Modelling Powder Spreading for Powder Bed Fusion Processes

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ESI Group

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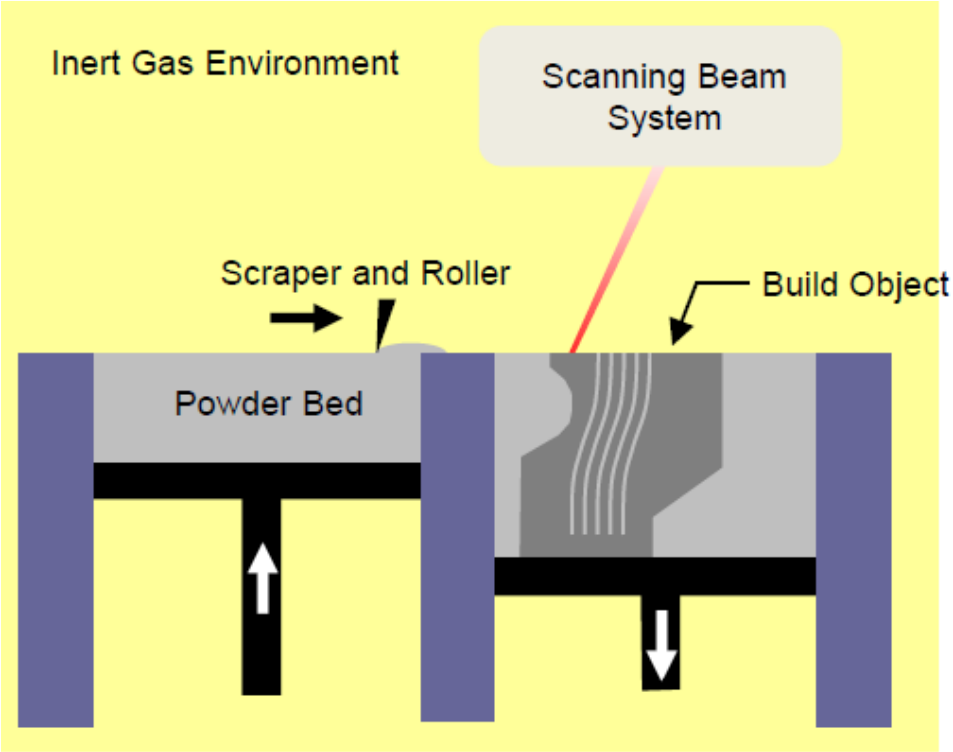
Modelling Powder Spreading

Powder Bed Fusion (PBF)

- Motivation
  - Relevance to process efficiency
  - Relevance to work piece quality
- PBF Modelling Chain
  - Focus on powder spreading
- Fields of ongoing research
- Summary & Conclusion



E.W. Reutzel, CIMP-3D National Forum, Oct. 22-24, 2014.

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Motivation

Modelling powder spreading

- The powder delivery system may contribute significantly to increasing productivity and reducing cost
- The characteristics of the powder layer affect material quality
- Part manufacturability is affected by delivery system in many ways
- Models could
  - Provide data that is not accessible
  - Capture and explain the interdependencies between process parameters
    - specifically including – powder bed characteristics

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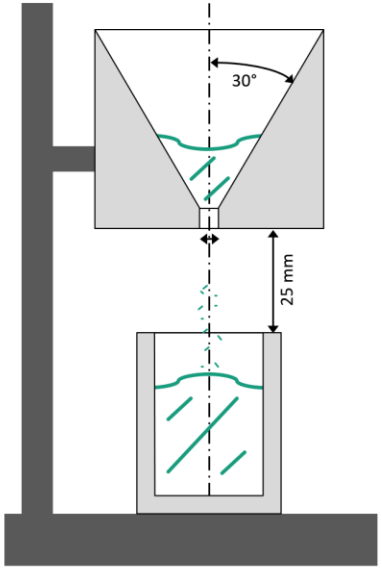
Powder Quality & Delivery

Powder Qualification

Processability	Properties	e.g. Hall-Flowmeter

■ Errorless powder handling and deposition of powder layer with available SLM systems
■ Realization of homogeneous powder layer
■ High bulk density of deposited powder layer
	■ Material / chemistry
	■ Production technique
	  ■ Water atomized
	  ■ Gas atomized
	  ■ Milled ...
	■ Flowability
	  1. Particle size distribution
	  2. Particle shape
	  ■ Spherical
	  ■ Irregular/blocky
	  3. Particle surface
	■ Bulk density ...
		

Powder Quality & Delivery

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		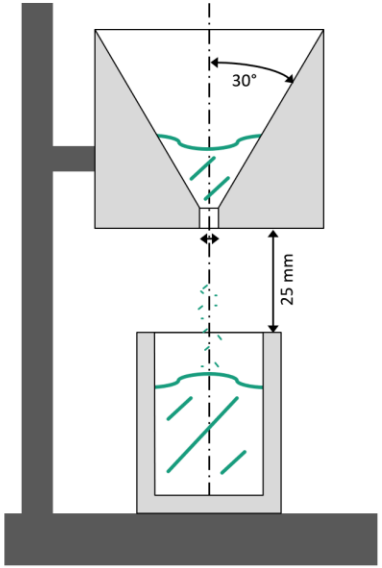

➡ Currently no general standard for powder qualification!

Powder Quality & Delivery

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		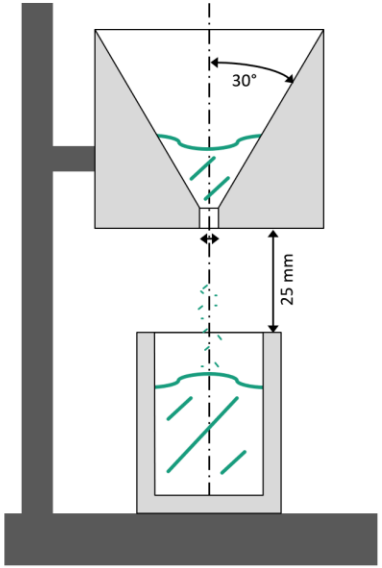

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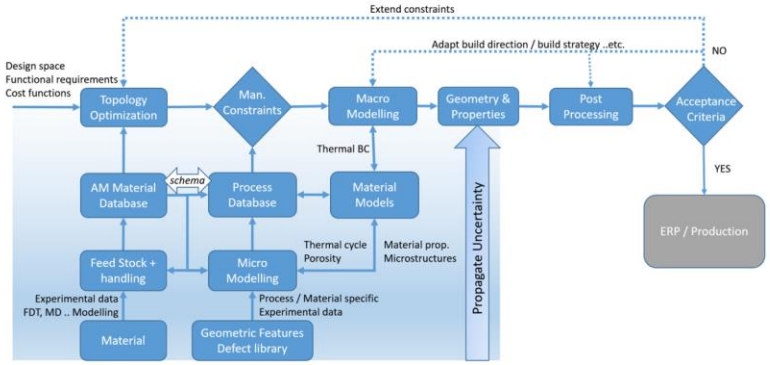
How to design reliable general purpose experiments or simulations?

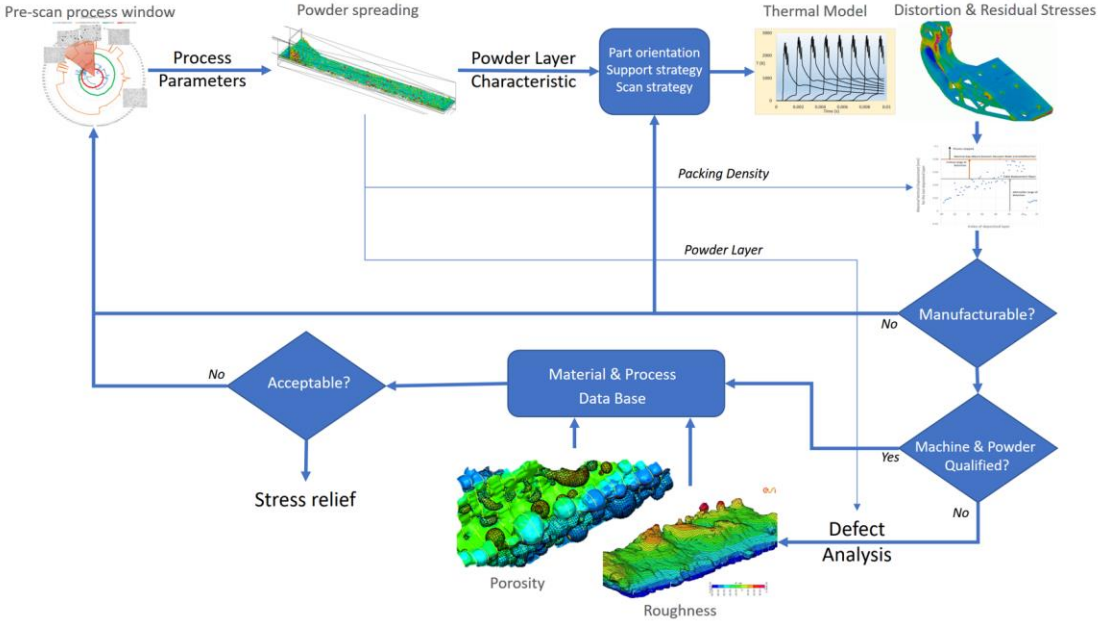
Modelling Powder Bed Fusion Processes

ESI – ICME



Megahed et al., IMMI, 2016
Peralta et al., IMMI, 2016

Derived modelling chain detailing role of modelling powder dynamics



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Conservation Equations

Micro models

Swansea University
Prifysgol Abertawe

Powder Feed Stock

$$\boldsymbol{m_i \frac{dv_i}{dt} = \sum_j f_{ij} + f_i^b + m_i g}$$

$$I_i \frac{dw_i}{dt} = \sum_j \boldsymbol{m_{ij} + m_i^b}$$

Melt Pool

$$\frac{\partial \rho}{\partial t} + \nabla \cdot \rho \vec{v} = 0$$

$$\frac{\partial \rho \vec{v}}{\partial t} + \nabla \cdot \rho \vec{v}\vec{v} = -\nabla p + \nabla \cdot \tau - \frac{C(1-f_L)^2}{f_L^3 + 10^{-10}} \vec{v} + \left[\sigma \kappa \vec{n} + \frac{d\sigma}{dT}\left(\nabla T - \vec{n}(\vec{n} \cdot \nabla T)\right)\right] \cdot \vec{n} + p_R \cdot \vec{n} + \rho \vec{g}$$

$$\frac{\partial \rho h}{\partial t} + \nabla \cdot \rho \vec{v} h = \nabla \cdot \left(\lambda \nabla T + \sum_i h_i \vec{j}_i\right) + \frac{\partial p}{\partial t} + \tau : \nabla \vec{v} - \frac{\partial \rho f_L L_f}{\partial t} - \nabla(\rho \vec{v} f_L L_f) - \frac{\rho \partial (1-f_v) L_v}{\partial t} + S_R \cdot \vec{n}$$

$$\frac{\partial \alpha_L}{\partial t} + \nabla \cdot \alpha_L \vec{v} = \frac{m_L}{\rho_L} - \frac{m_V}{\rho_L}$$

$$\frac{\partial \rho Y_i}{\partial t} + \nabla \cdot \rho \vec{v} Y_i = \nabla \cdot \vec{j}_i, i = 1, \dots, N_{sp}$$

Macro models

Thermal history

$$\rho \frac{dh}{dt} = \nabla \cdot (\lambda \nabla T) + Q_V$$

Mechanical Analysis

$$\nabla \cdot \sigma + \vec{f}_{int} = 0$$

$$\sigma = \boldsymbol{C}\epsilon$$

$$\epsilon = \epsilon^e + \epsilon^p + \epsilon^{th}$$

$$\epsilon^e = \frac{1+\nu}{E}\sigma - \frac{\nu}{E} tr(\sigma)\mathbb{I}$$

$$\epsilon^p = g(\sigma_Y)$$

$$\epsilon^{th} = \alpha(\theta - \theta_0)$$

M. Megahed et al., Integrating Materials and Manufacturing Innovation (2016) 5:4 – DOI: 10.1186/s40192-016-0047-2

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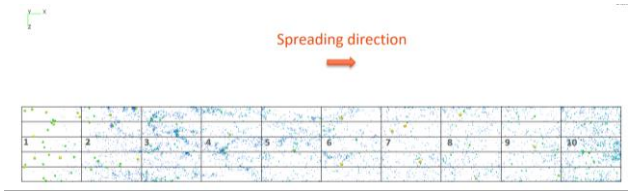
Modelling Powder Spreading

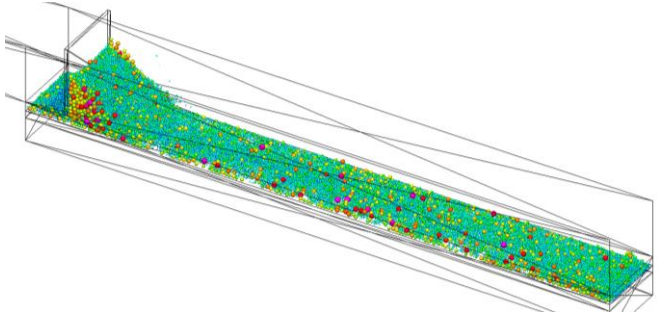
Assumptions & Results

- Hard spheres
- Coating mechanisms
  - Rigid coater arm
  - Roller
  - “Soft” coater
- Friction coeff. are “determined” via uncertainty quantification

Statistical Analysis



- D50
- D_{av}
- Powder size distribution
- Packing density



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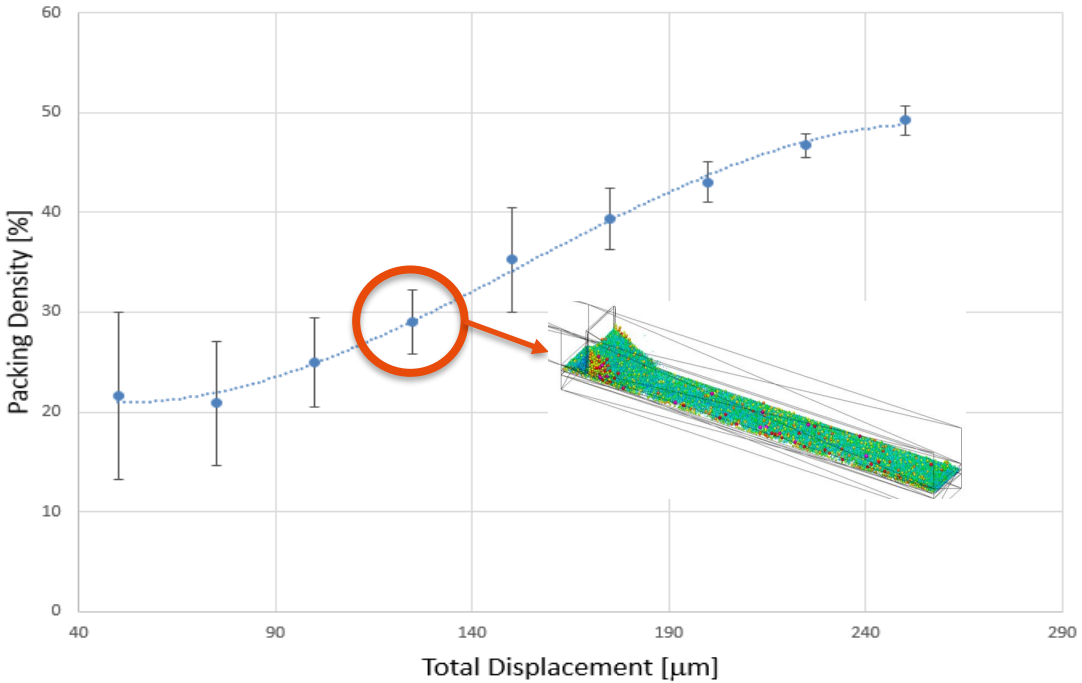
Coating Models

Powder Bed Packing Density



H.-W. Mindt et al., Metallurgical and Materials Transactions A, Vol. 47A, No. 4, 2016, DOI: 10.1007/s11661-016-3470-2.

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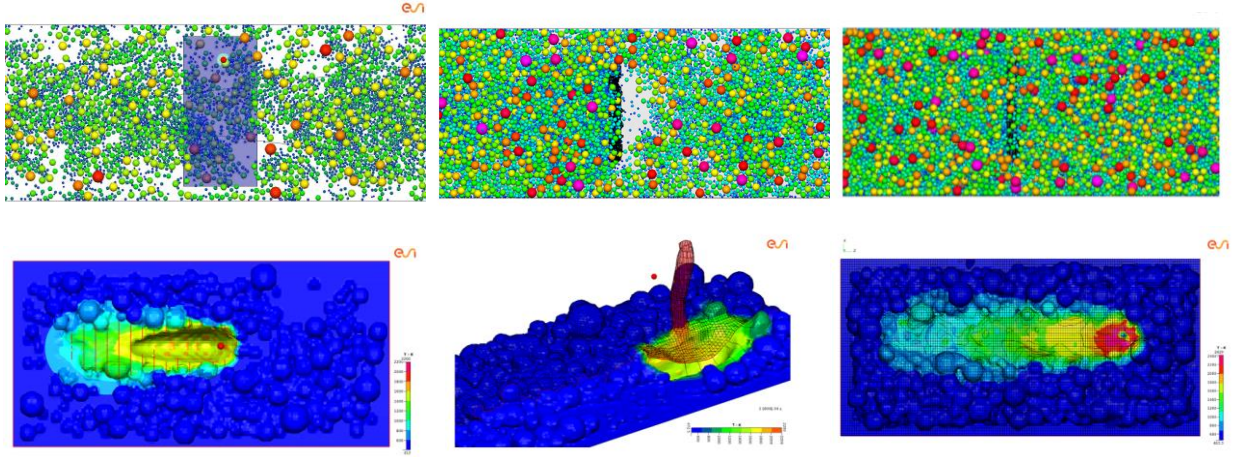
Detailed Process Modelling



Relevant Splatter

Melt pool

	Experiment Fraunhofer ILT	Simulation
Depth	111,83 ± 9,27 µm	129,59± 7,85
Width	116,50 ± 18,56 µm	94,00 ± 10,00

H.W. Mindt et al., 7th European Conference for Aeronautics and Space Sciences (EUCASS), July 3-6, 2017, Milano, Italy

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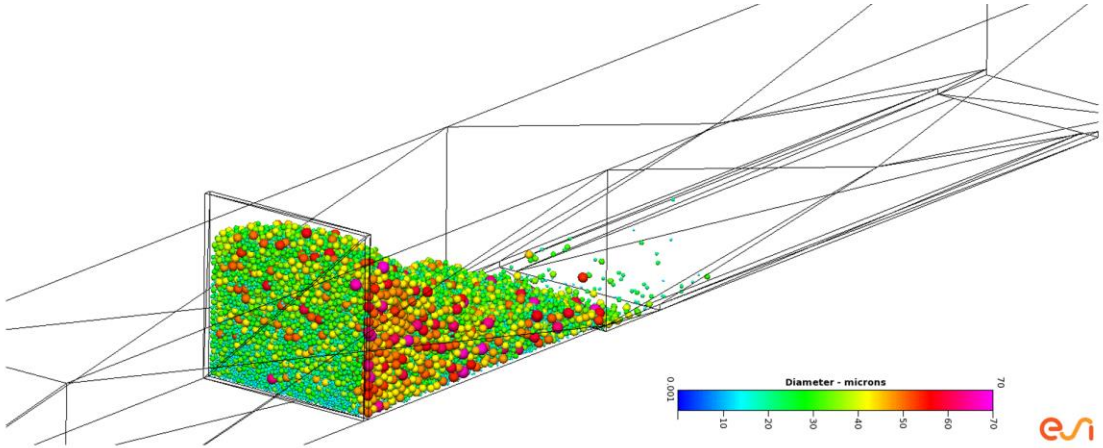
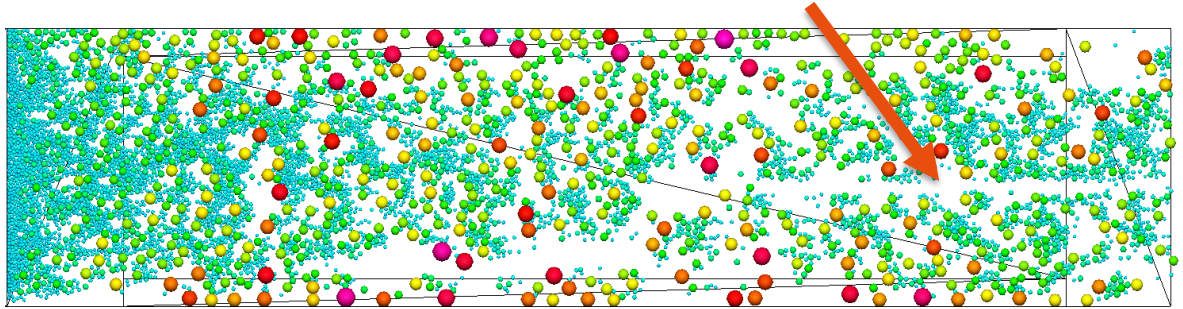
Powder Bed Uniformity

Corn rowing





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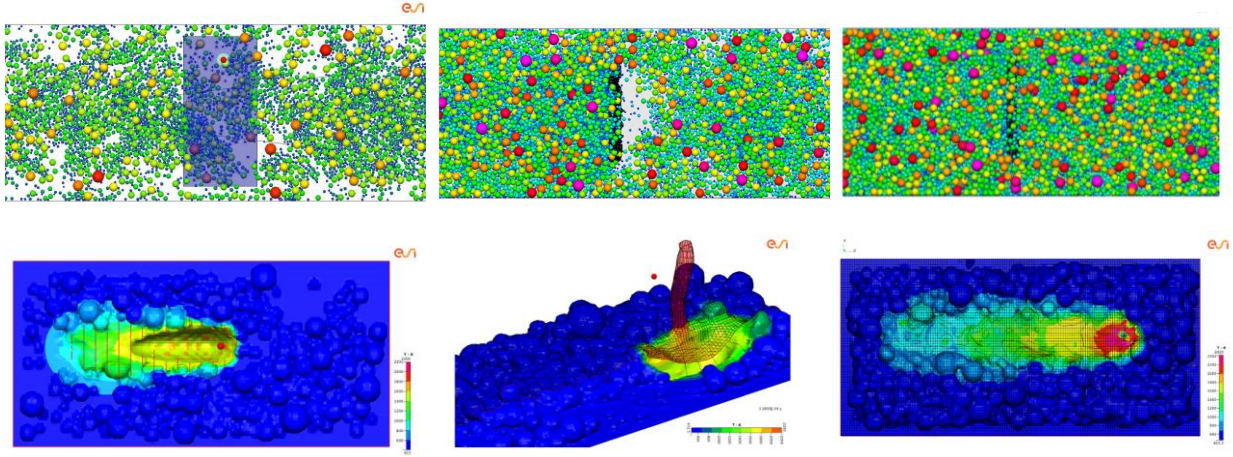
Detailed Process Modelling



Relevant Splatter

- Consequences of powder layer nonuniformity
  - Porosity
  - Corn rowing
- Note worthy observations
  - Differing layer thicknesses
  - Particle segregation

Melt pool

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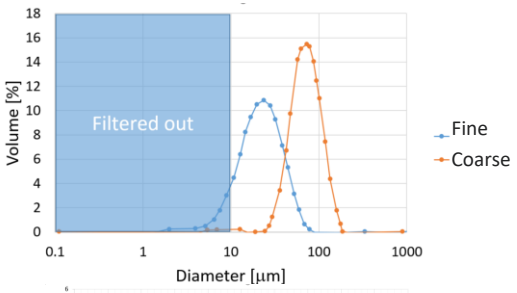
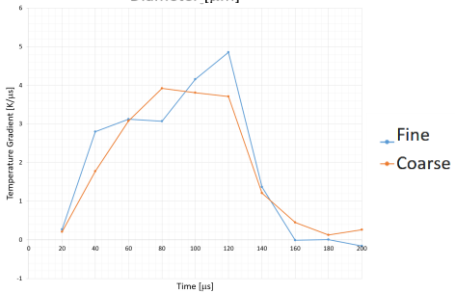
Other Topics

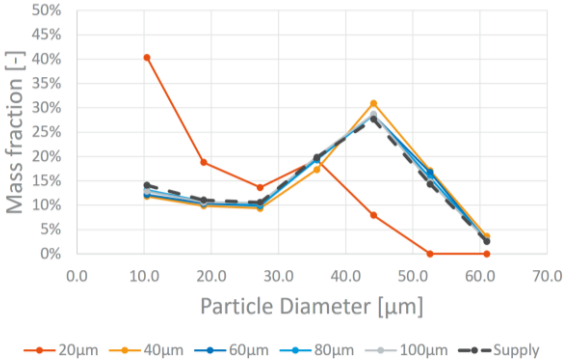
PSD & Coating Mechanism

PSD

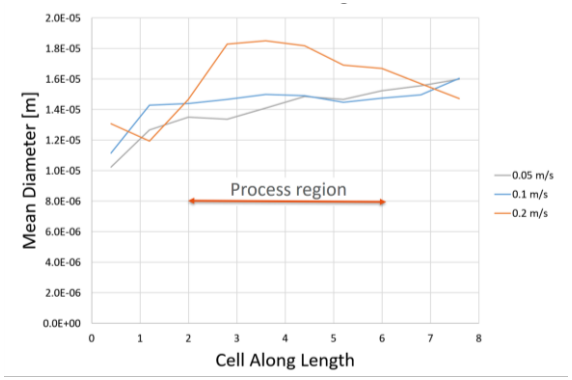




Recycling



Coater arm speed



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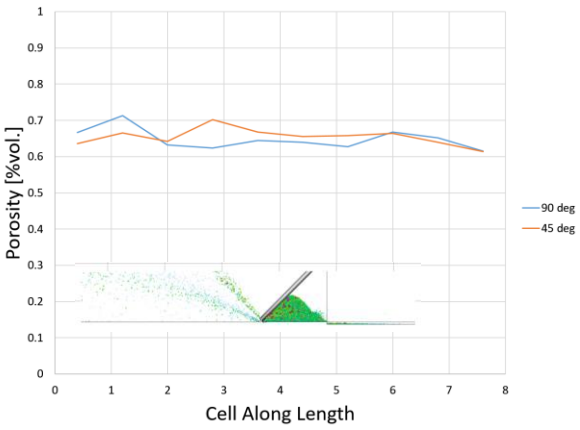
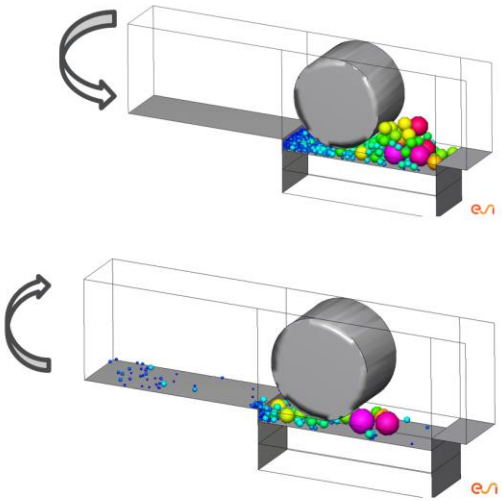
Other Topics

Coating Mechanisms & Design Parameters

Blade design



Coating Mechanism



…&.

- Container
- Vibration
- Gas flow
- …

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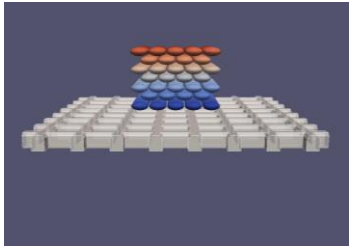
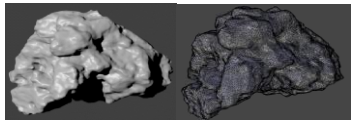
Outlook

Modelling

- Non-spherical particles
- Agglomeration and additional particle interactions





Experimental Work

- Sensors to confirm and quantify many of the observed phenomena
- Need dedicated effort to identify influence of unexpected behavior on final product quality

Feedback to Real Life

- Standardization of powder quality metrics
- Standardization of powder layer quality metrics
- Machine design

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Summary

- Powder delivery system affects manufacturability in many ways
  - Build orientation
  - Material consolidation
  - Potential for speed up
- Modelling is a powerful tool
  - Hostile environment can be analyzed in detail
  - Captures many of the known phenomena reliably
  - Revealed some unexpected behaviors
- Need for more validation data
- Need for standardization

- I look forward to the breakout sessions …

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Thank you

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