Ghadiri (2000)
- Agglomerates with internal voids
- Removed particle and bridges from midsection of agglomerate
- Removed 1, 3 or 5 particles, various spatial arrangements

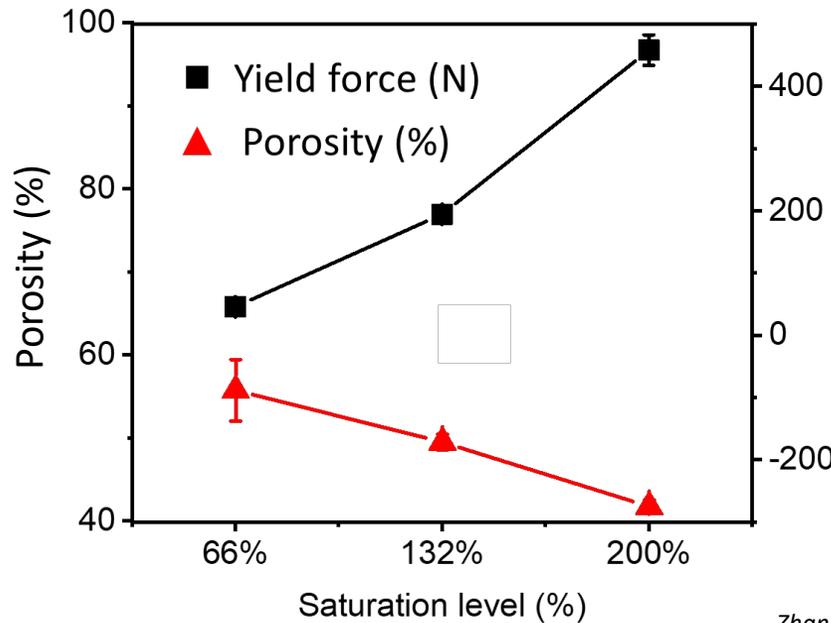


1c. Breakage of Binder jetted agglomerates

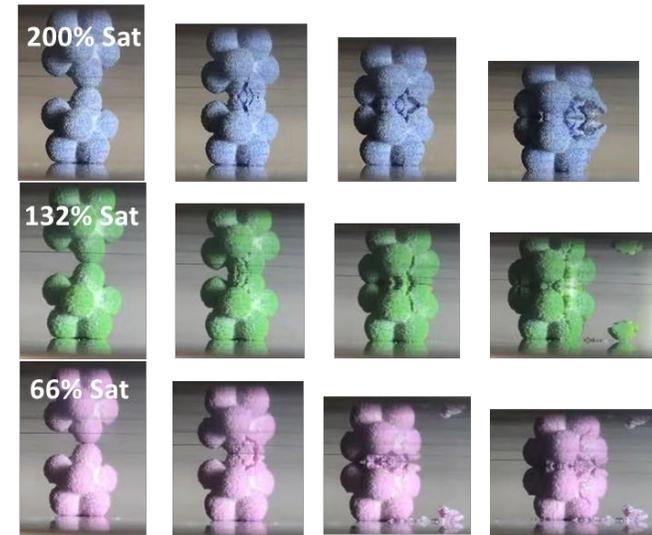
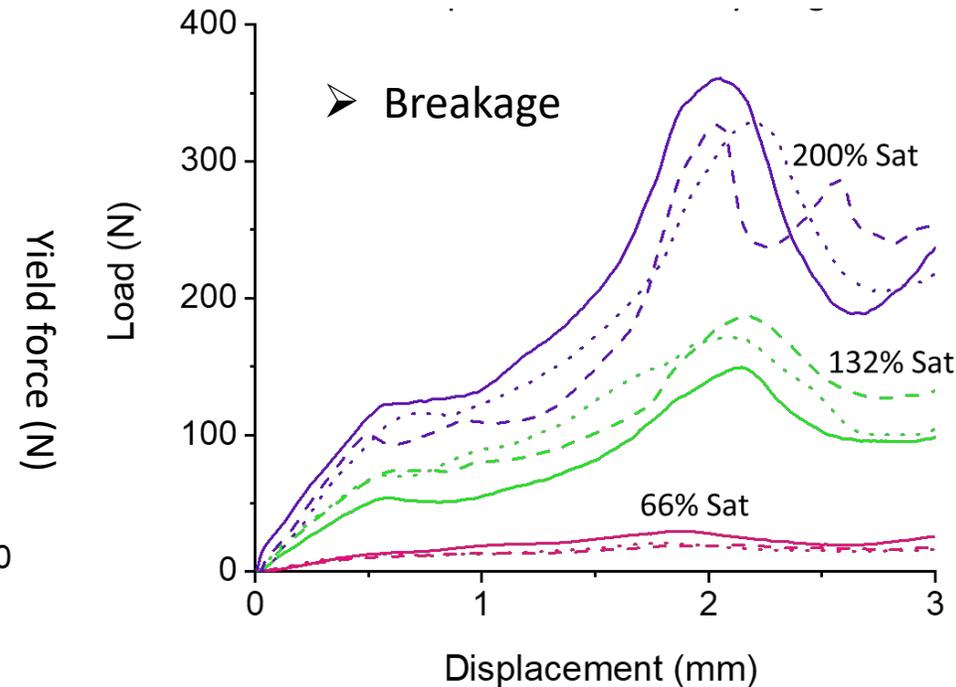
Binder jet printing



➤ Structure-Property relationship



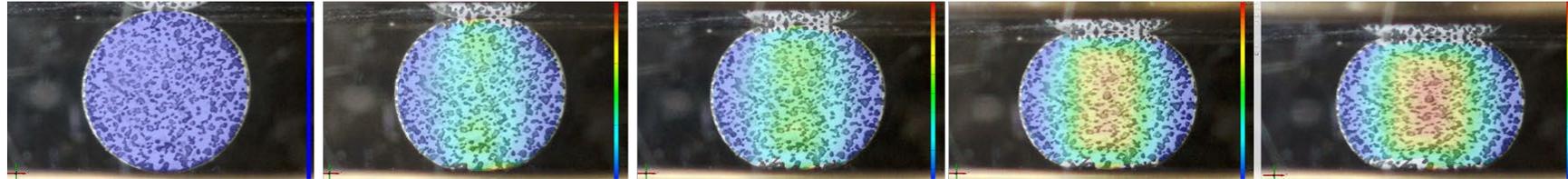
➤ Breakage



2. Tracking of deformation and breakage

- Analyse (in-situ) of the experimental deformation using GOM Correlate software
- Speckle pattern stamped onto surface of 3D printed disc in agilus material

DIC Strain Distribution



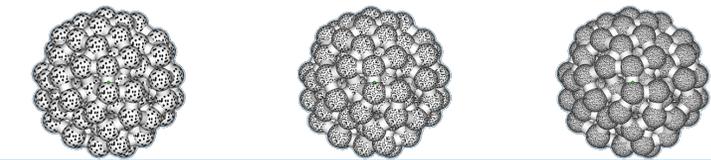
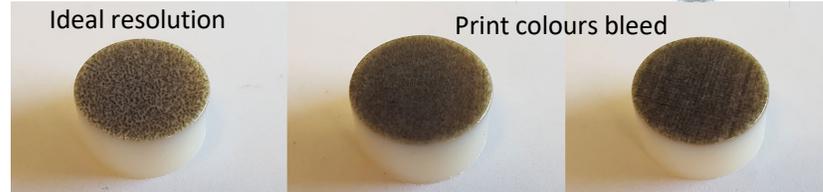
- Mapped 2D speckle images onto the surface of each individual particle (various speckle resolutions)
- 3DPrint showed bleeding of pattern, experiments awaiting access to labs



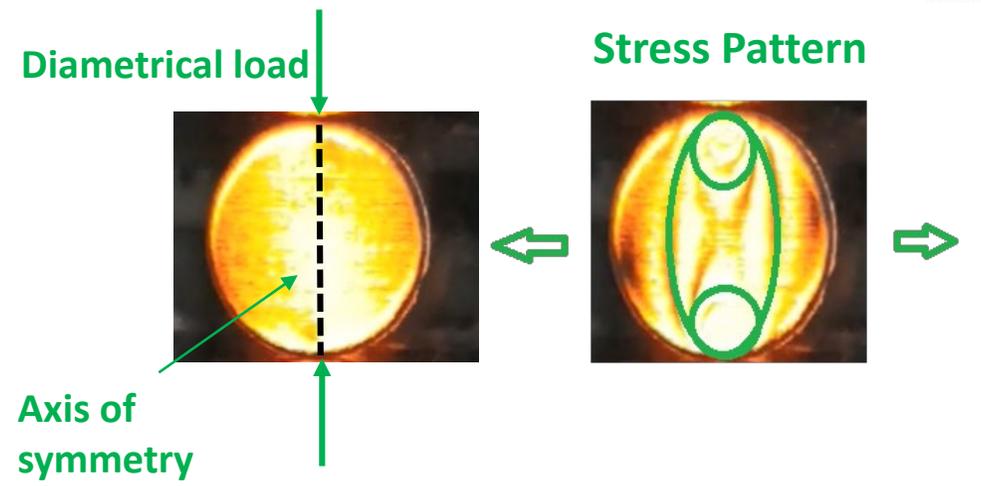
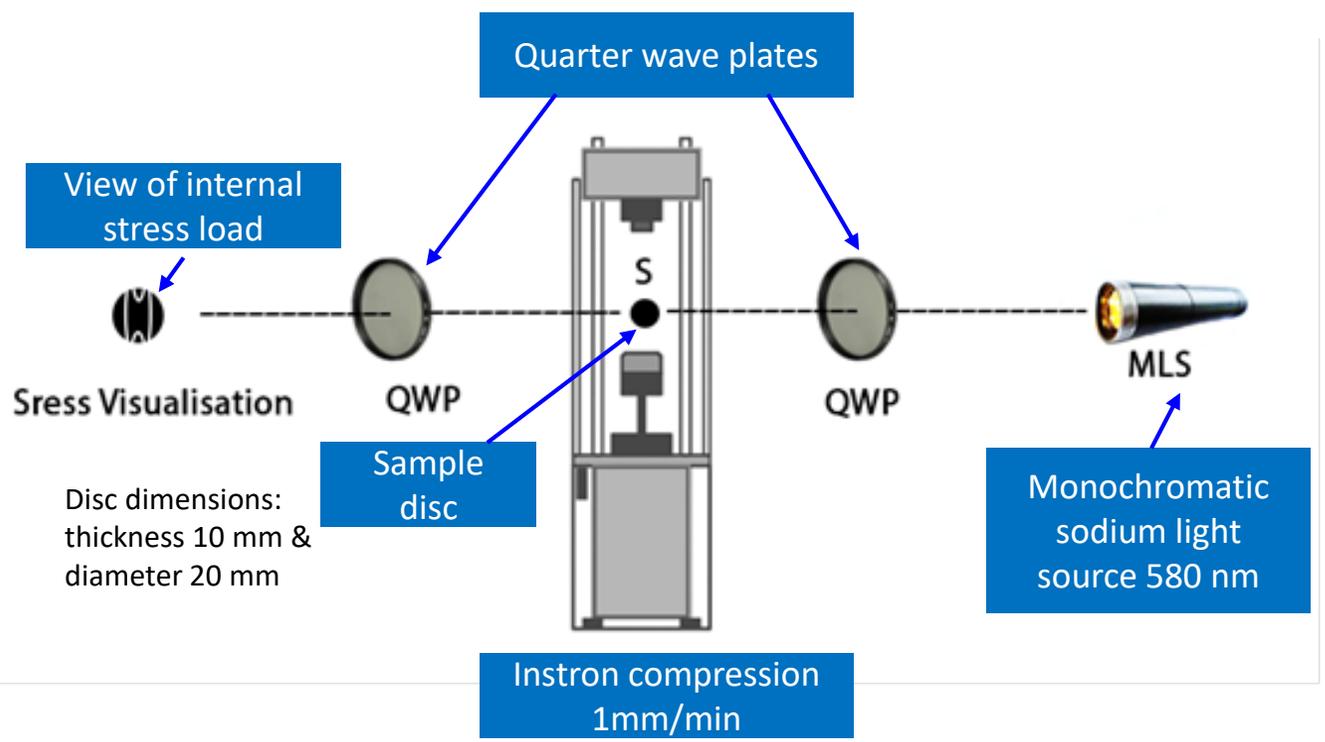
CAD



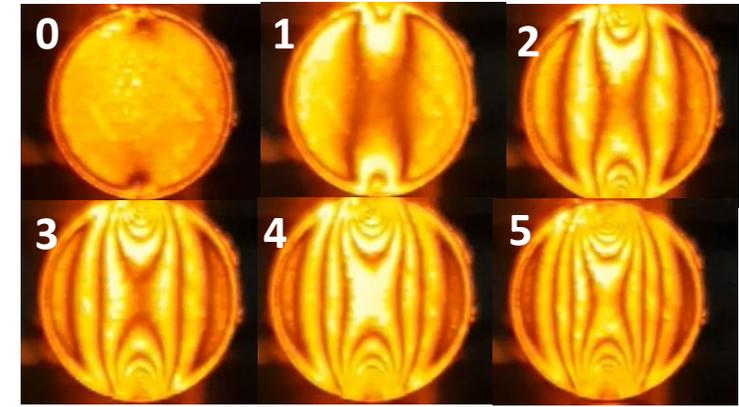
3D Print



3. Photoelastic stress visualisation



Incremental stress fringes during compression



Disc dimensions: thickness 10 mm & diameter 20 mm

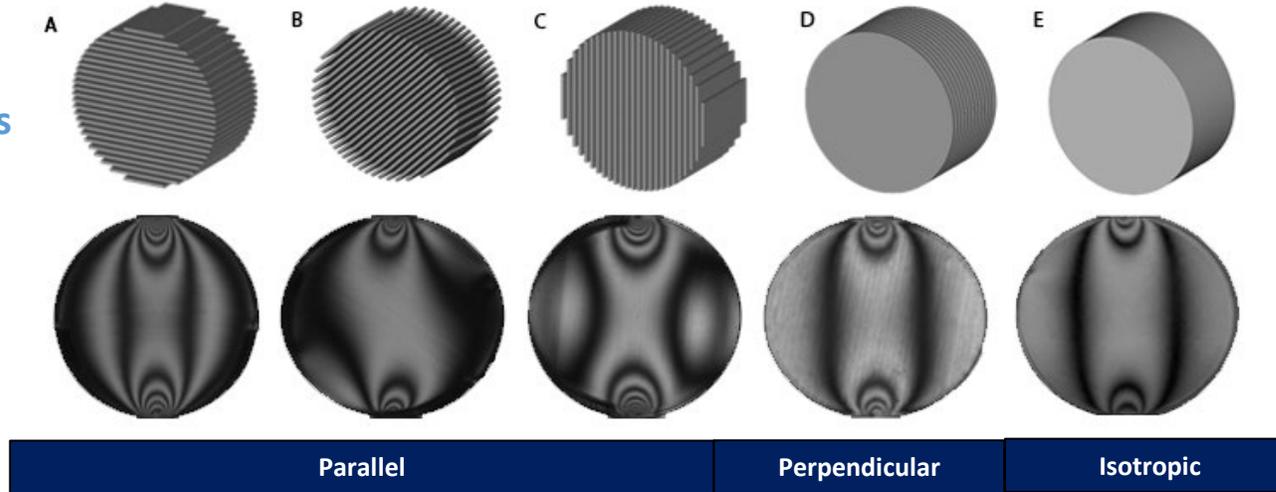
- Compression of a simple disc at 1 mm/min
- Successfully observed stress visualisation
- No lines from 3D printing visible
- No residual stress from polyjet print method

3. Photoelastic stress visualisation

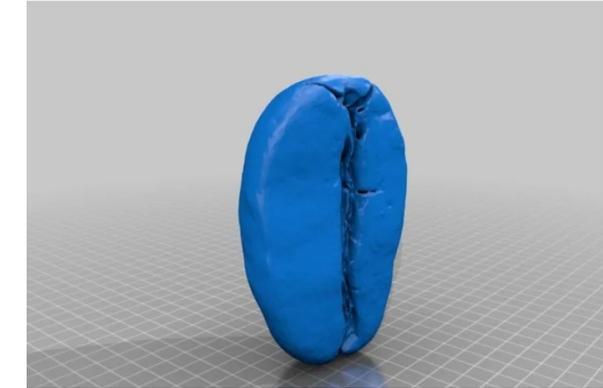
- 2D discs: Difference in stress observed but not macroscopic mechanical properties

Layer orientations

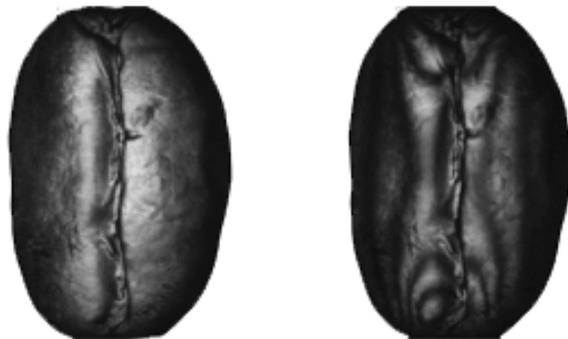
Experiment:
1st fringe



Coffee bean
by 3Dpowdersgroup June 11, 2019



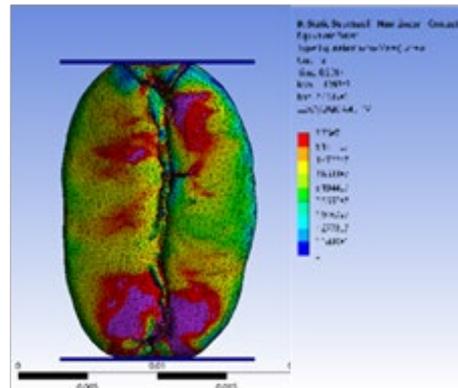
Experimental 3D stress



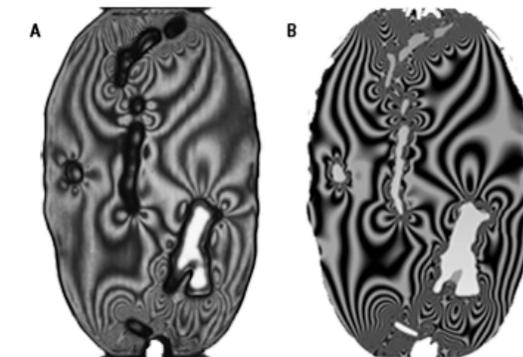
Uncompressed

Compressed

FEA 3D stress analysis



2D bean slice stress comparison



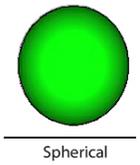
Experiment

FEA + fringes

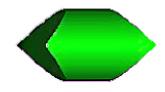
5. Flow of irregular shaped particles



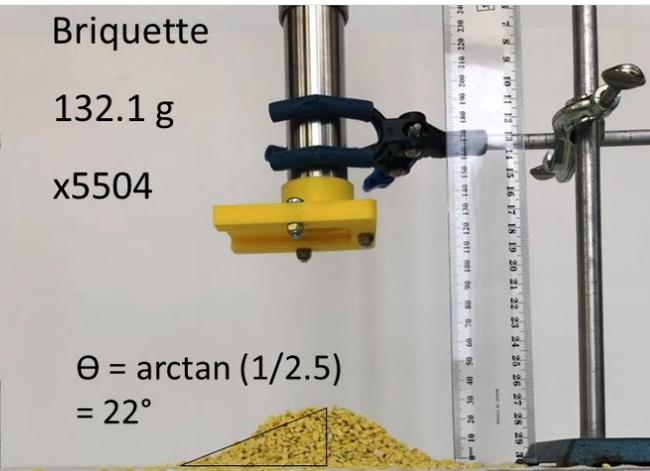
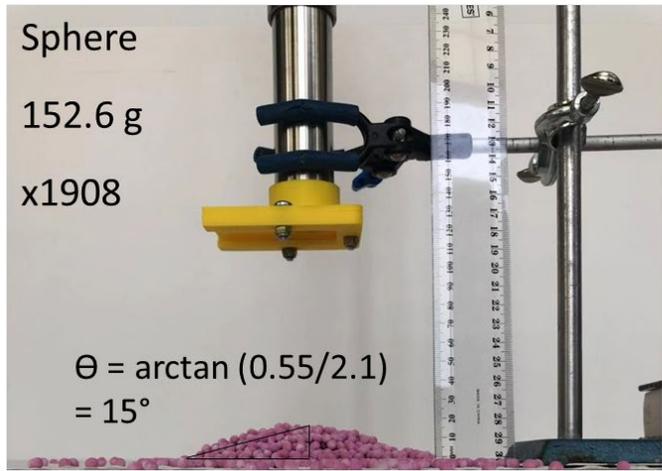
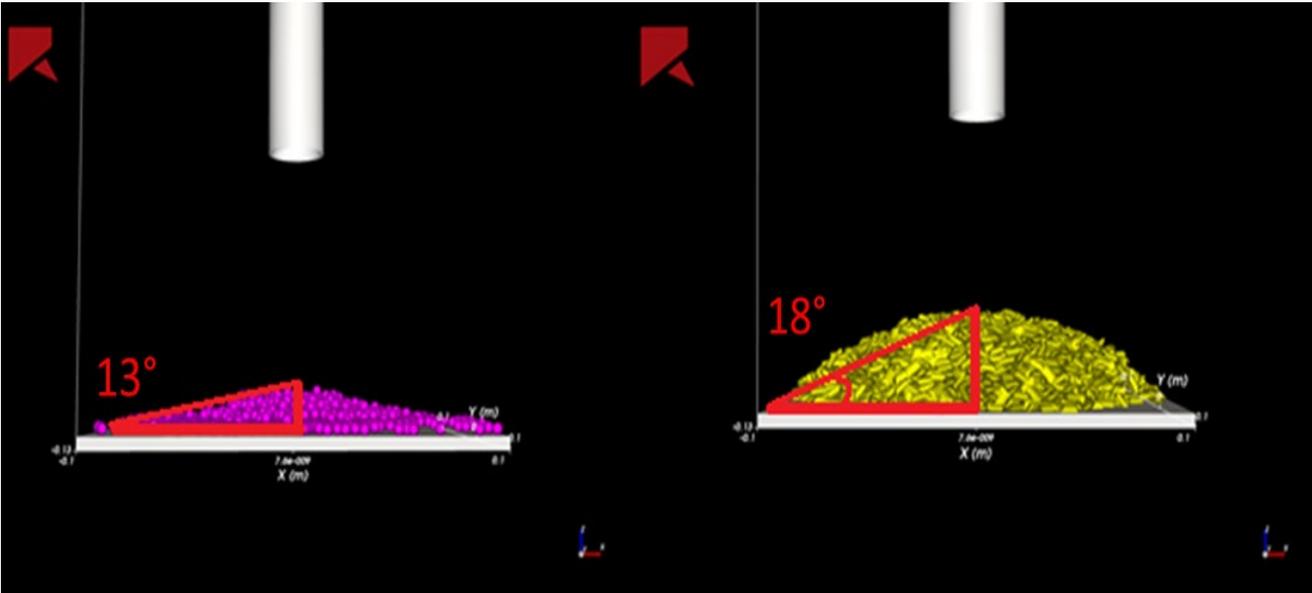
➤ Angle of repose



Spherical



Briquette



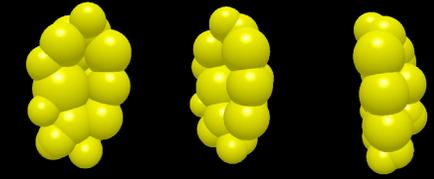
Work in Progress...



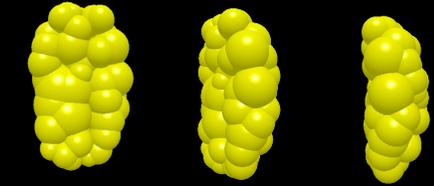
3D prints



~ 20 spheres



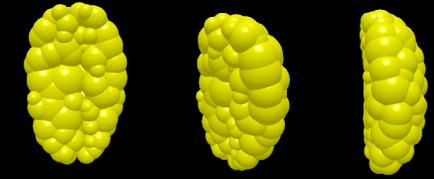
~ 60 spheres



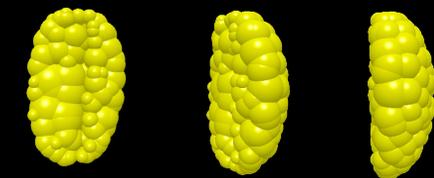
TBA



~ 110 spheres



~ 150 spheres

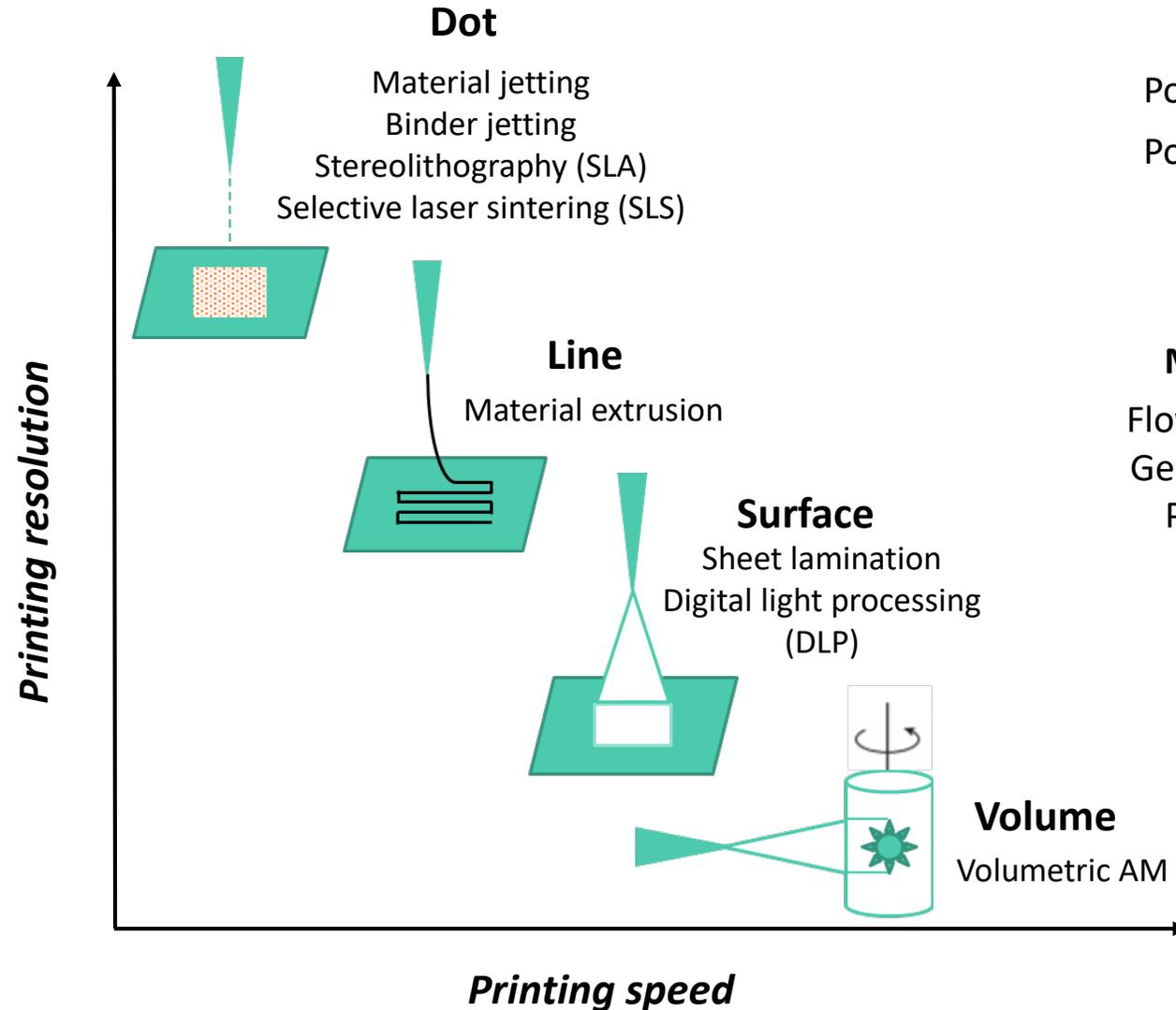


CAD



3D printing Overview

➤ Techniques



➤ Particulate materials

Dry system

Powder spreading methods
Powder deposition methods

- Powder flow
- Drop penetration
- Powder engineering

Wet system

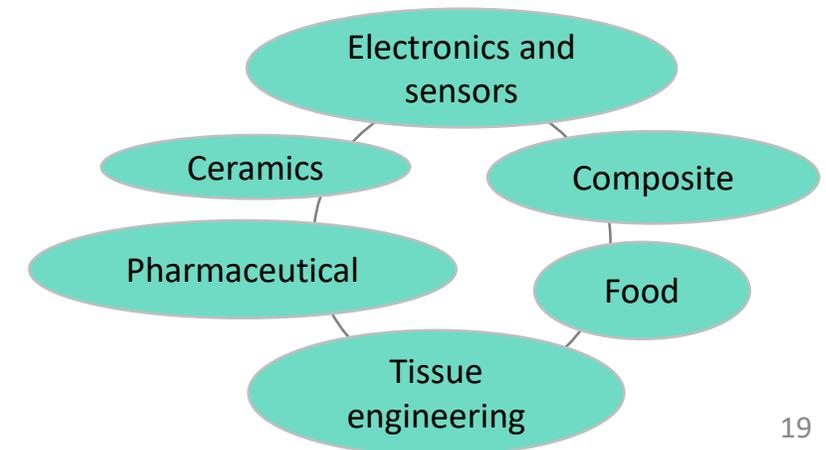
Matrix + **Particle**

Flowing liquid
Gels & Pastes
Polymers

Micro particle
Nano particle
Fibers

- Ink rheology
- Reinforcement
- Functionality

➤ Applications

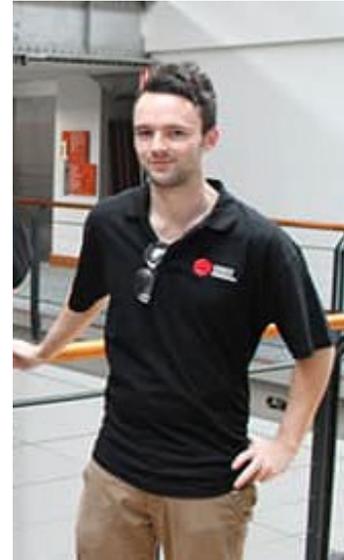


Deakin 3D Powders group



Special thanks to:

- IFPRI
- Prof David Morton
- Dr John Long
- Dr Michael Pereira
- Josh Tuohey (*MechE UG*) →



<https://blogs.deakin.edu.au/3dpowdersgroup/>

3D printing STL files at Thingiverse

<https://www.thingiverse.com/3Dpowdersgroup/designs>

-

My last IFPRI Presentation 2015-2020

