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DEM simulations to predict the powder bed quality for additive manufacturing processes

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July 23rd, 2024

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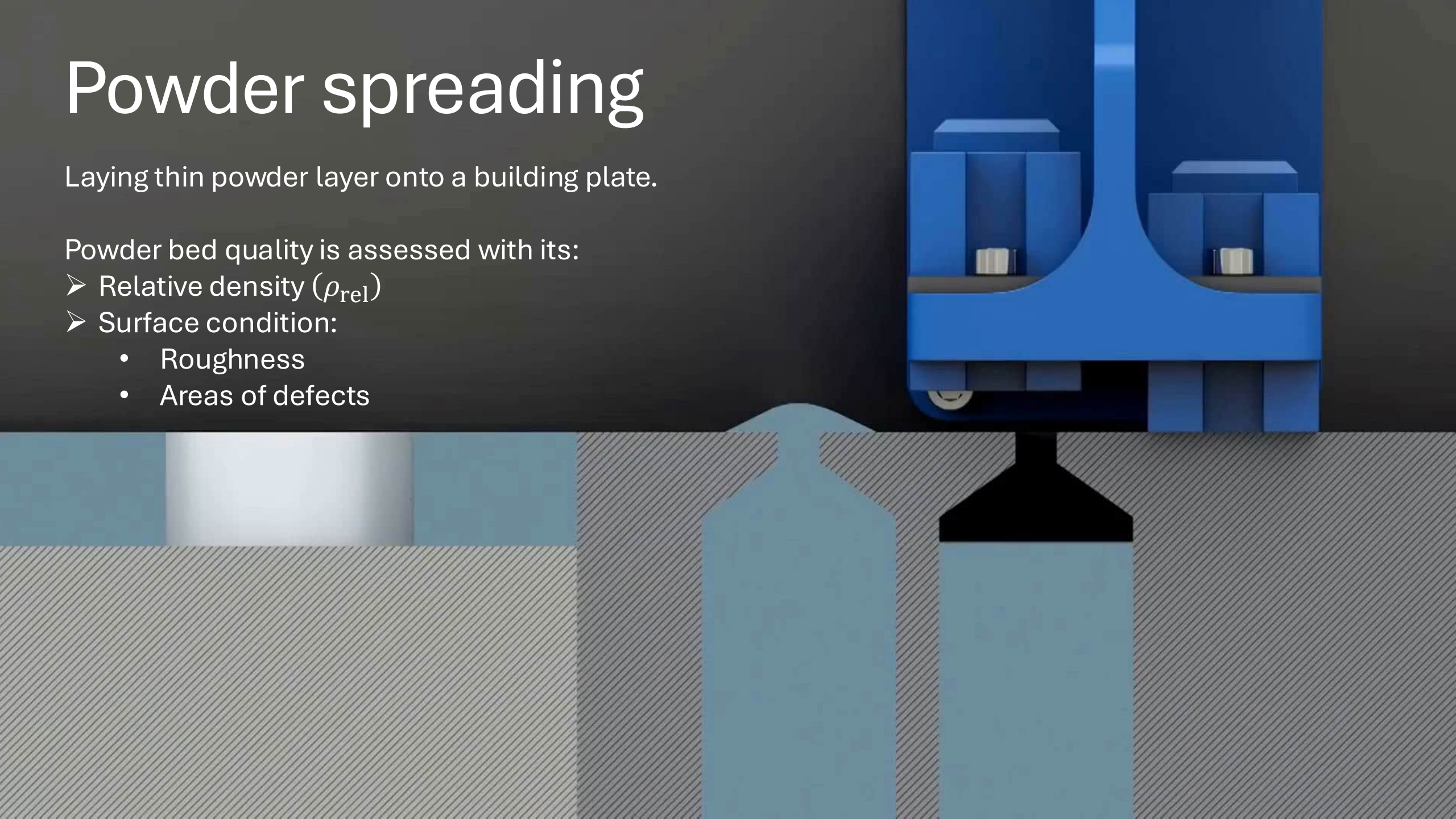
TECHNOLOGICAL UNIVERSITY

Powder spreading

Laying thin powder layer onto a building plate.

Powder bed quality is assessed with its:

- Relative density (ρ_{rel})
- Surface condition:
  - Roughness
  - Areas of defects



Powder spreading

The powder bed can impact the entire additive manufacturing (AM) process:

- Affects energy absorption (LPBF, EB-PBF)
- Affects powder-binder interaction (BJ)

Poor powder bed quality leads to defects:

- Porosity
- Lack of fusion

Powder spreading is time consuming:

- Represent 5-25% of the total manufacturing time

Poor powder spreading lead to:

- **Lower yields**
- **Lower production**
- **Slows the broad adoption of AM**

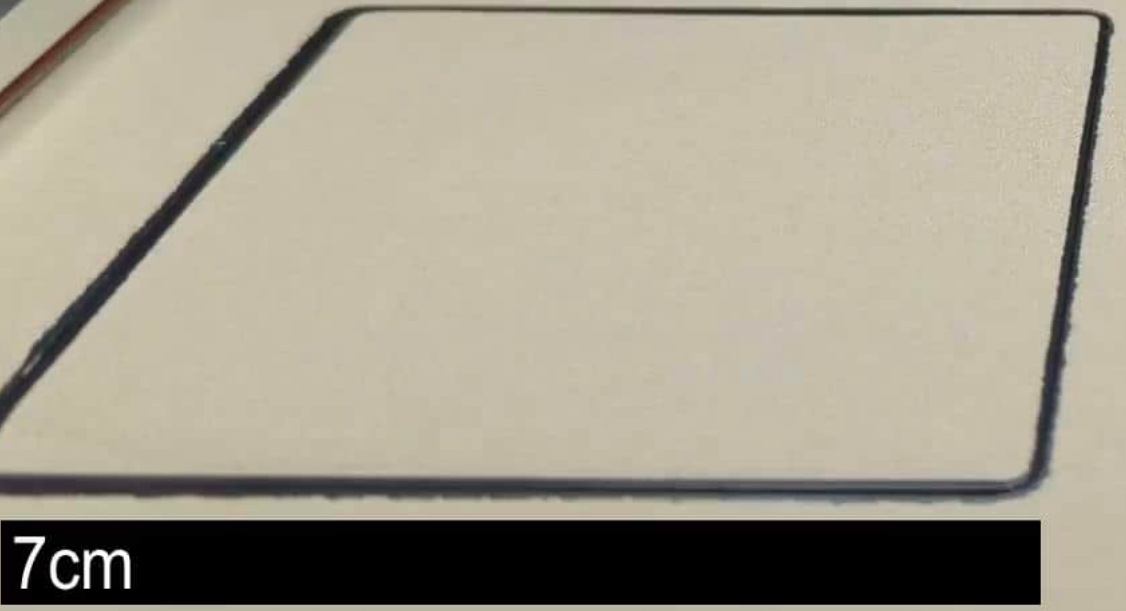
Assess what influences the powder bed quality.

Experimental set-up

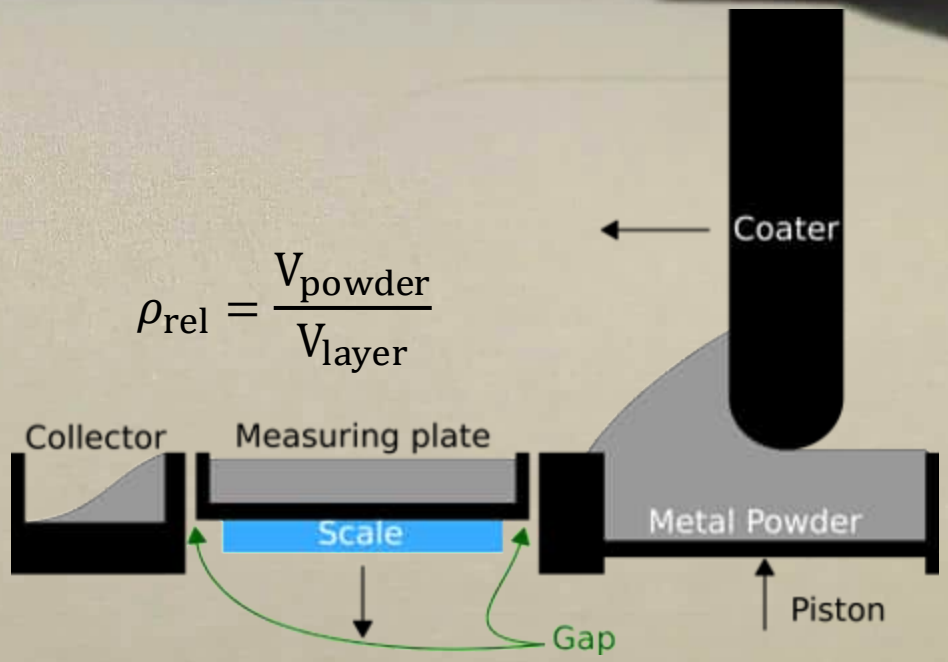
Assess the influence of operating parameters on the powder bed relative density (ρ_{rel}).

How it works :

- Extrude
- Push
- Vacuum
- Measure



$$\rho_{\mathrm{rel}} = \frac{\mathrm{V_{powder}}}{\mathrm{V_{layer}}}$$



Experimental set-up

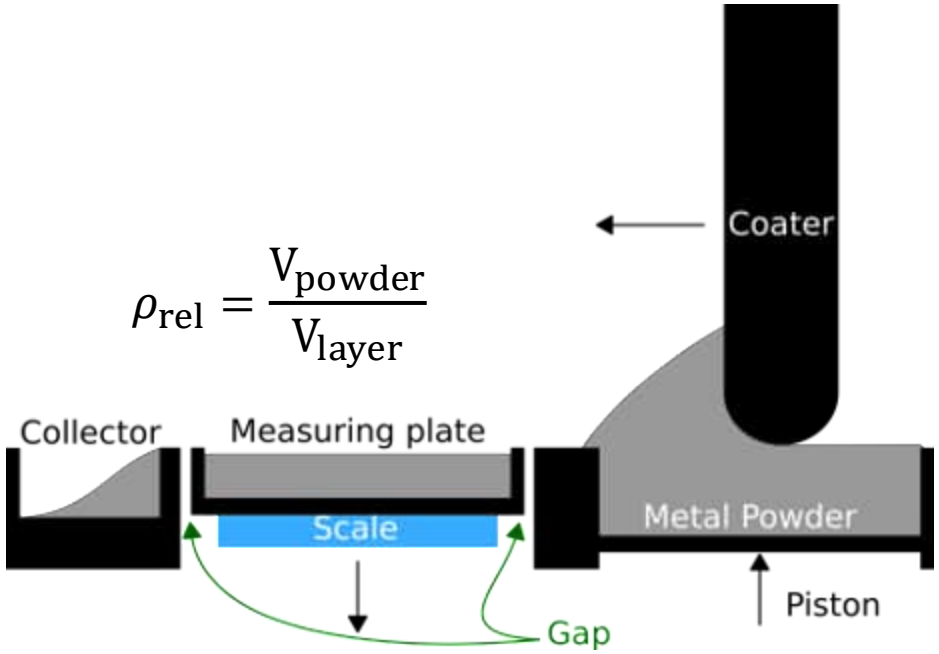
Assess the influence of operating parameters on the powder bed relative density (ρ_{rel}).

Operating parameters:

- Coater geometry
  - Round blade
  - Flat blade
  - Roller
- Layer thickness (L_{t})
- Coater traverse velocity (V)

Measure powder weight deposited each layer.

- Able to retrieve the:
  - Layer effective relative density (LRD)
  - Cumulative relative density (CRD)



Experimental set-up

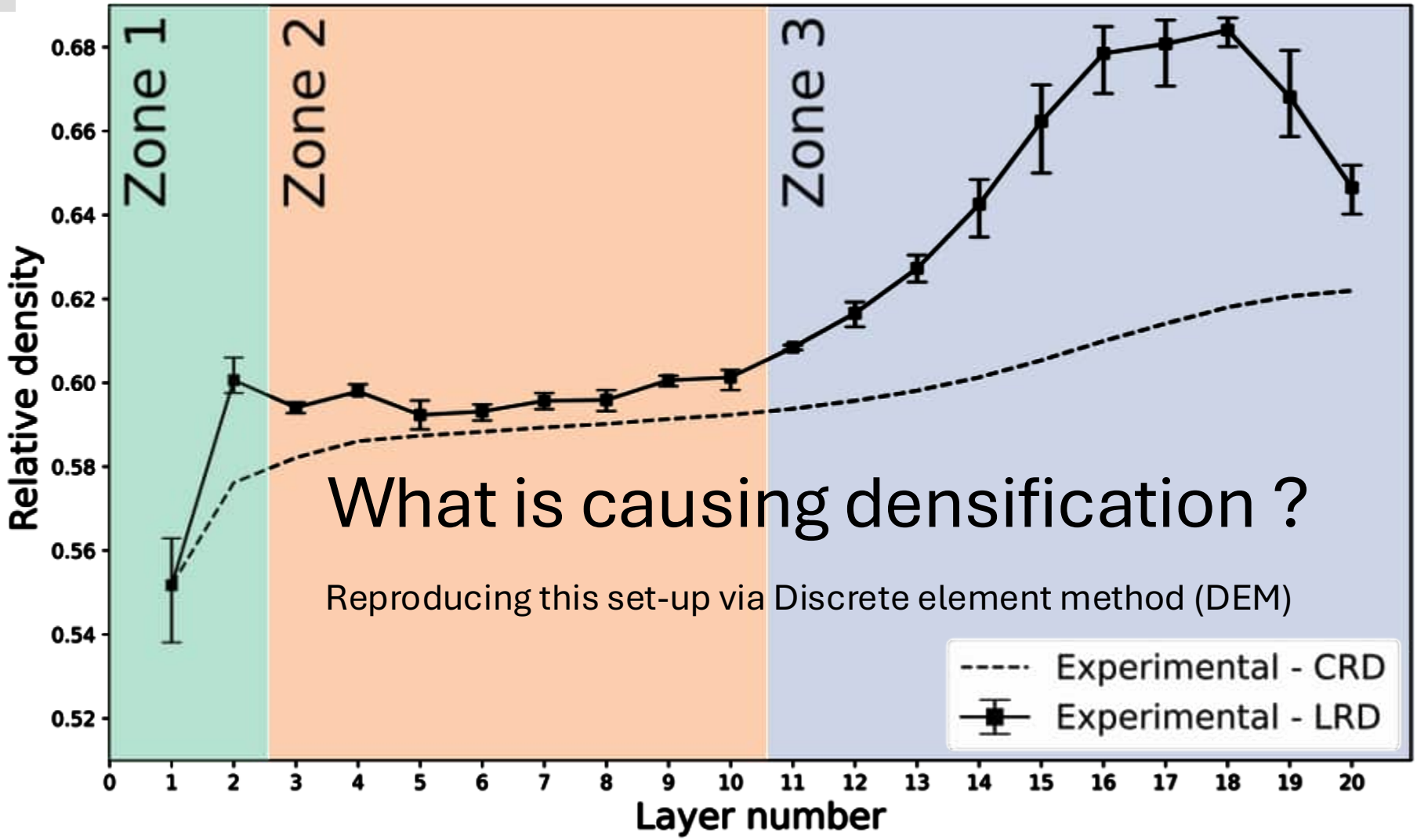
Ti-6Al-4V : 45-106 µm
$V = 10$ mm/sec
$L_t = 100$µm

3 zones can be seen:

Zone 1: First layer effect

Zone 2: Plateau

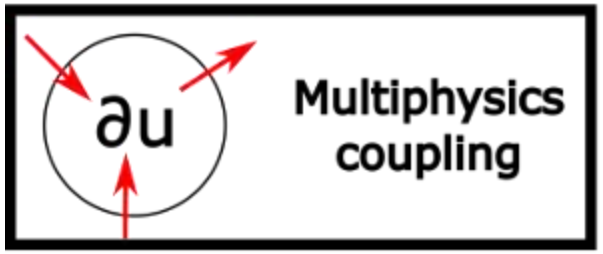
Zone 3: Densification

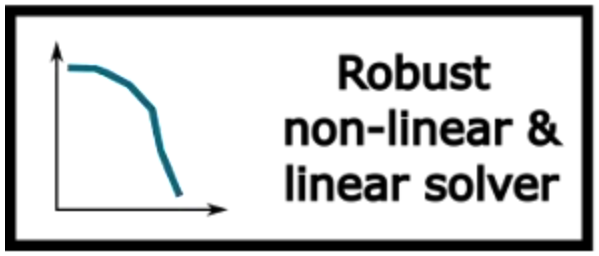


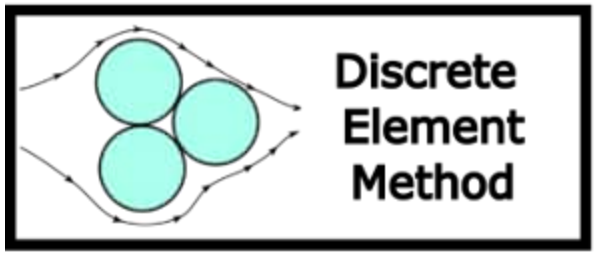
Presentation outline

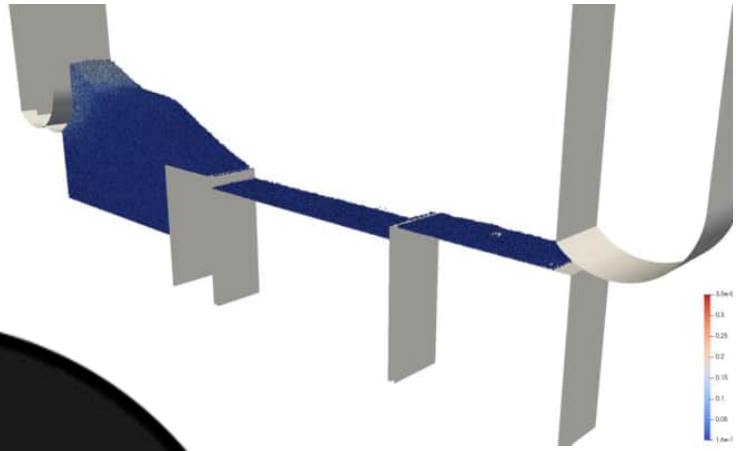
1. Proposed solution: Discrete element method
2. Simulation results
3. Concluding remarks
4. Future work

1. Proposed solution









https://github.com/chaos-polymtl/lethe

deal.II

Discrete element method (DEM)

- Useful tool to model granular system, including powder spreading.
- Provides insights at the particle scale.
- Method based on Lagrangian description of particle motion.

Newton's second law of motion:

$$m_i \frac{d\mathbf{v}_i}{dt} = \sum_{j \in C_i} \left(\mathbf{F}_{ij}^n + \mathbf{F}_{ij}^t\right) + m_i \mathbf{g}$$

Euler's law of angular motion:

$$I_i \frac{d\boldsymbol{\omega}_i}{dt} = \sum_{j \in C_i} \left(\mathbf{M}_{ij}^t + \mathbf{M}_{ij}^r\right)$$

m_i: Particle mass

$\mathbf{v_i}$: Particle velocity

$\mathbf{F}_{ij}^n$: Normal contact force

$\mathbf{F}_{ij}^t$: Tangential contact force

$\mathbf{g}$: Gravity

I_i: Moment of inertia

$\boldsymbol{\omega}_i$: Angular velocity

$\mathbf{M}_{ij}^t$: Tangentiel friction torque

$\mathbf{M}_{ij}^r$: Rolling friction torque

Additive manufacturing powders

Particle size distribution generally between 10 and 100 μm

- Cohesive forces: Van der Waal (VdW)
  - Same order of magnitude as gravity
  - Affect the spreadability of powders

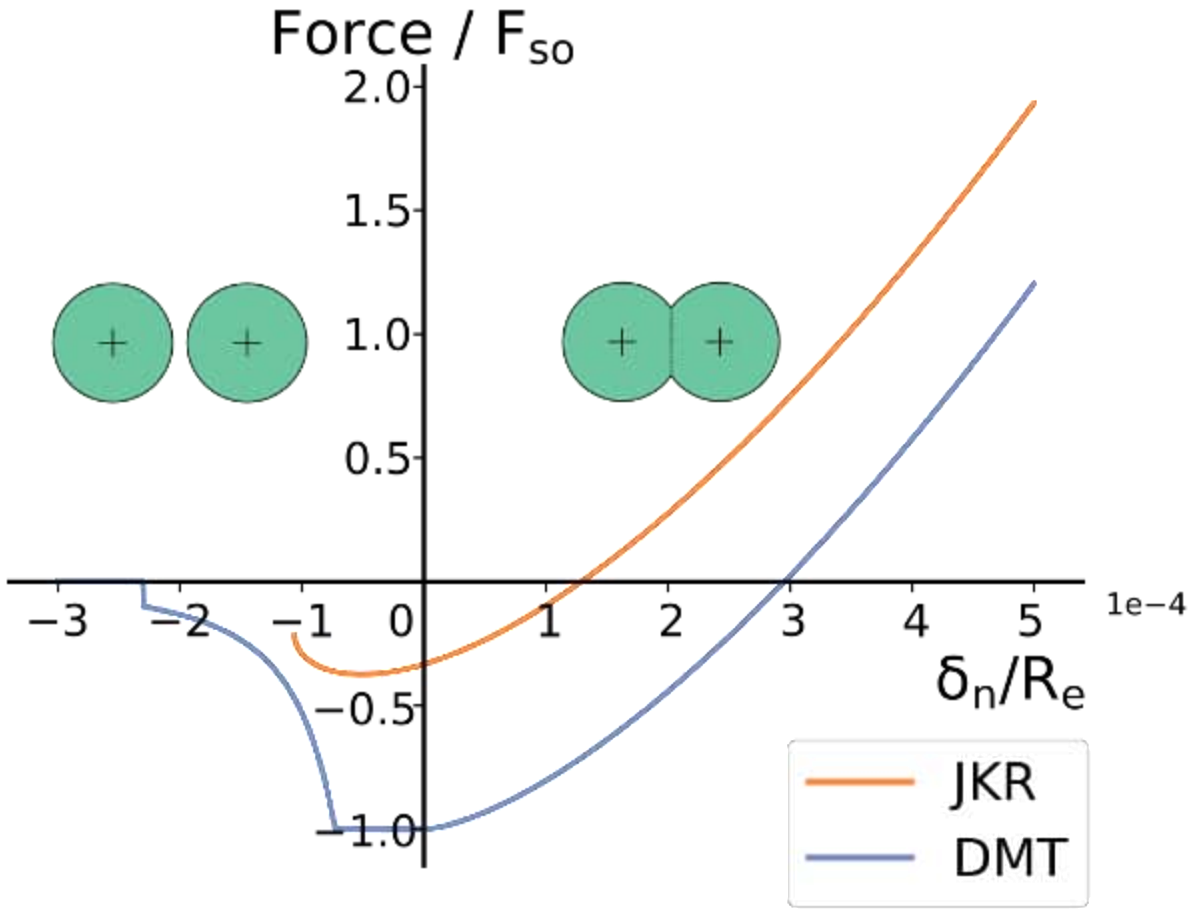
Need to consider cohesive forces:

- Johnson-Kendall-Roberts (JKR)
- Derjaguin-Muller-Toporov (DMT)

Particle properties need to calibrated:

- Friction coefficient (μ_T)
- Rolling friction coefficient (μ_R)
- Surface energy (γ)

Note: Results shown today use the JKR model.



R_e: Effective radius F_{so}: DMT Pull-off force

δ_n: Normal overlap

Simulation set-up

DEM simulation can be computationally expensive.

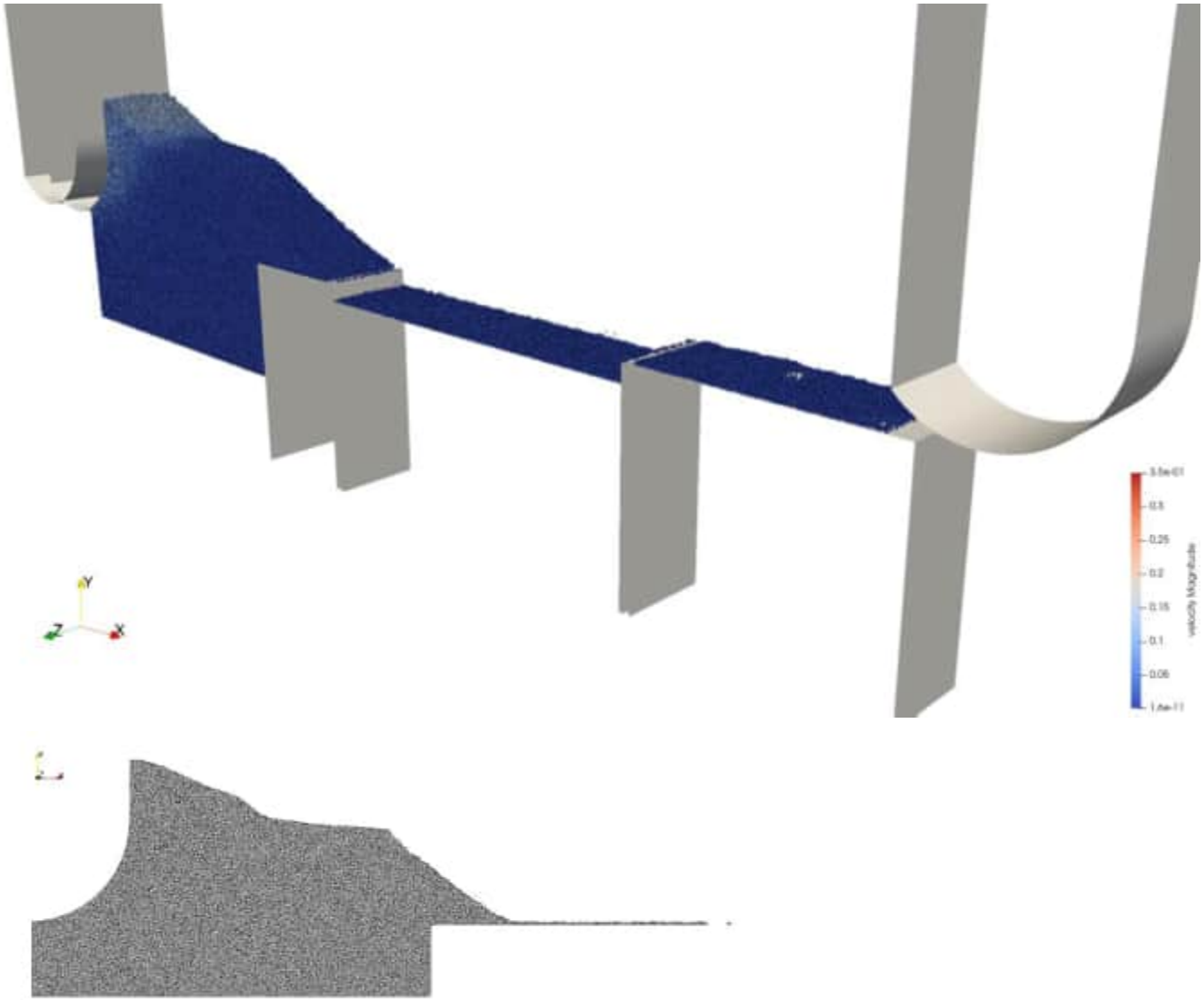
- Number of particles (> 1 million)
- Process duration
- Time step (< 3e-7)

Features have been implemented to minimize simulation cost:

- Superposing coaters displacement.
  - Reduce down time between layer.
- Particle insertion.

Model reduction hypothesis:

- Periodic boundary conditions.
- Build plate 1 centimeter long instead of 7.



2. Simulation results

Results for two sets of surface properties

Plan of simulations:

- 20 layers simulations
- Different friction coefficient (μ_T)

First simulation (1) :

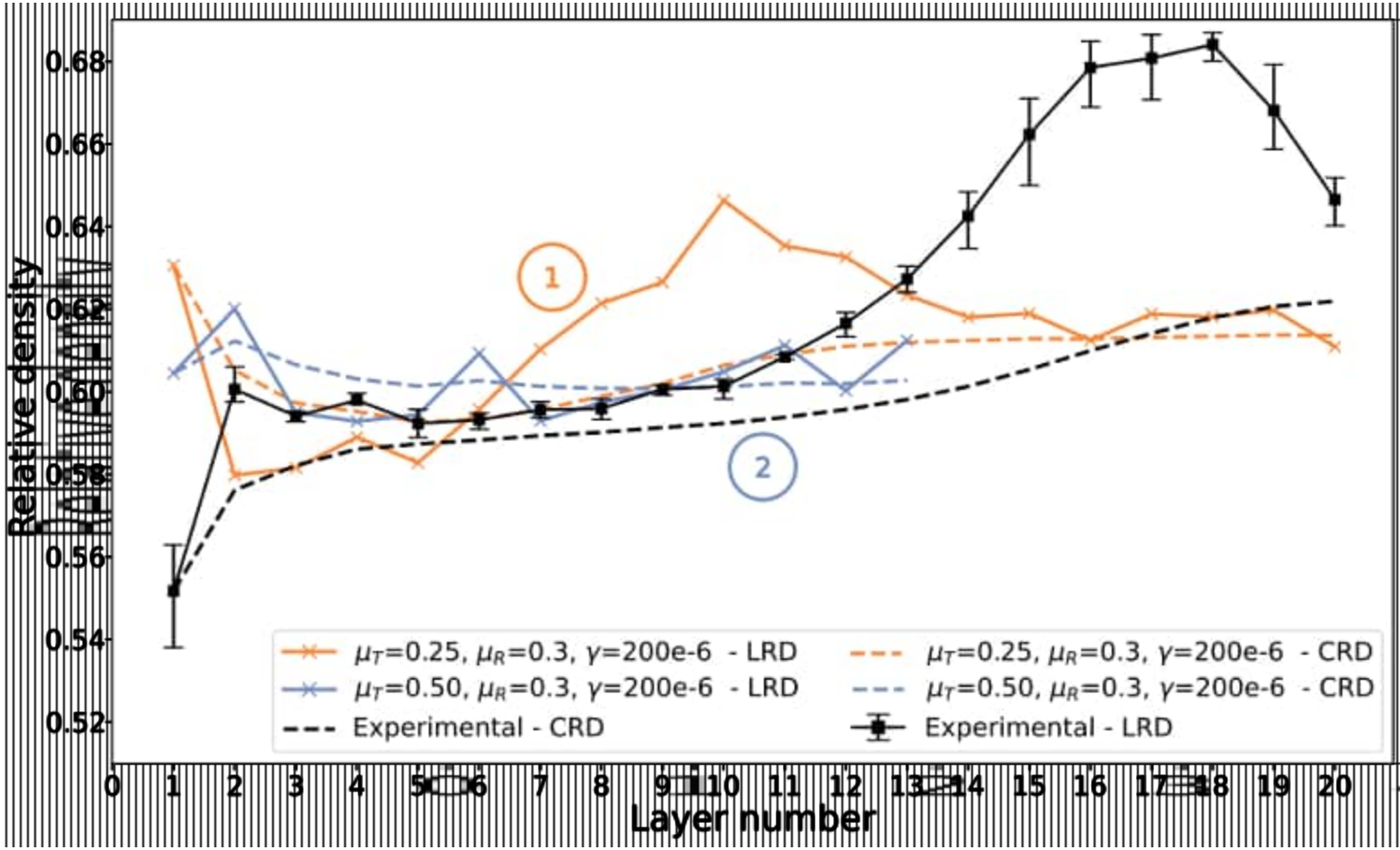
- Small densification phenomenon starts at layer #7.

Second simulation (2):

- No densification.

Surface properties have an impact on the relative density.

What is happening on the build plate for the first simulation?



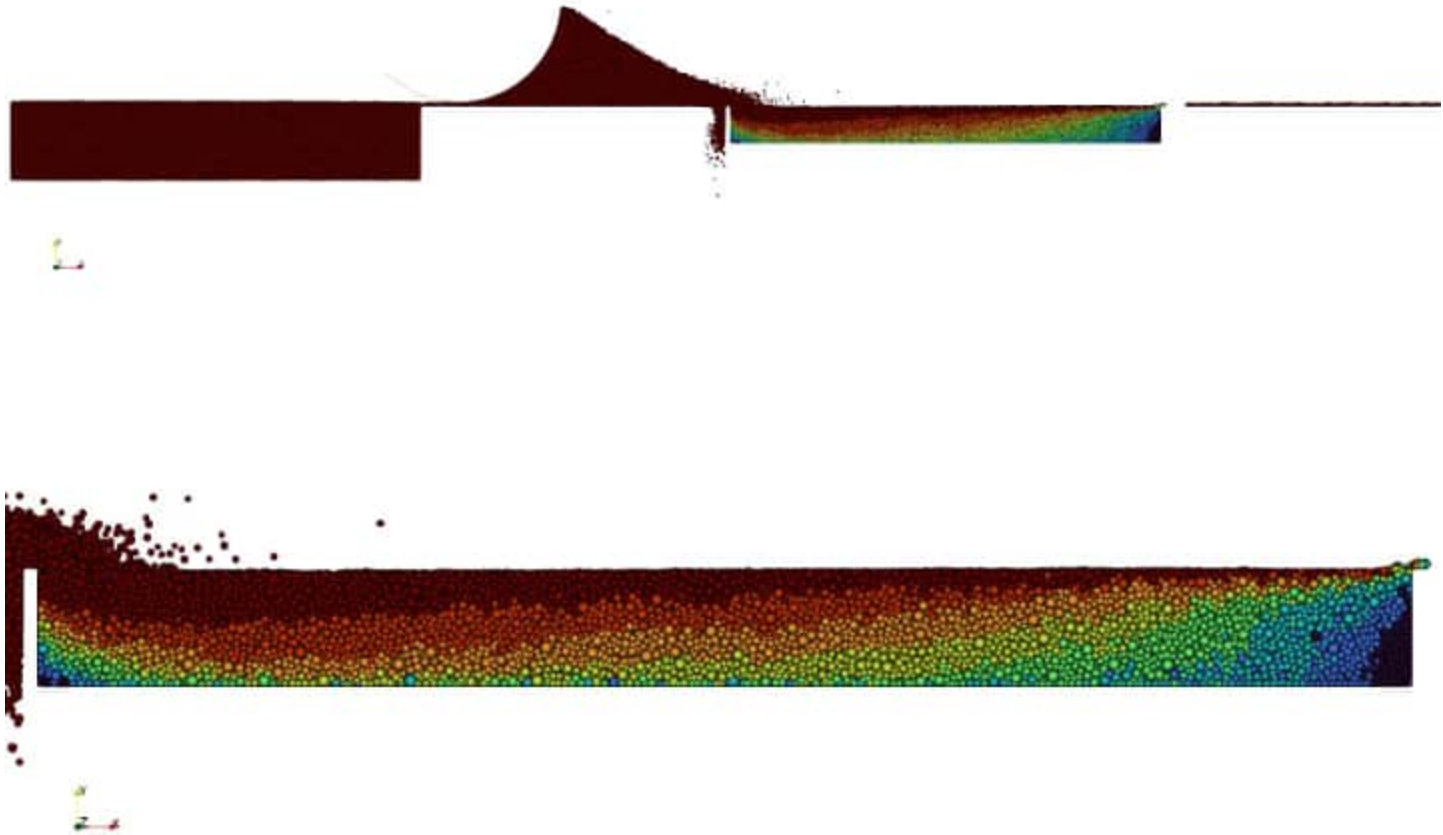
LRD: Layer Relative Density

CRD: Cummulative Relative Density

Build plate side view

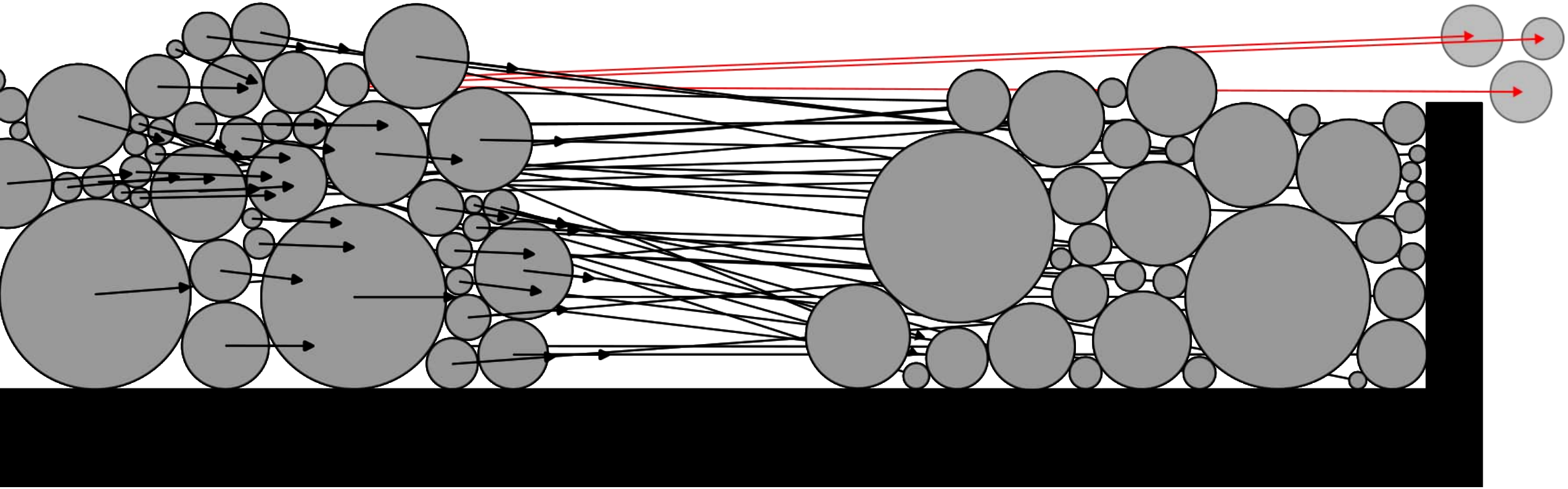
Each particle has been colored according to its layer number.

- A lot of particles are being removed.
- A lot of particle mixing between layers.
- Static zones are forming at start and at the end of the build plate.



How can we better visualize the particle displacement on the powder bed?

Displacement field



Displacement field: Simulation 1

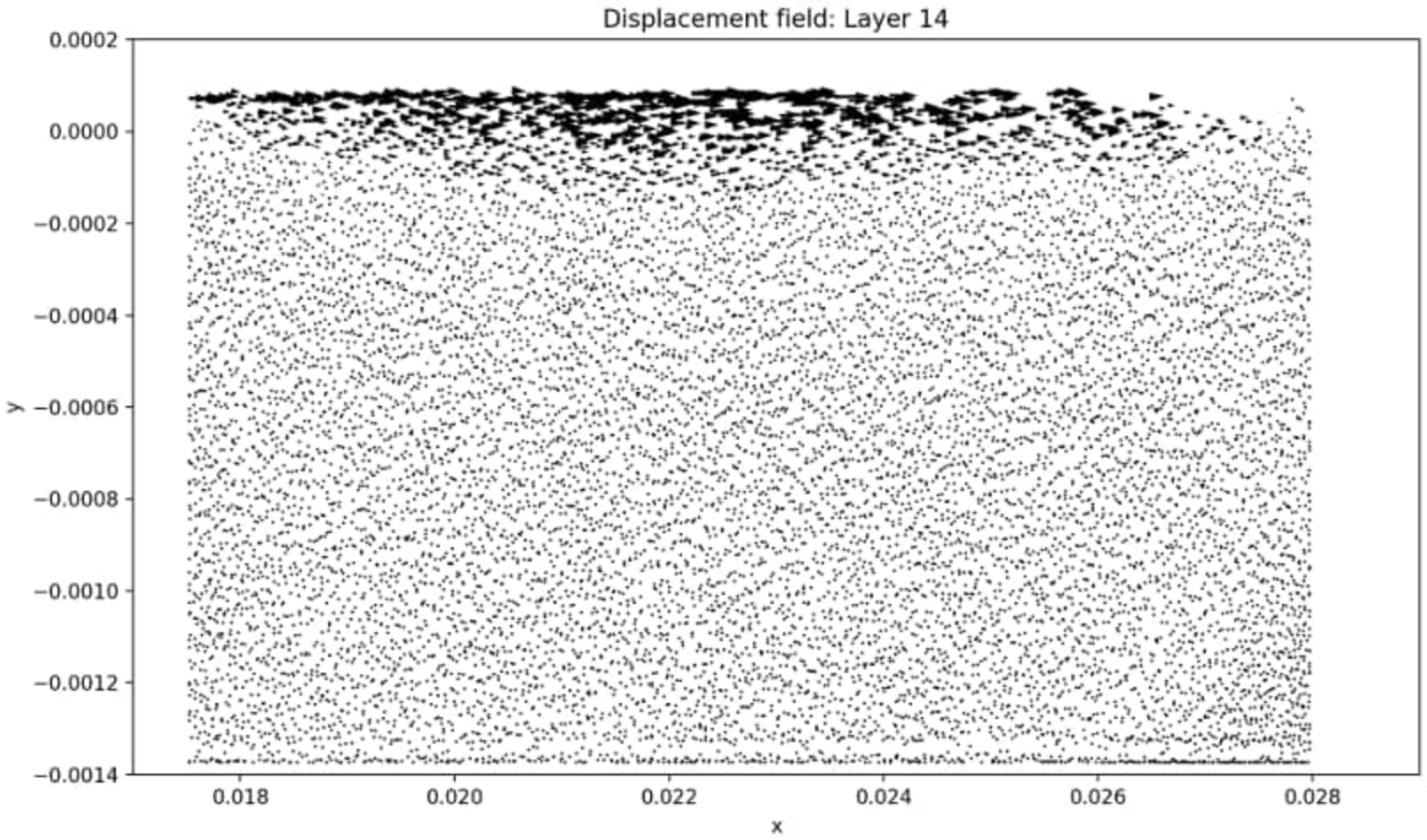
First set of surface properties:

- Densification starts at layer 7.
- Peaks at layer 9 to11.
- Decrease at layer 12 and after.

Densification begins when the two static zones connect.

Decrease begins when the powder bed start to behave like a fluid.

What is happening for the set of surface properties?



Displacement field: Simulation 2

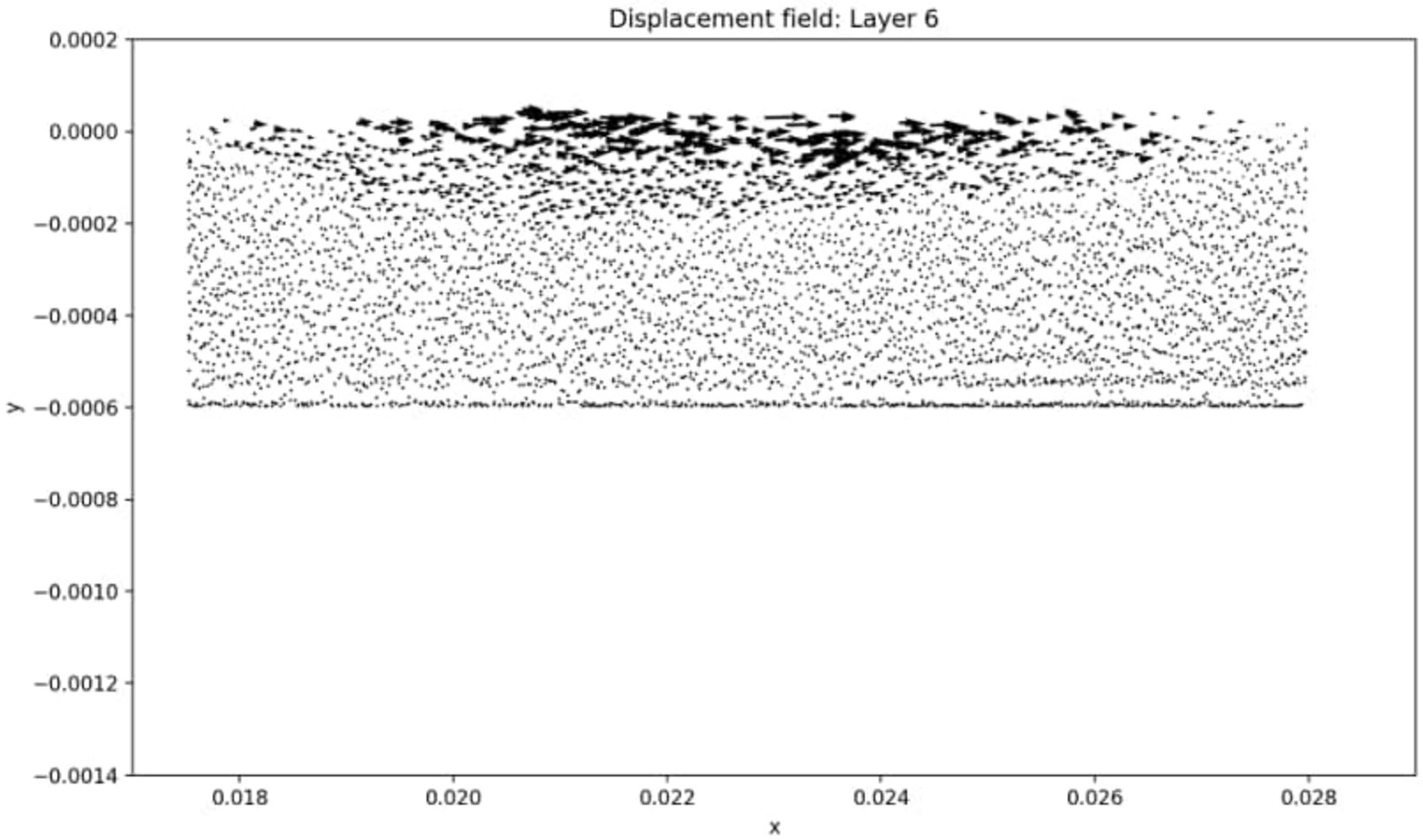
Second set of surface properties:

- No densification

Static zones connect earlier.

- The powder bed is too shallow to allow for a densification.

What happens if we increase the length of the domain in the X direction?



Increase the length in spread direction

Length of the domain has been increased by a factor 2:

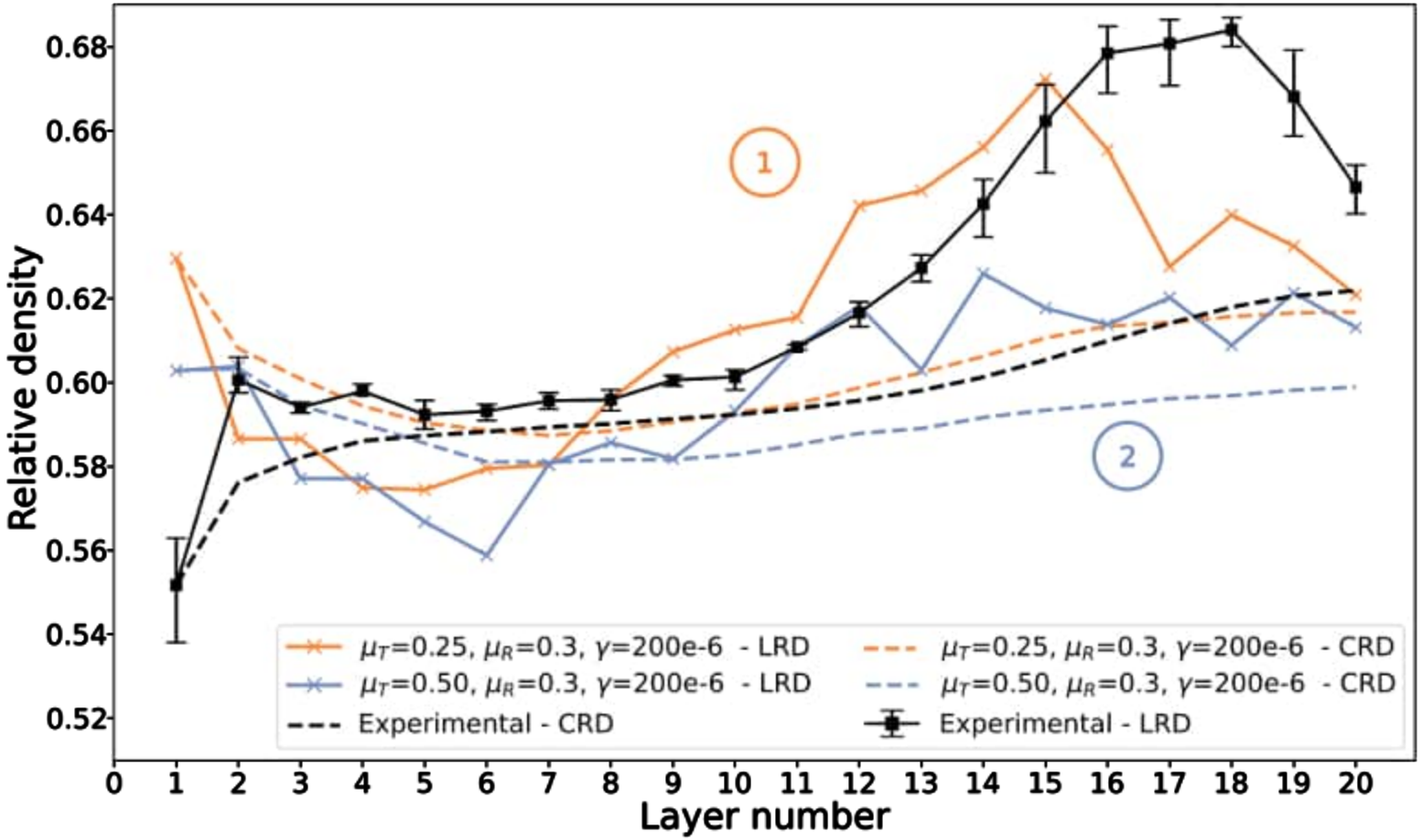
- 2 centimeters instead of 1.

First simulation (1)

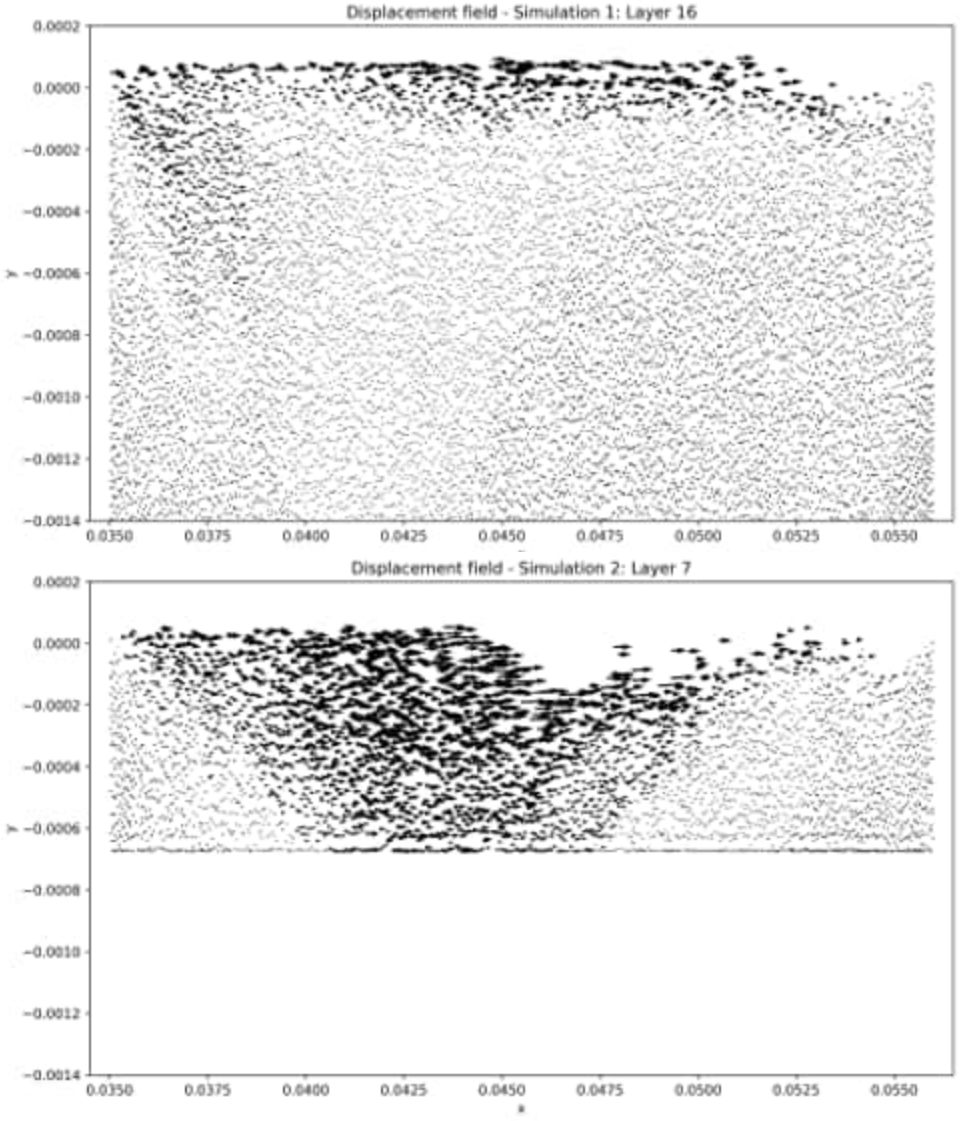
- Better agreement with experimental results.

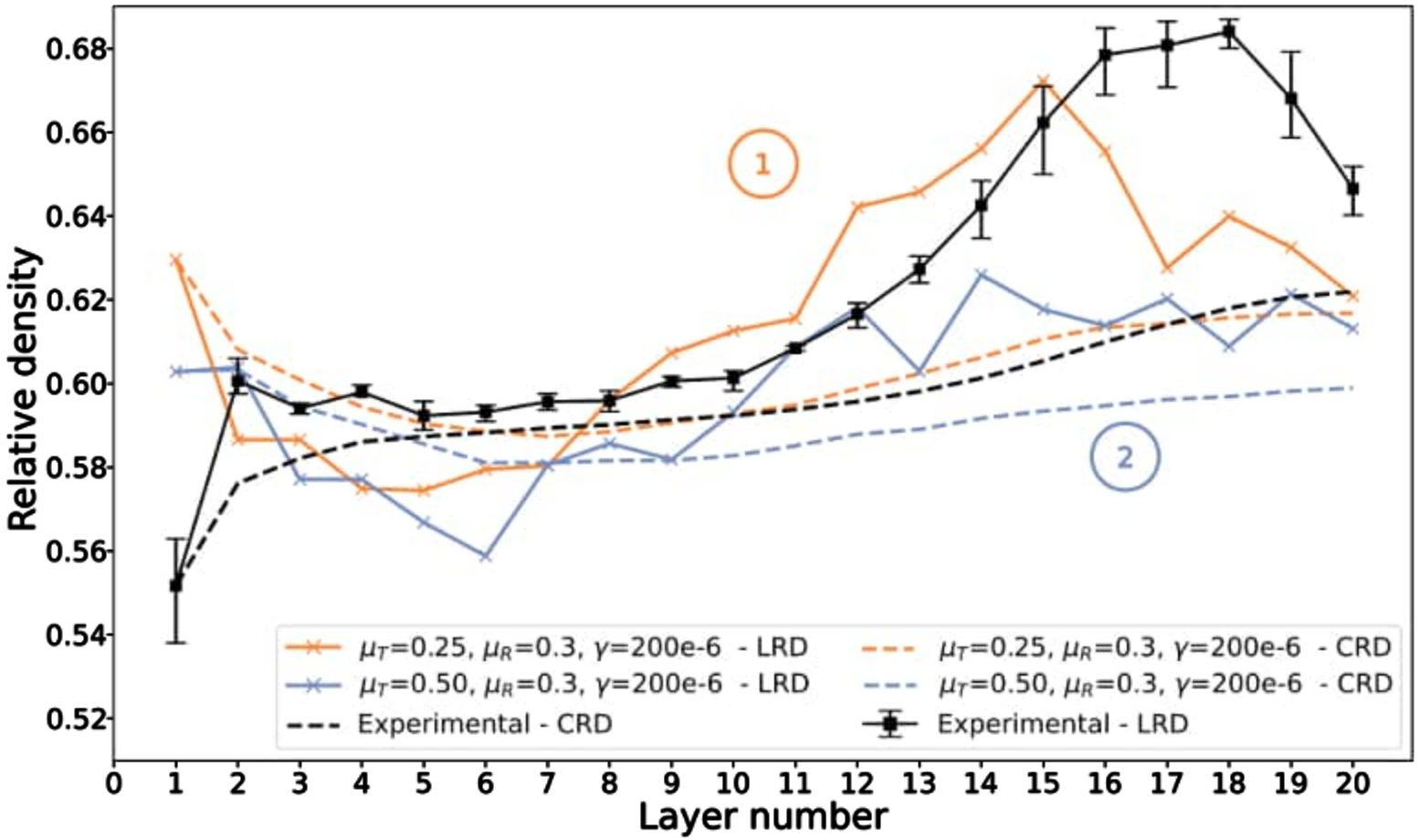
Second simulation (2):

- Densification occur at layer 10.



Increase the length in spread direction





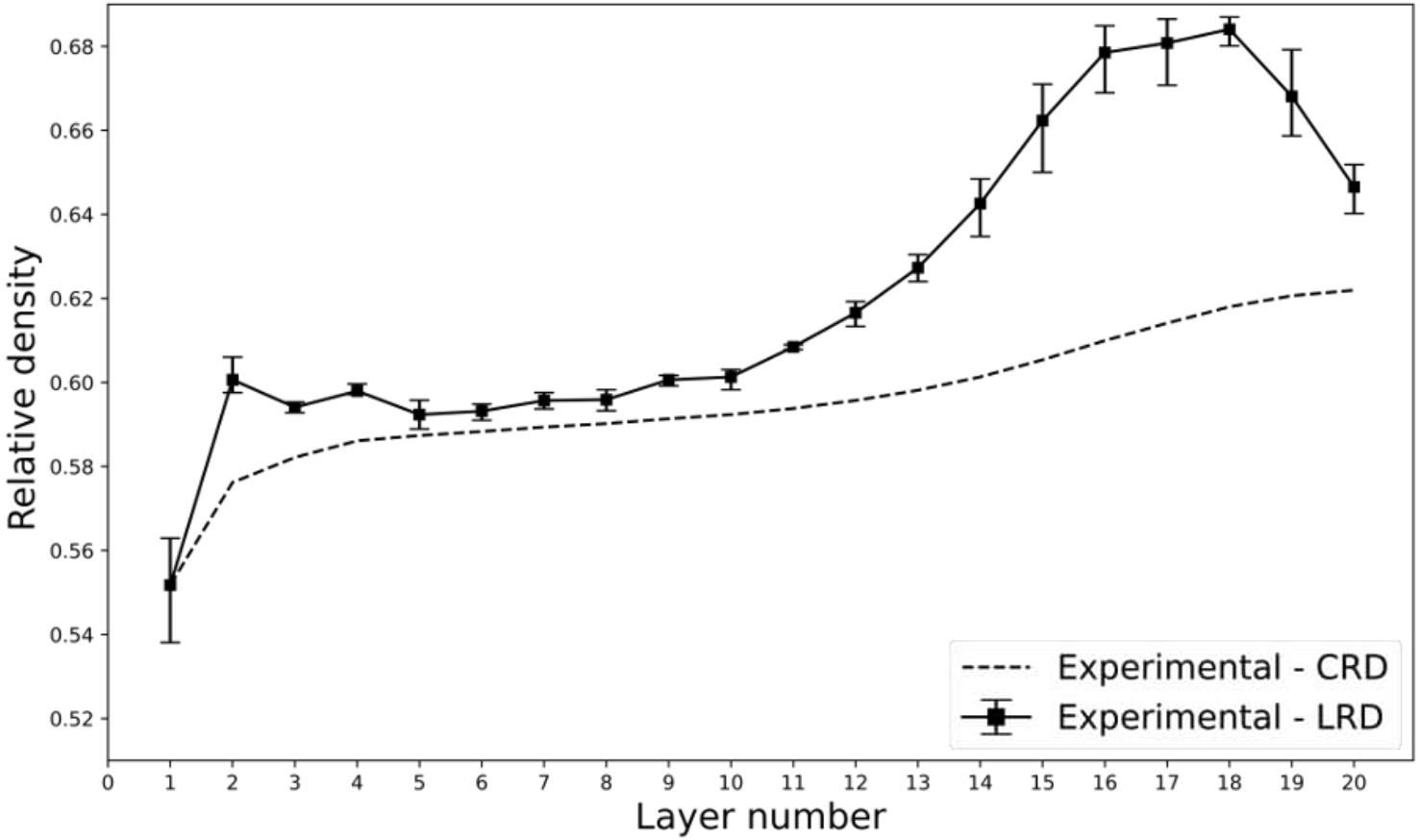
Concluding remarks

- DEM simulations can reproduce the **densification phenomenon** seen on the experimental set-up.

- The densification phenomenon is related to the **length of the build plate** and the **particles surface properties.**

Future work

- Geometry and parameter optimization.
- Flexible coater spreading simulations.



Thank you

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