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
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

- 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

1Powder 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

![Graph showing frequency and cumulative percentage for different AR values](image)

- Initialisation using a Rainfall technique

![Diagram showing initialisation process](image)

Simulation Set-up

oko Particle Shapes

Imapet Milled PEEK 450G

<table>
<thead>
<tr>
<th>$A_r$</th>
<th>Frequency</th>
<th>Cumulative %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>3</td>
<td>40</td>
<td>60</td>
</tr>
<tr>
<td>4</td>
<td>60</td>
<td>80</td>
</tr>
<tr>
<td>5</td>
<td>80</td>
<td>100</td>
</tr>
</tbody>
</table>

$D_p = 50 \, \mu m$

$A_r = 1.0$

$A_r = 2.5$

oko Initialisation using a Rainfall technique\(^1\)

Simulation Set-up

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

![Diagram showing simulation set-up with various labels and notations](image)
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

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

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The Process Parameters Impact\(^1\)

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Particle Alignment

- Spreader Speed
- Bed thickness
- Aspect ratio
- Isotropic distribution

\[ \Pr(\zeta < |20|) = 0.06 \]

Initial Distribution (After Rainfall)

<table>
<thead>
<tr>
<th>Ar</th>
<th>1.5</th>
<th>2.0</th>
<th>2.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>\Pr(\zeta &lt;</td>
<td>20</td>
<td>)</td>
<td>0.088</td>
</tr>
</tbody>
</table>
Can the bed volume fraction be controlled by controlling particle shape distribution

Shape/Size segregation
Rainfall technique

- Some recent publications 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

![Diagram showing Neck Growth rates with non-dimensional neck size and non-dimensional time on the axes. The graph illustrates increasing aspect ratio (Ar) with Ar=1.0 and Ar=2.75, where separation occurs.]
Blade Geometry Optimisation\textsuperscript{1}

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

\[
\left(\frac{y}{a_s}\right)^{n_s} + \left(\frac{z}{b_s}\right)^{n_s} = 1
\]

\textsuperscript{1} Haeri, Powder Technology, 321 (2017) 94-104
Effectiveness of the Design

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

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- 50 combinations of $a_S$, $b_S$ and $n_s$ are tested
Realistic Particles

If the new design is still effective for realistic particle shapes

An improved multi-sphere approximation method based on Li’s

1 Haeri, Powder Technology, 321 (2017) 94-104
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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\(^1\) Haeri, Powder Technology, 321 (2017) 94-104
Realistic Particles

Is the new design still effective for realistic particle shapes

- An improved multi-sphere approximation method\(^1\) based on Li’s\(^2\)

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

\(^{1}\) Haeri, Powder Technology, 321 (2017) 94-104
Realistic Particles

- Is the new design still effective for realistic particle shapes
- An improved multi-sphere approximation method\textsuperscript{1} based on Li’s\textsuperscript{2}

\begin{align*}
N_{MSA} &= 726 \\
N_{MSA} &= 26 \\
N_{MSA} &= 11
\end{align*}

\textsuperscript{1} Haeri, Powder Technology, 321 (2017) 94-104
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?