Powder spreading in additive manufacturing

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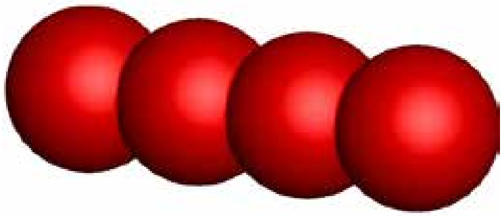
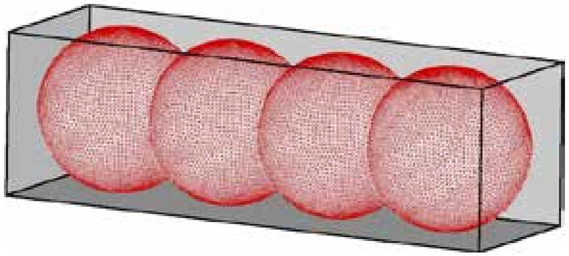
Outline

- Overview of Additive Manufacturing Technologies
- Powder based AM
  - Types of powder and
  - Challenges and opportunities
- Process modelling
  - Background
  - Impact of process parameters
  - Geometric optimisation of the spreader
  - Particle shape effects
  - Impact of liquid bridge and moisture content
- Conclusions

Additive Manufacturing

- An umbrella term encompassing a wide range of manufacturing techniques
  - Also referred to as 3D printing
  - Solid objects are built layer-upon-layer
- Additive manufacturing process
  - Producing a CAD model of the final part
  - Model manipulation and conversion to STL
  - Choose appropriate printing technology
    - Product size, precision, cost and type of material
  - Extraction and post processing
    - Detachment from the build plate and/or build material



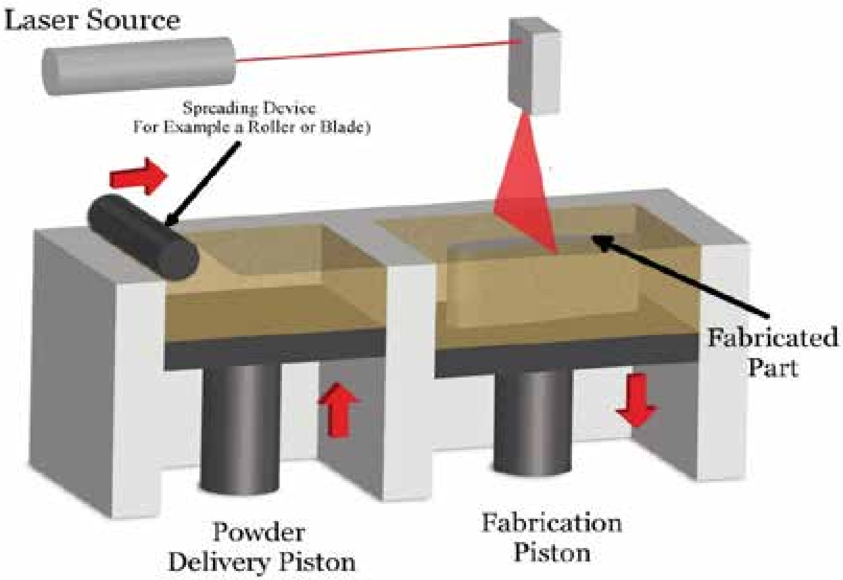


Benefits of AM

- Low volume production
  - Mass-customisation rather than mass-production
- Complex designs
  - No (almost) geometrical limitation in design
    - increase product functionality and performance
- Lower environmental impact
  - By using material efficiently
  - By increasing part functionality and efficiency
- Economic impact
  - New supply chains and business models
  - A fast growing industry by itself

AM Processes

- Powder Bed Fusion
  - Widely used to produce final parts (Direct production rather than rapid prototyping)
  - High strength and stiffness
  - A wide range of available post-processing techniques allows for smooth finish
  - Challenges
    - Powder handling
    - Internal Porosity and shrinkage/distortion



Powder Bed Fusion - - Metals, Polymers, Ceramic → Binder Jetting

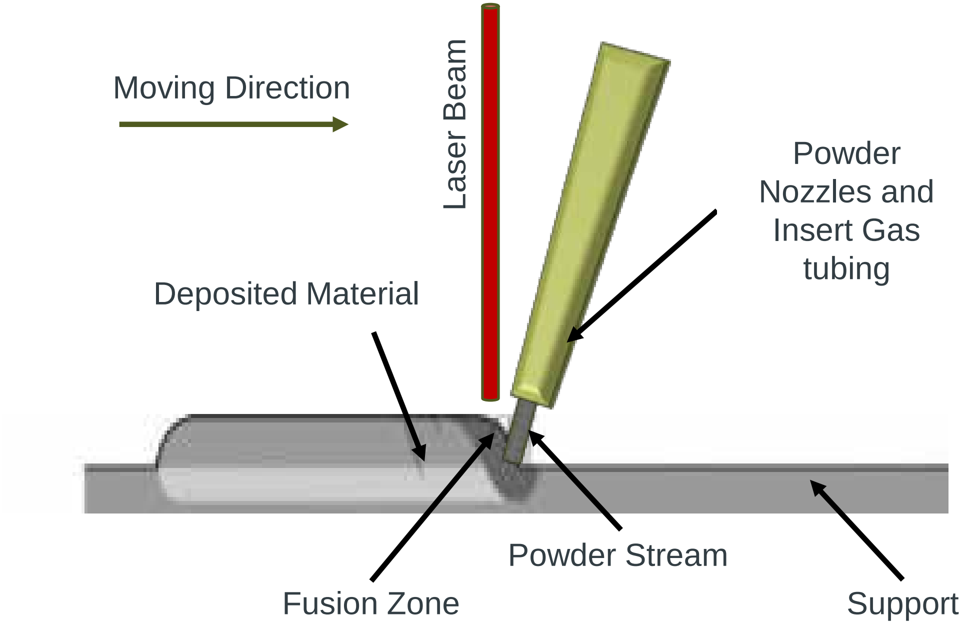
Powder Bed Fusion → Polymers → Laser Sintering: Nylon, PEEK, PEK, PEAK, TPU

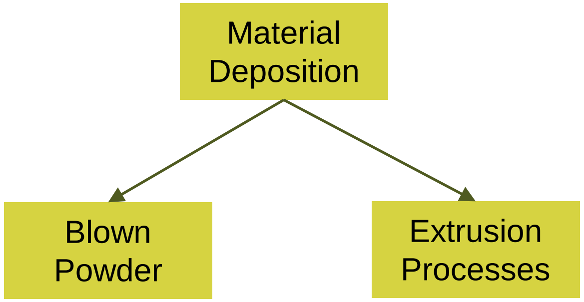
Powder Bed Fusion → Metals → Laser Melting: Aluminum, titanium, stainless steel, nickel alloys, cobalt-chrome

Powder Bed Fusion → Metals → Electron Beam Melting: Titanium, Cobalt-chrome

AM Processes

- Material Deposition
  - Blown Powder
    - Large scale, metallic powder
    - Particularly useful for coating
    - Support structure required
  - Extrusion Processes
- Other technologies
  - Material Jetting
    - High quality prototypes
    - Brittle mechanical properties
  - Vat photo-polymerization
    - Small scale applications with fine details





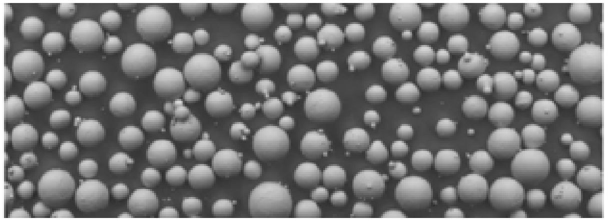
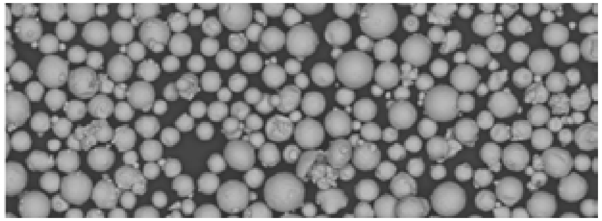
Powder Bed Fusion

- Research Directions[1]
  - Calibrated and validated models
    - Particle scale simulations: Discrete Element Method (DEM)
  - Effect of particle shape, size and size distribution
  - Flowability, Spreadability and Segregation
  - To relate part requirements to powder layer characteristics
  - Powder recycling and handling
- Opportunities and Challenges
  - DEM modelling can potentially reduce the cost of AM but
    - size and shape distribution need to be included
    - Liquid-bridge, van der Waals and Contact cohesion
    - Interstitial air effects (Perhaps!)
  - Should be used for machine and spreader design
  - Reduced-order modelling of DEM data

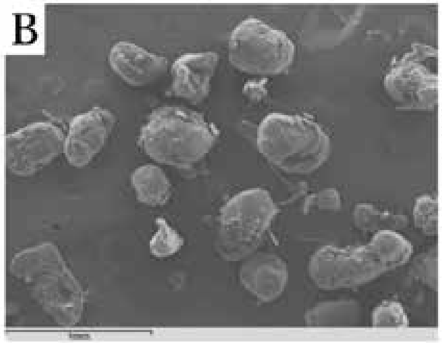
[1]Powder Dynamics Meeting Report, Wayne King, Lawrence Livermore National Laboratory, Aug 2017

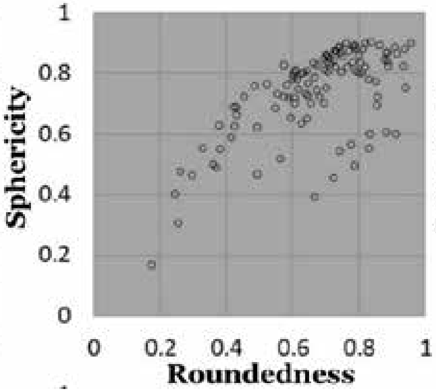
Shape/Size distribution

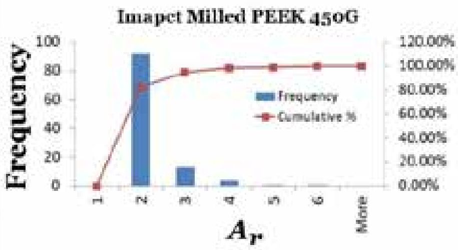
- Why consider non-spherical particles?
  - Better predictability
  - High Production Costs
    - Gas, Plasma and Plasma rotating electron atomised processes
    - Usually only available for metals

  - For new material shape irregularities are a rule!
    - Polymeric powders







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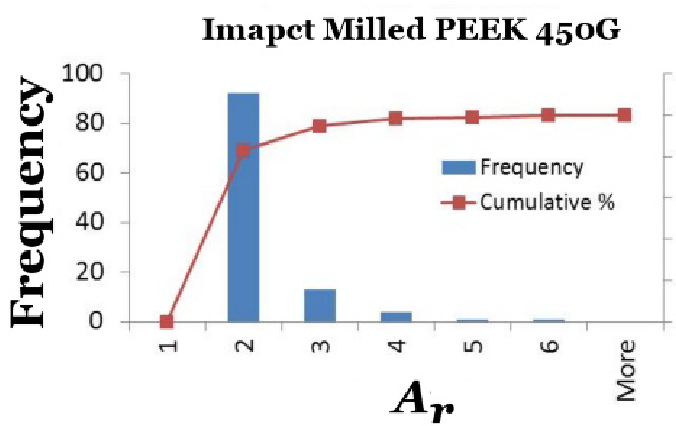
Numerical Modeling

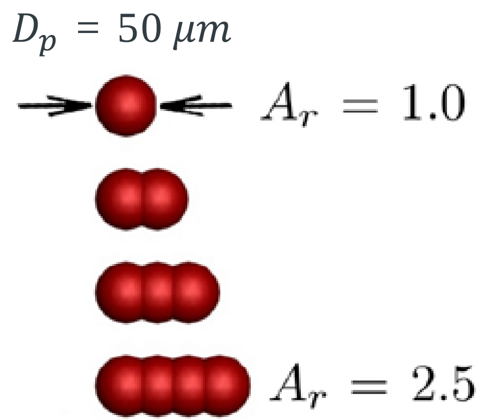
- Standard DEM
  - Simulations based on LAMMPS and LIGGGHTS
  - Spring-Dashpot/Hertz Model
    - Model Parameters set according to Di Renzo[1]
  - Rolling Friction
  - Clumped-Sphere Approach for non-spherical particles
  - About the simulations
    - ARCHER (T-1 facility) and Cirrus (T-2 facility)
    - Domain Decomposition and Load Balancing
    - Typical simulation: 20-hours on 96 cores.

[1] Chemical Engineering Science 59 (2004) 525-541

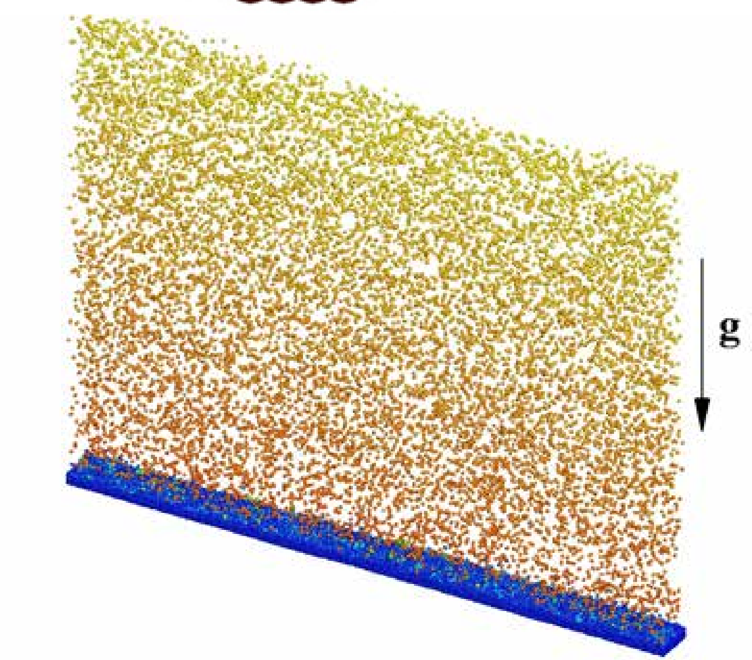
Simulation Set-up

– Particle Shapes





– Initialisation using a Rainfall technique[1]



[1] Haeri et al., Powder Technology, 306 (2017) 45-54.

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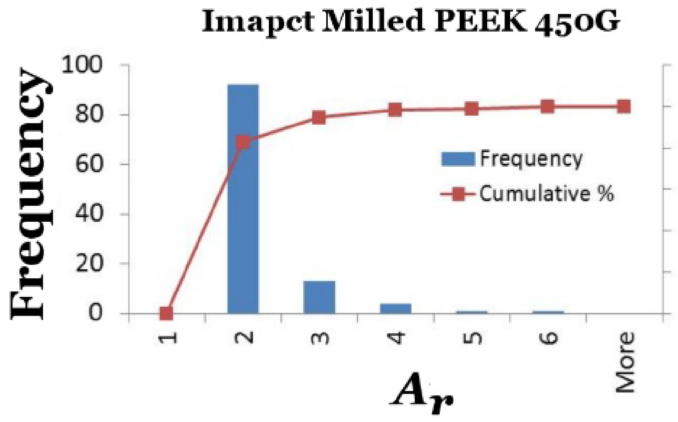

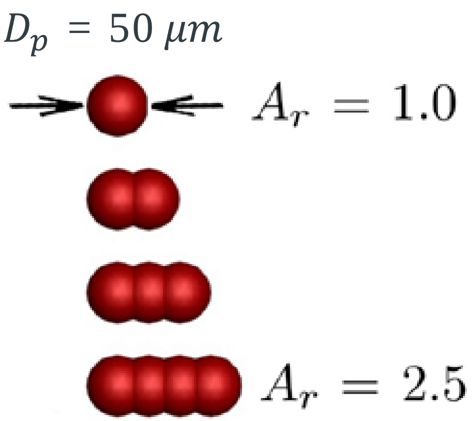

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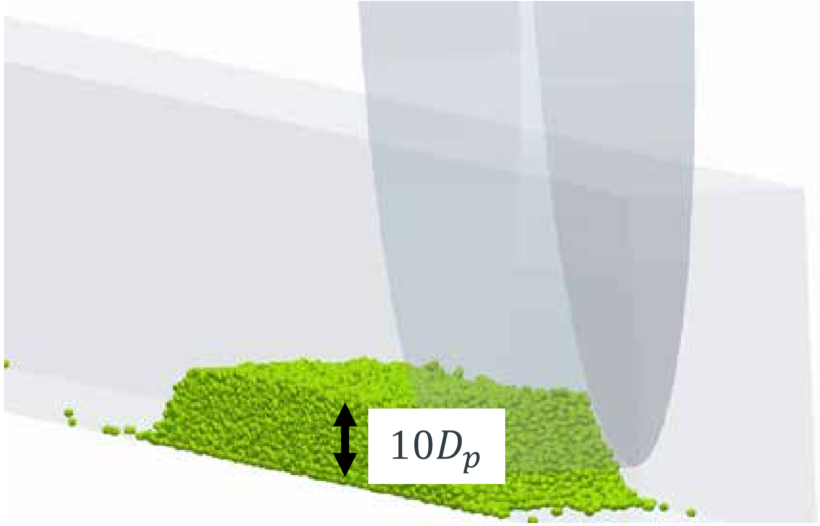
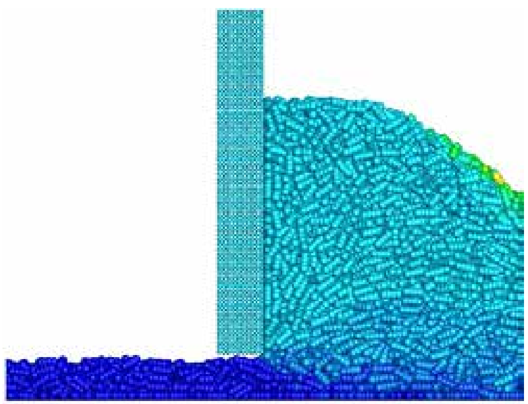


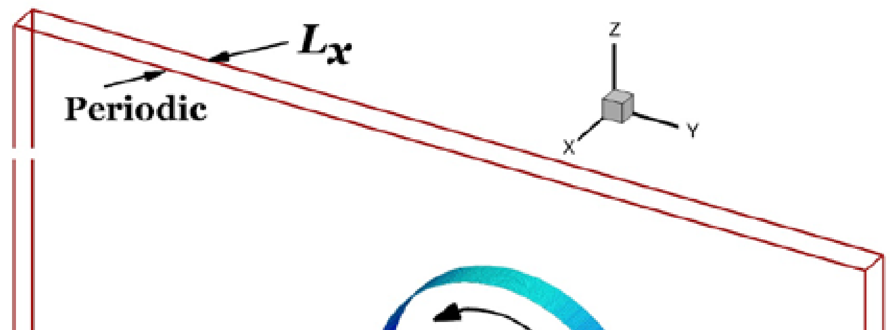
[1] Haeri et al., Powder Technology, 306 (2017) 45-54.

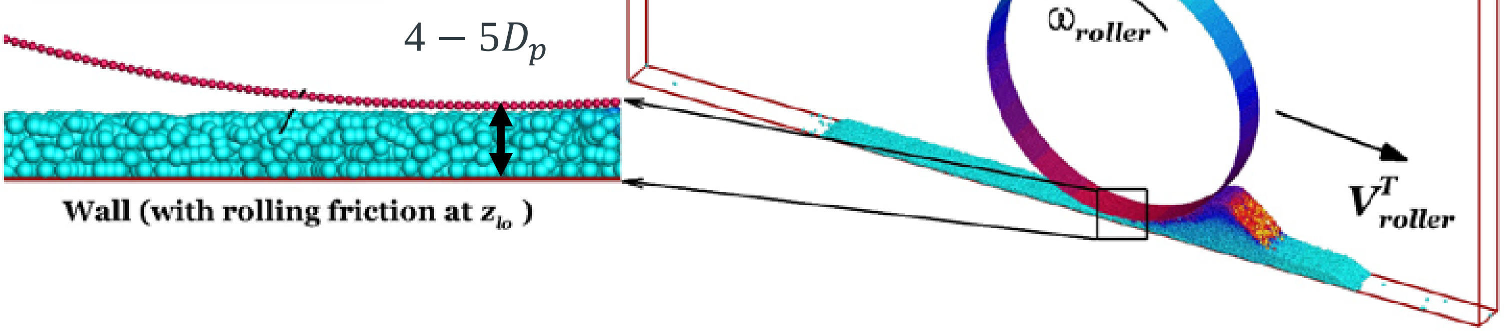
Simulation Set-up

University of Strathclyde Engineering

- Simulation set-up to scale
  - Blade and Roller Tested

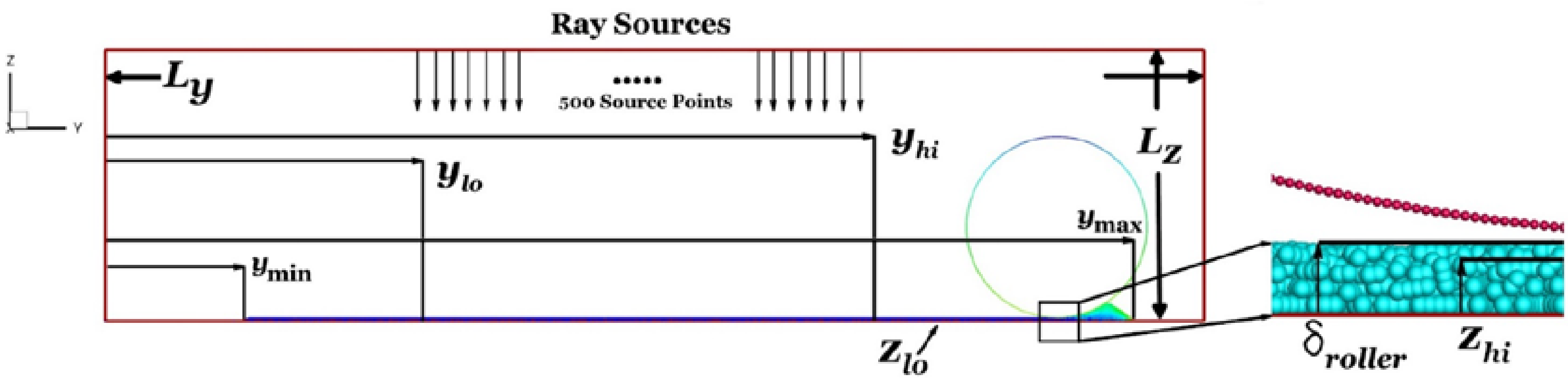






Post-processing

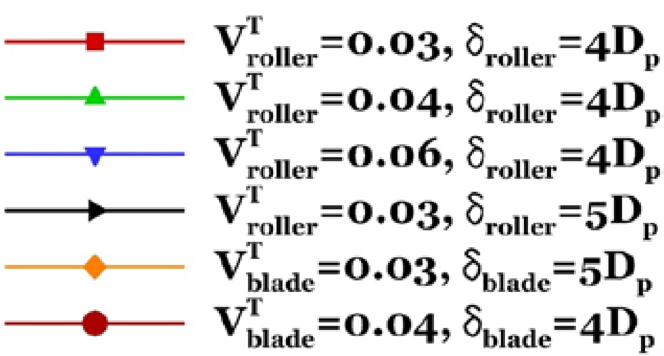
- Post processing
  - Calculation of bed volume fraction (good compactions, uniformity and no cracks)
  - Calculation of bed surface roughness (wrinkles)
- A section of the bed is used for the post processing

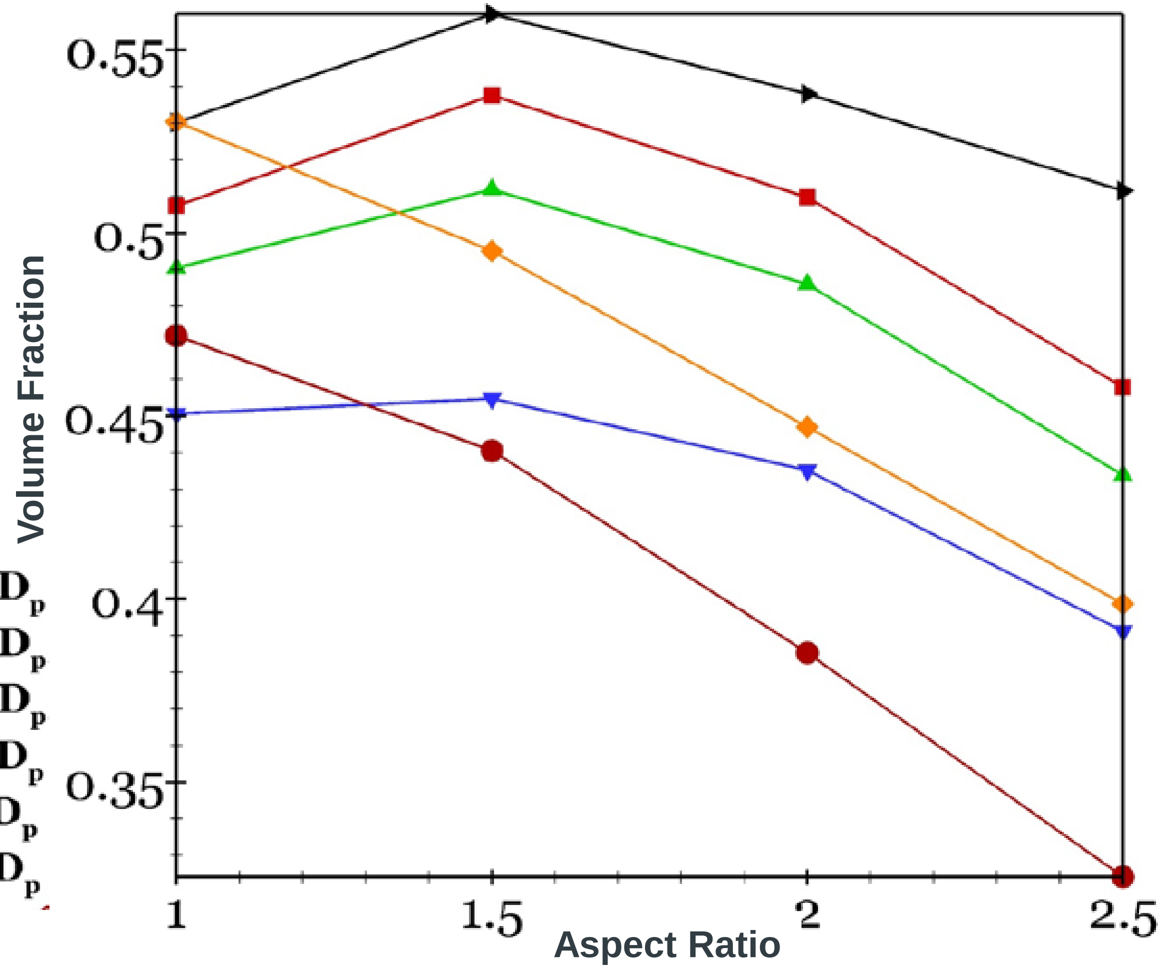


- Volume fraction calculation: Voronoi Tessellation
- Surface Roughness: Ray Tracing

The Process Parameters Impact[1]

- Spreader Speed
- Spreader type
  - Blade
  - Roller
- Bed thickness
- Aspect ratio





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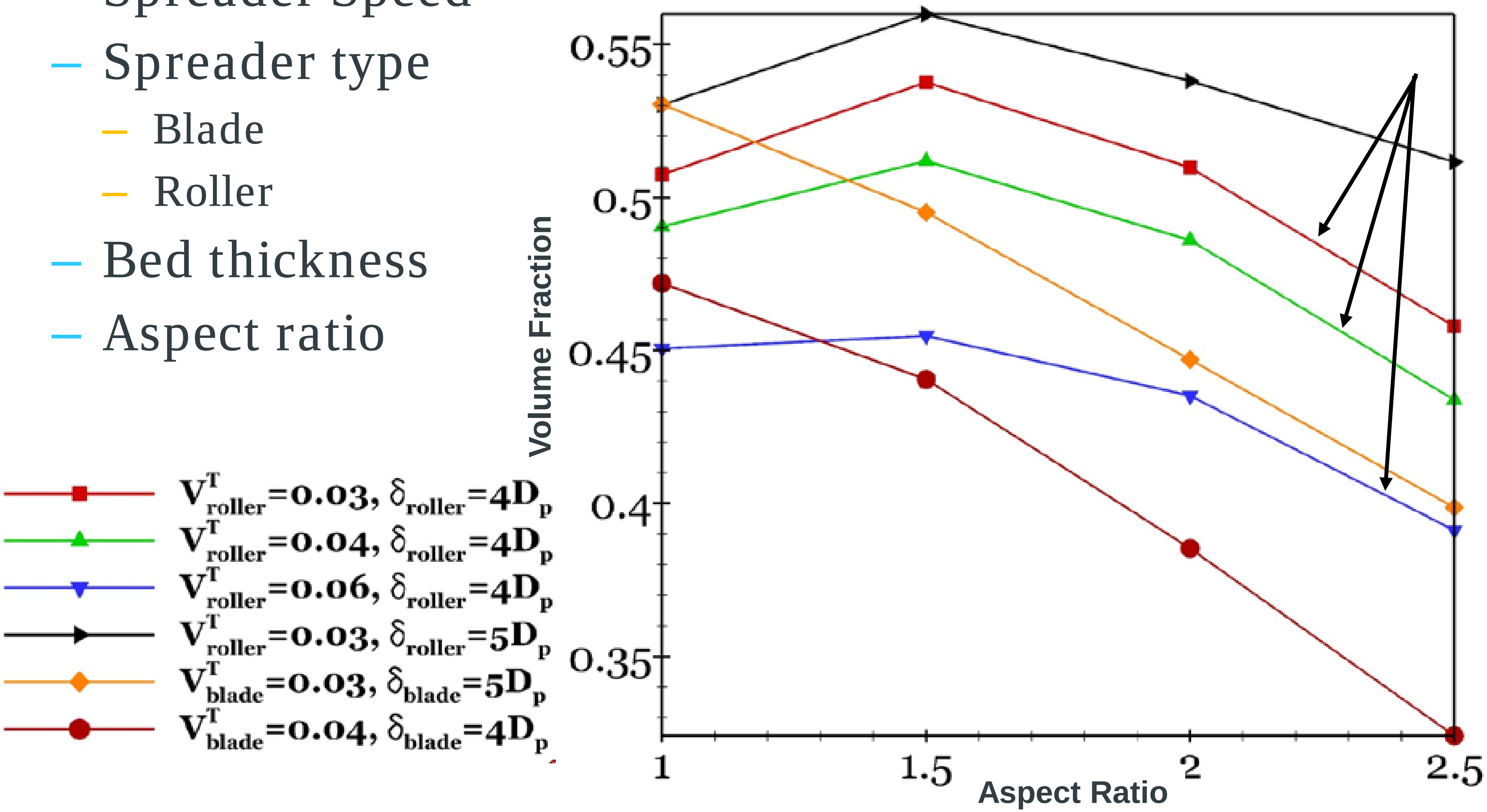

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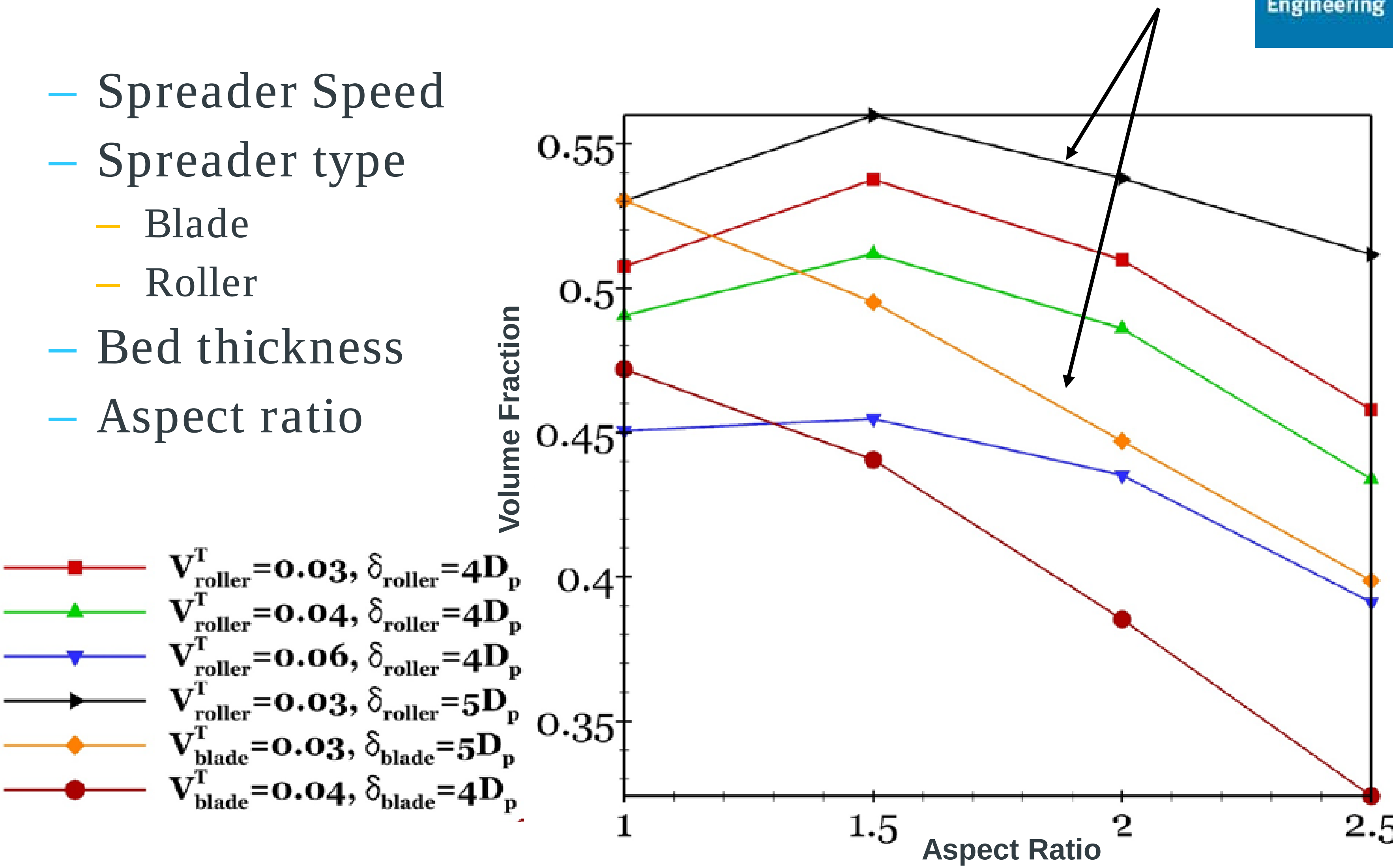

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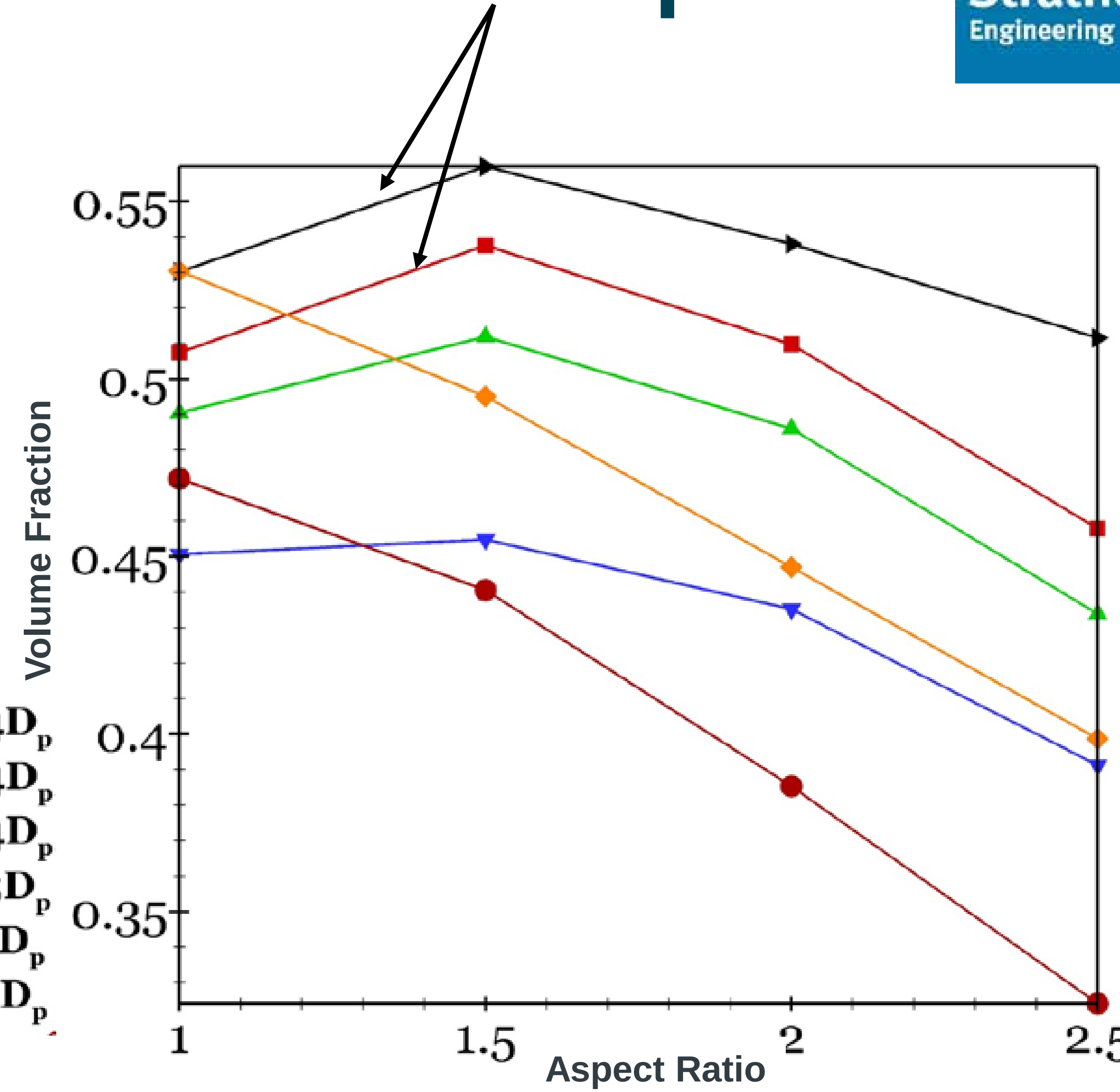

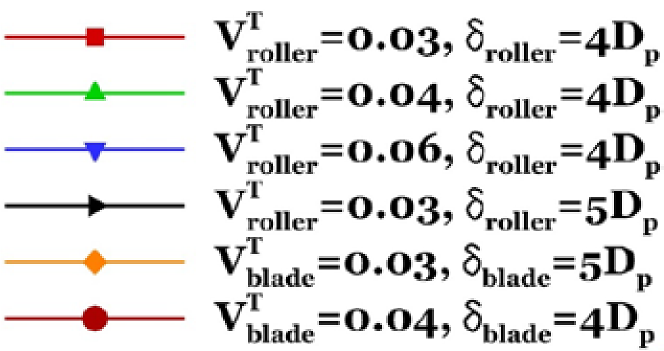

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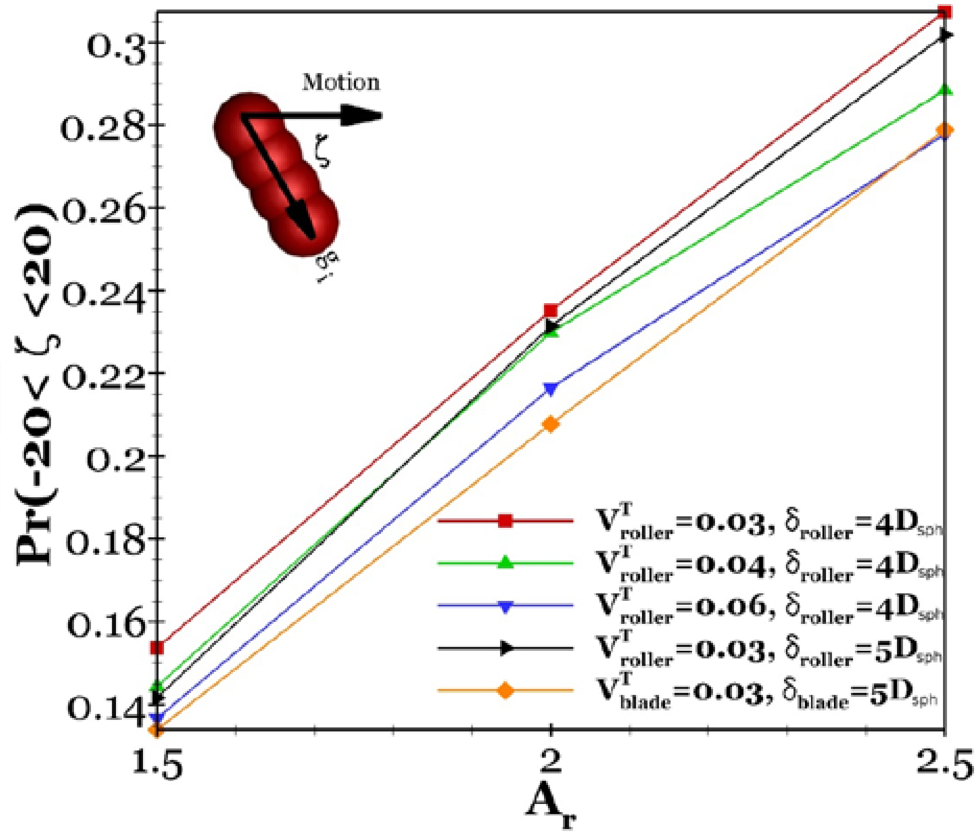
Particle Alignment

- Spreader Speed
- Bed thickness
- Aspect ratio
- Isotropic distribution
  - $Pr(\zeta < |20|) = 0.06$

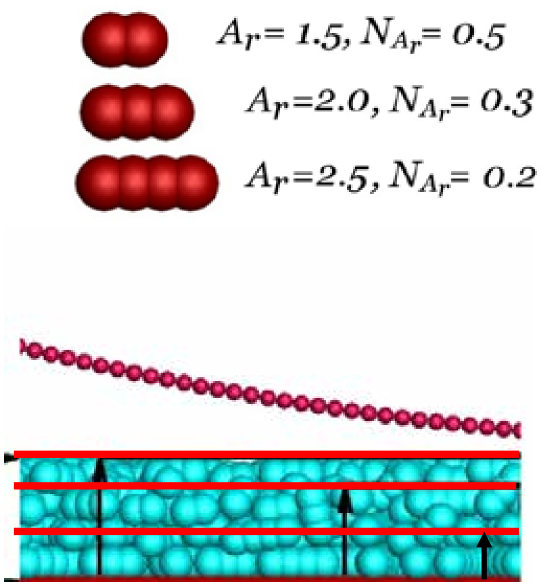
Initial Distribution (After Rainfall)

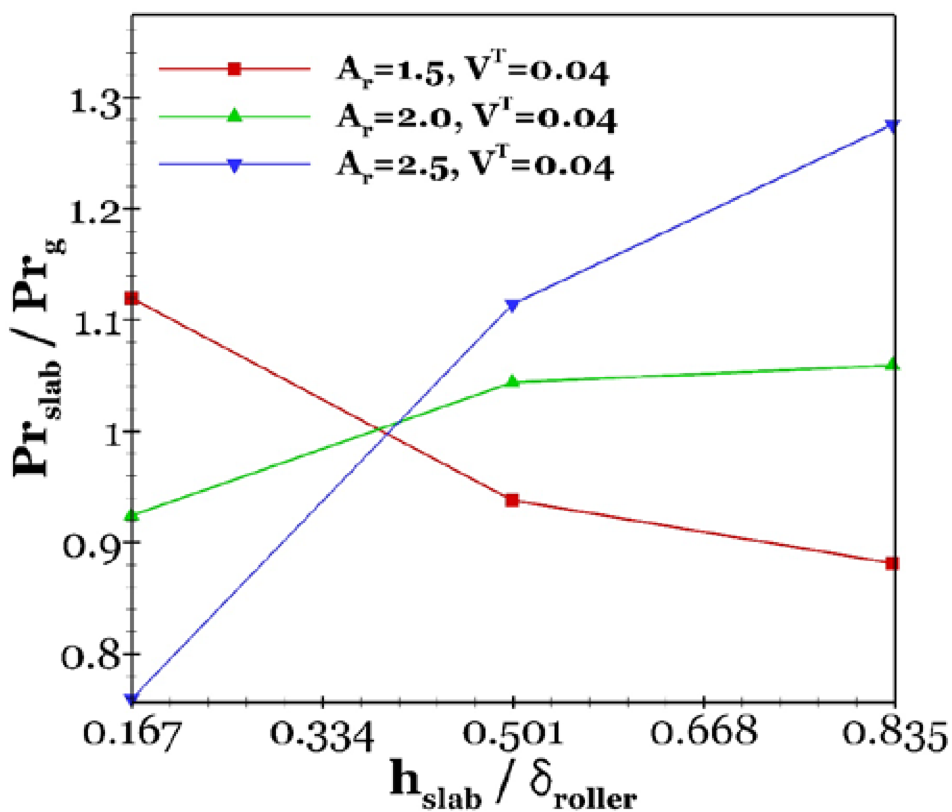
Ar	1.5	2.0	2.5
$Pr(\zeta < \lvert 20 \rvert)$	0.088	0.097	0.11



Size/Shape Segregation

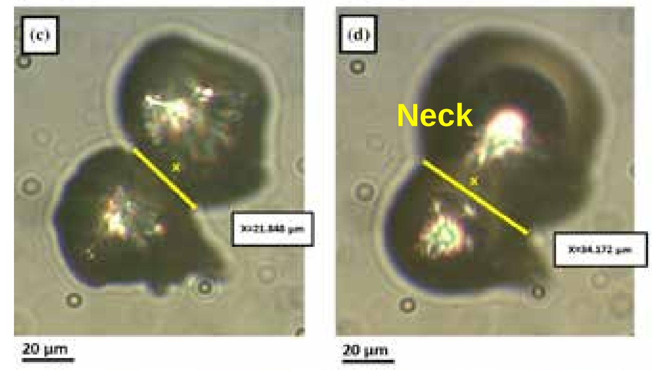
- Can the bed volume fraction be controlled by controlling particle shape distribution
  - Shape/Size segregation

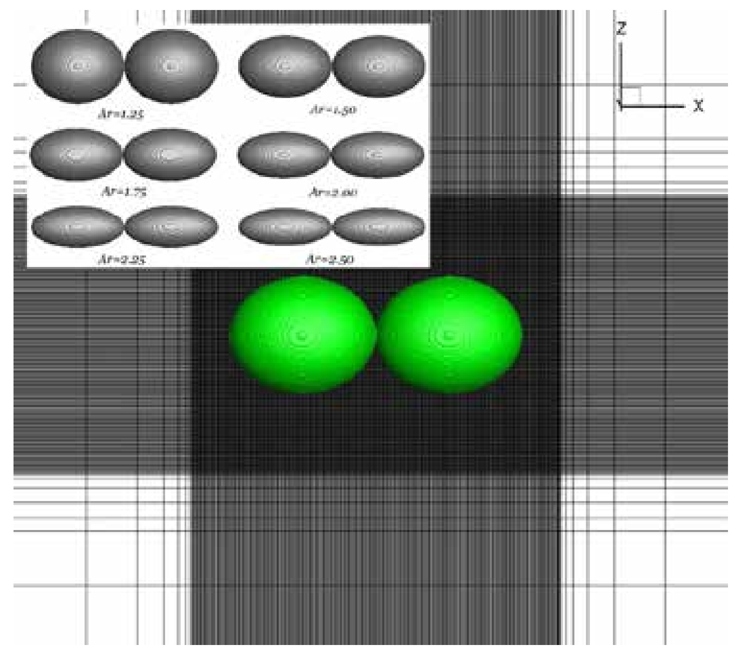




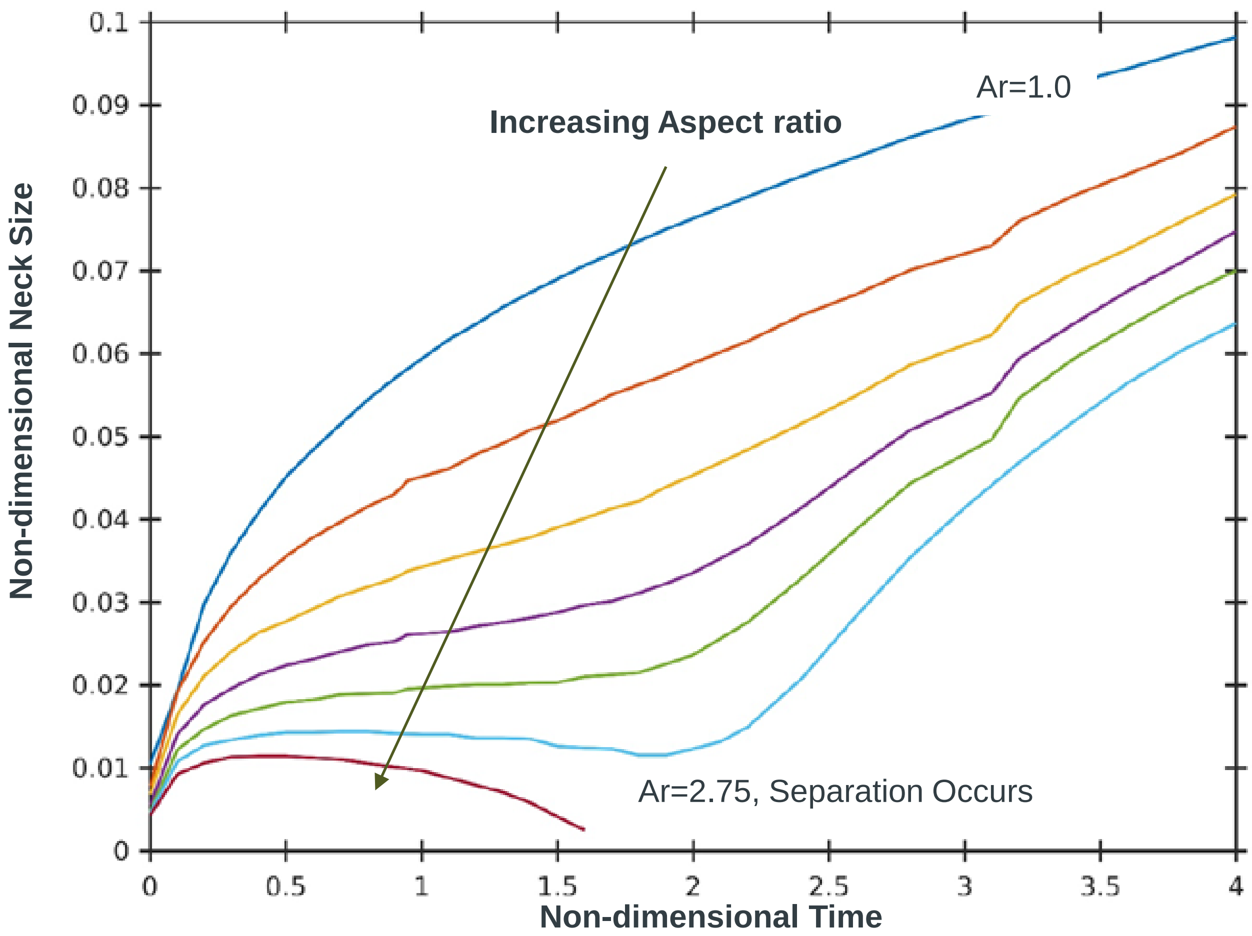
Rainfall technique

- Some recent publication suggest using a tuned rainfall technique to generate the bed
  - Initial condition to other simulators for other stages of process
  - Provide some understanding of bed behaviour
  - The spreading process significantly impacts the microstructure of the powder
  - The microstructure impacts other stages of the process





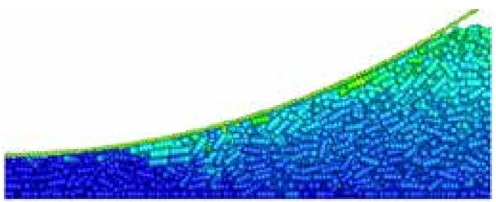
Neck Growth rates

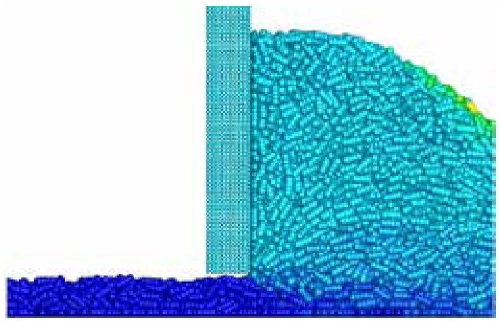


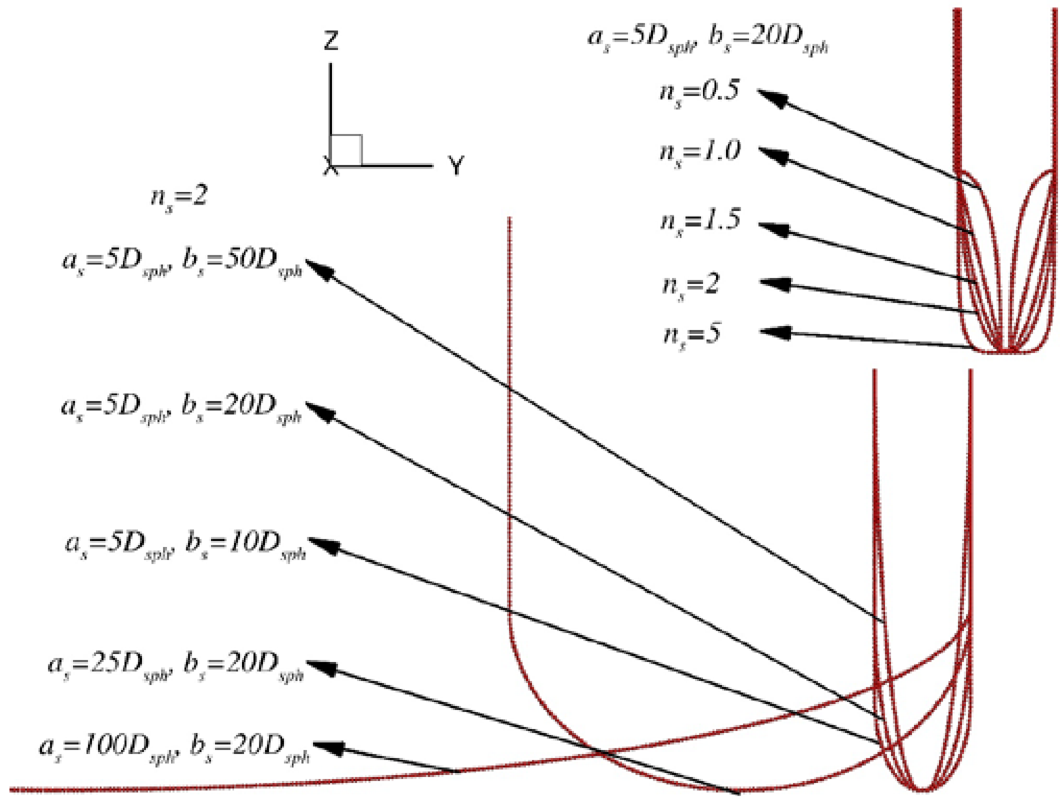
Blade Geometry Optimisation[1]

- Blades are less efficient than rollers
  - Related to spreader-particle contact dynamics
  - Geometric problem

$$\left|\frac{y}{a_s}\right|^{n_s} + \left|\frac{z}{b_s}\right|^{n_s} = 1$$







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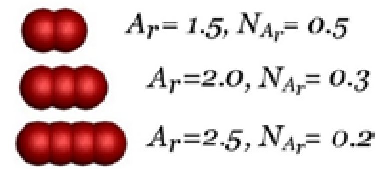
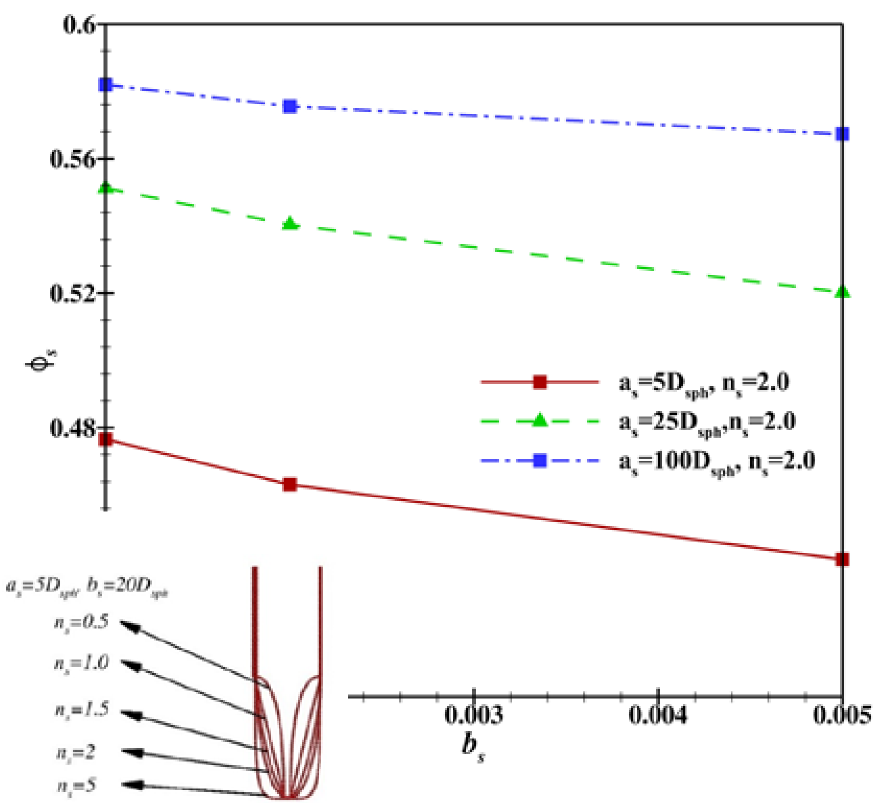
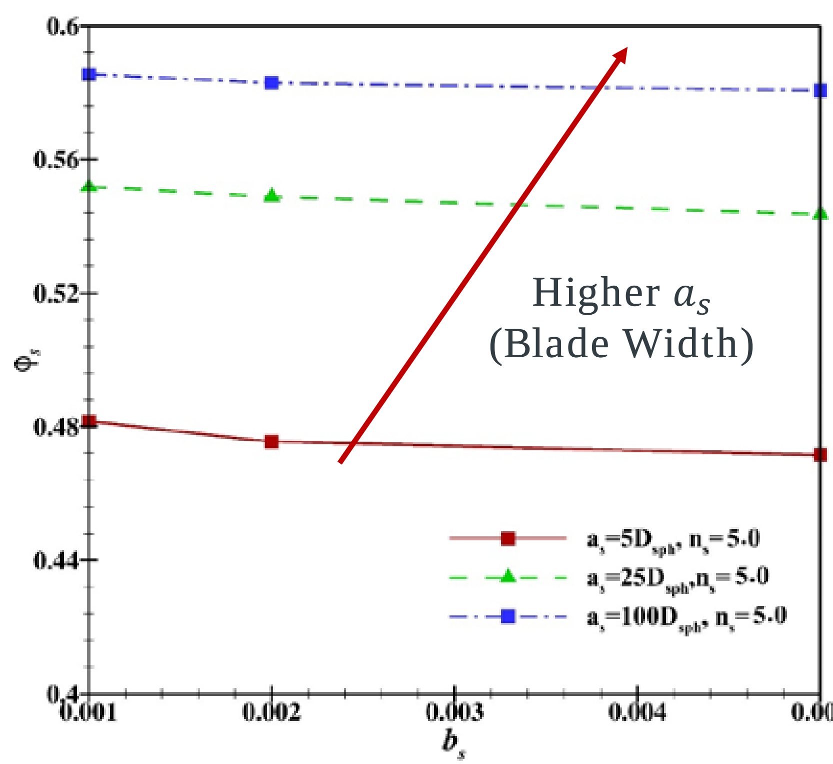
Effectiveness of the Design

- A mixture of rod-shaped particles is considered.
  - 50 combinations of a_s, b_s and n_s are tested



Particle Shapes





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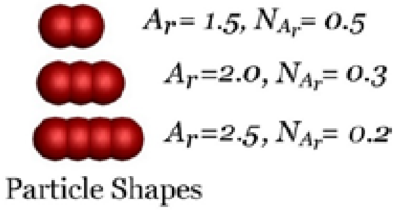

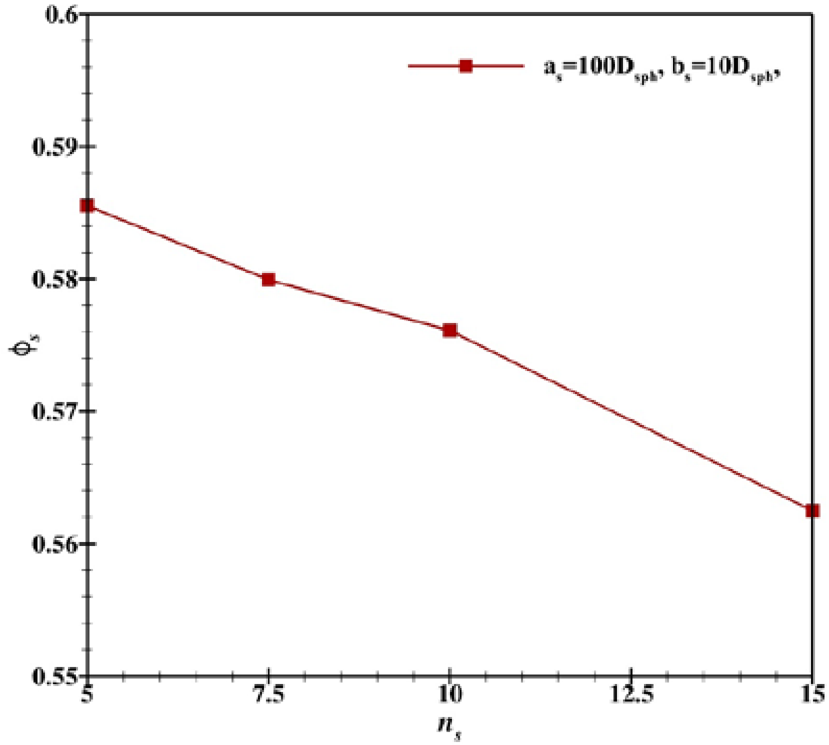

Realistic Particles

- Is the new design still effective for realistic particle shapes
  - An improved multi-sphere approximation method[1] based on Li's[2]

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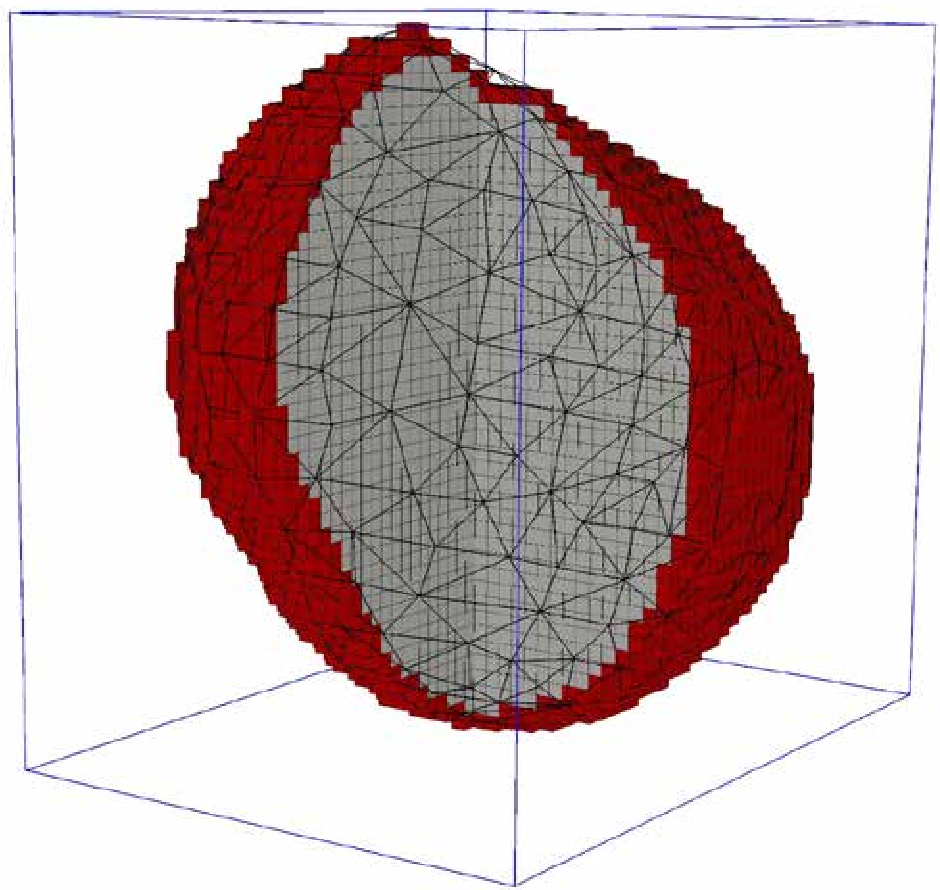

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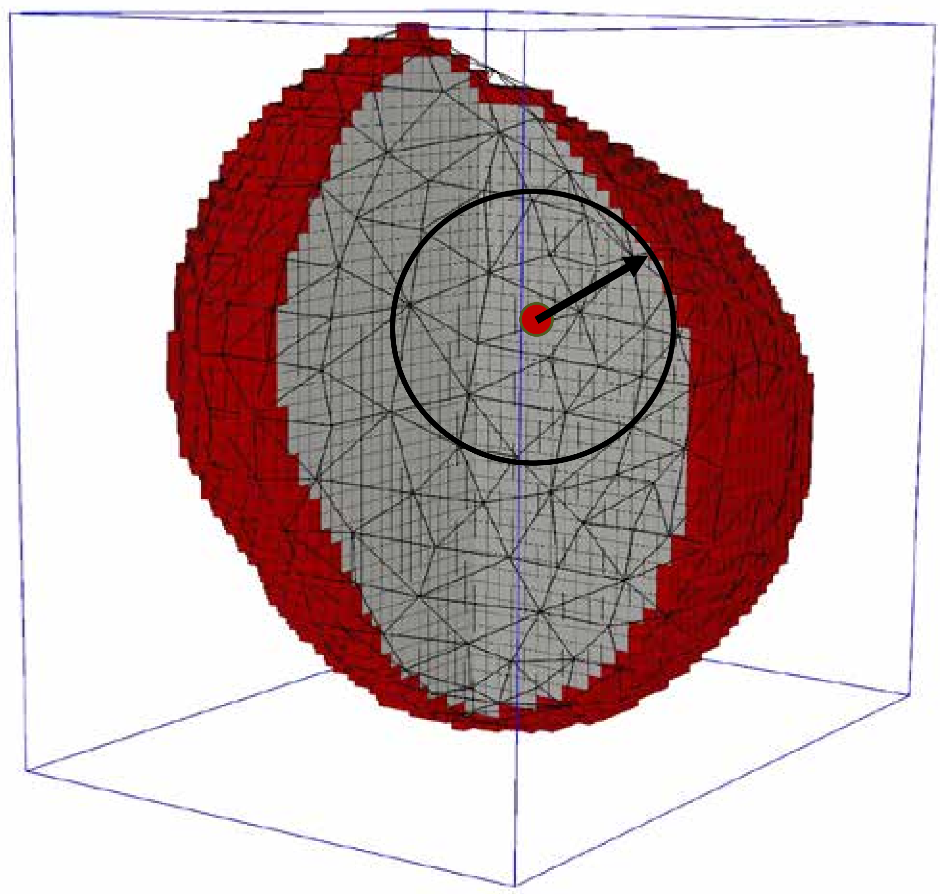
$$\begin{bmatrix} m_{11} & \cdots & m_{N1} \\ \vdots & \ddots & \vdots \\ m_{1N_{int}} & \cdots & m_{NN_{int}} \end{bmatrix}$$



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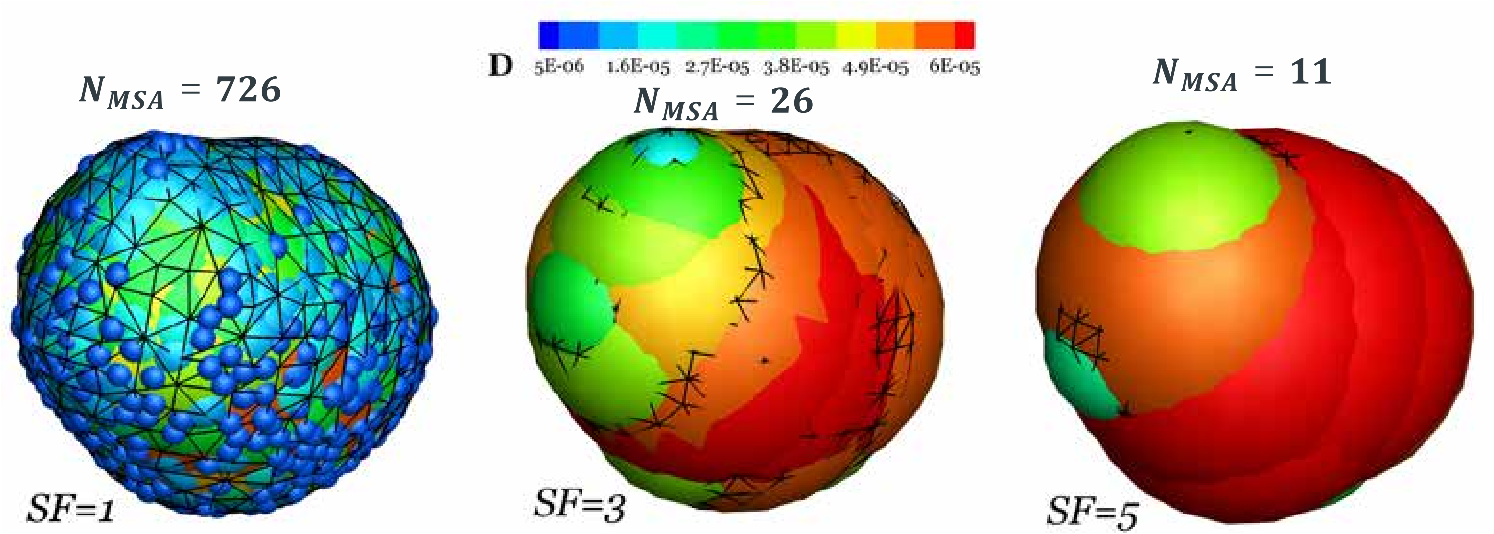

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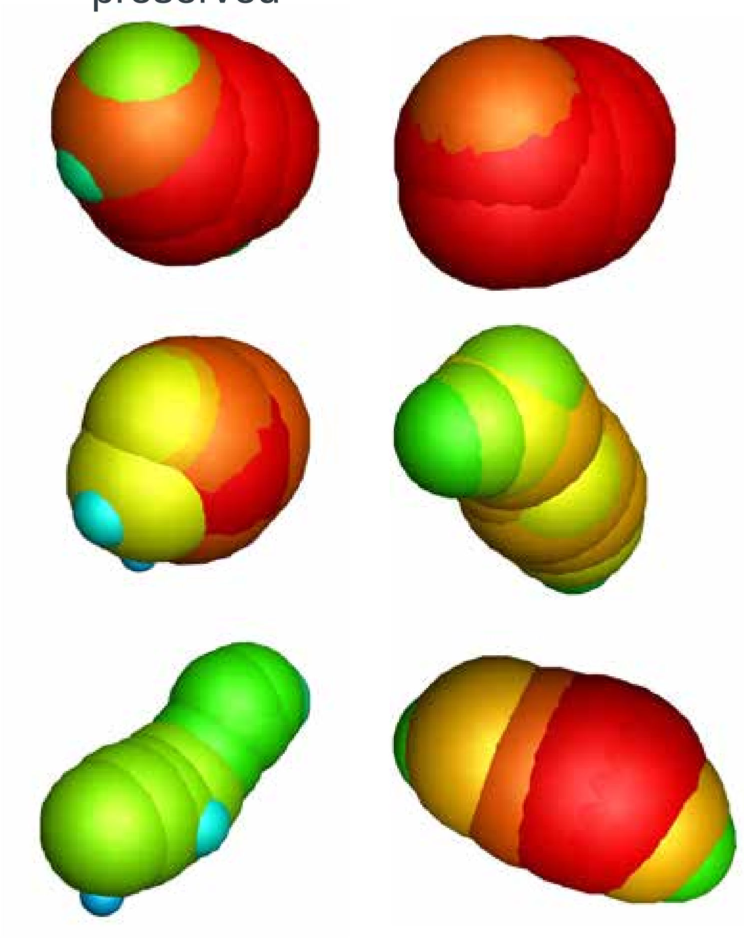
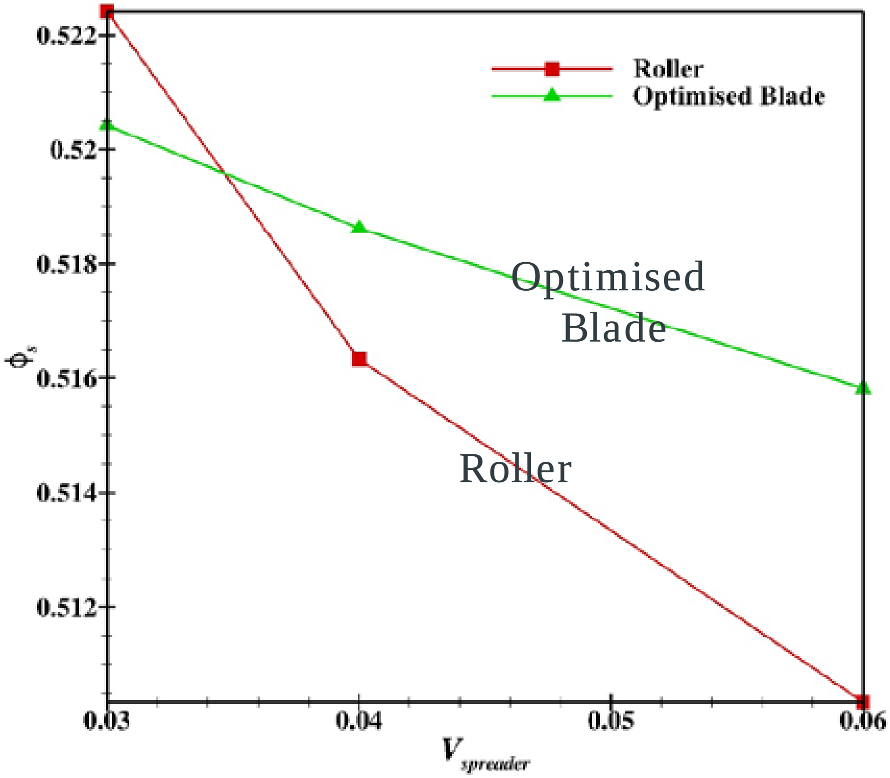
Comparison with the Roller

Selected Particle Shapes

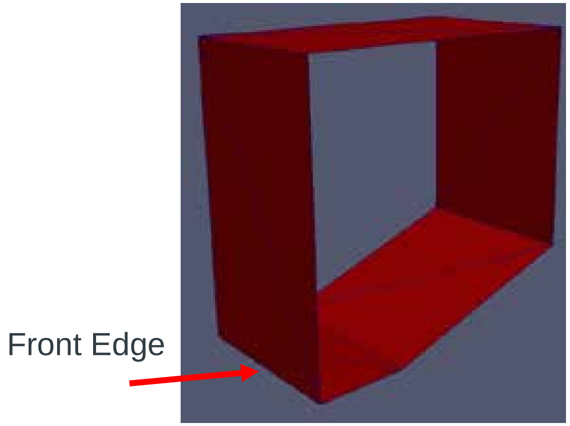
- Mixed With Equal Proportions
- Mean sphericity of roundedness is preserved

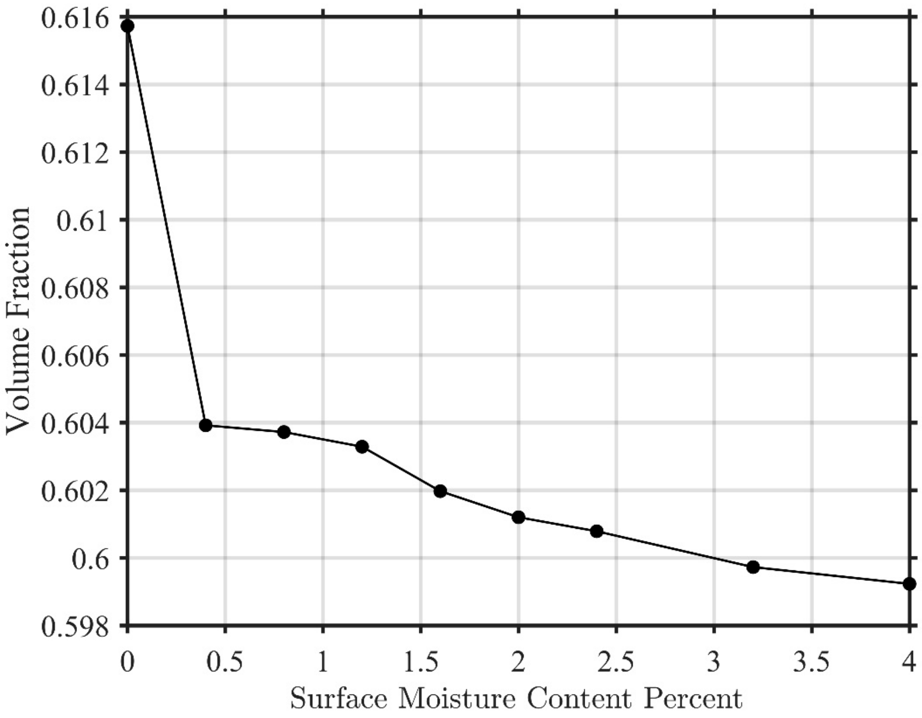




Powder Moisture Content

- Similar approach, using actual blade geometry





- Seems drier powder generally behaves better
  - Interstitial gas effects for dry powder

Summary

- AM and Powder Bed Fusion
  - Economical impact
  - Technological advancement
- Complexity of the Process
  - High-fidelity simulations
- Discrete Element Method
  - Device-scale simulations are feasible
  - Better understanding of the process
  - Assist in development of new designs and processes optimisation
  - Providing accurate initial conditions for further simulations
    - Full simulation of the spreading process required.
  - May still be too expensive to be used on the shop floor
    - A reduced-order modelling techniques may be applied to DEM data

Thank you for your attention!

Questions?