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

Gaboriault, Olivier; Pelletier, Roger; Lefebvre, Louis-Philippe; Mélançon, David; Blais, Bruno

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

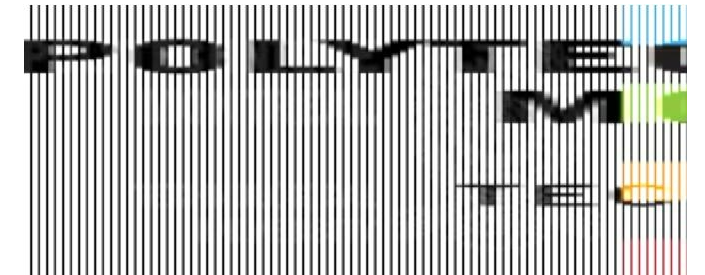
**Olivier Gaboriault**<sup>1,2</sup>, Roger Pelletier<sup>3</sup>, Louis-Philippe Lefebvre<sup>3</sup>, David Mélançon<sup>2</sup>, Bruno Blais<sup>1</sup>

July 23rd, 2024

<sup>1</sup>Chaos laboratory, Polytechnique Montréal

<sup>2</sup>LM2, Polytechnique Montréal

<sup>3</sup>National Research Council Canada

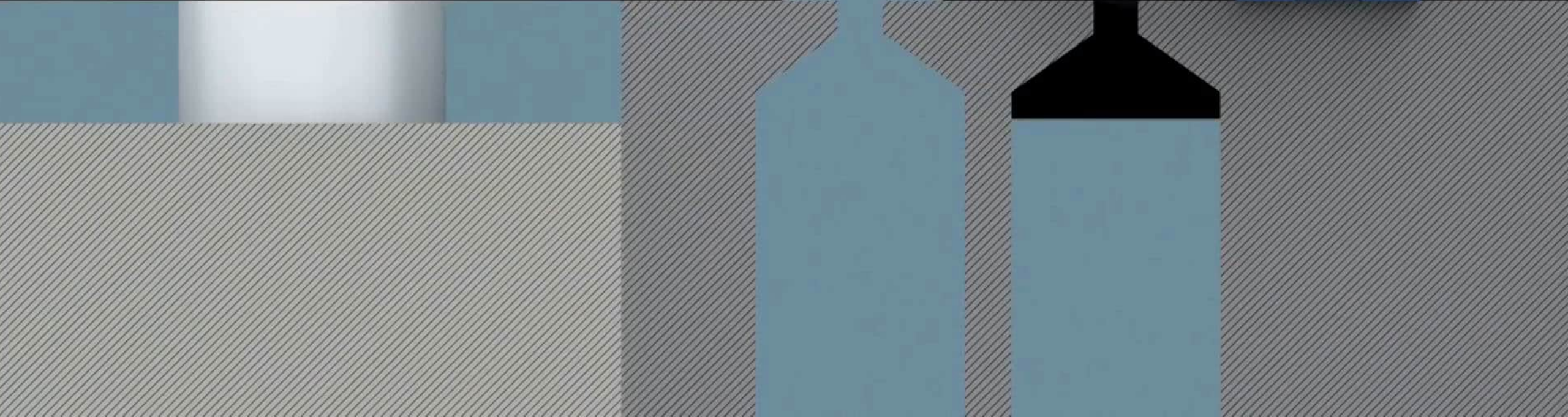


# Powder spreading

Laying thin powder layer onto a building plate.

Powder bed quality is assessed with its:

- Relative density ( $\rho_{rel}$ )
- 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**

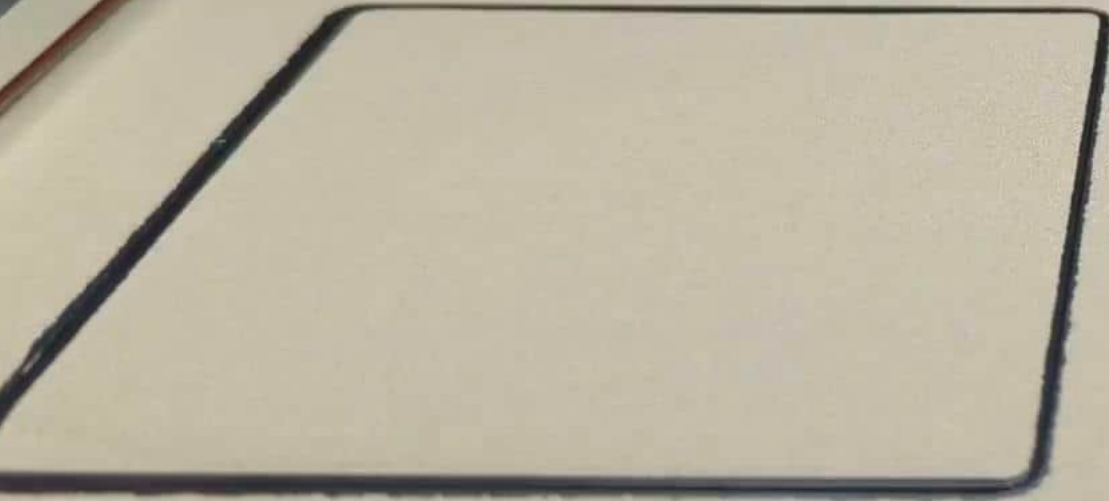
**Assess what influences the powder bed quality.**

# Experimental set-up

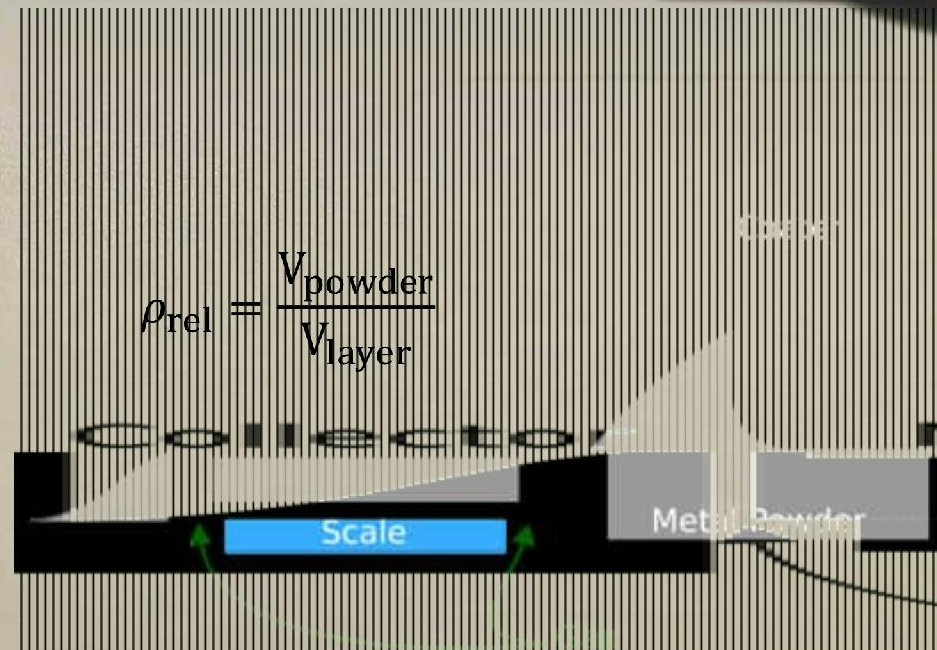
Assess the influence of operating parameters on the powder bed relative density ( $\rho_{\text{rel}}$ ).

How it works :

- Extrude
- Push
- Vacuum
- Measure



7cm



# Experimental set-up

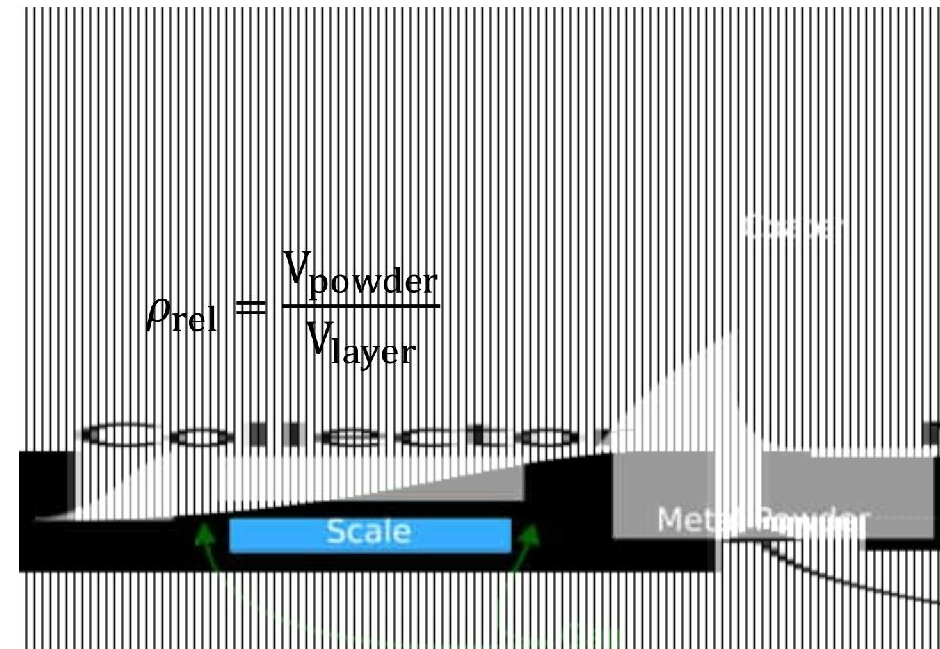
Assess the influence of operating parameters on the powder bed relative density ( $\rho_{\text{rel}}$ ).

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

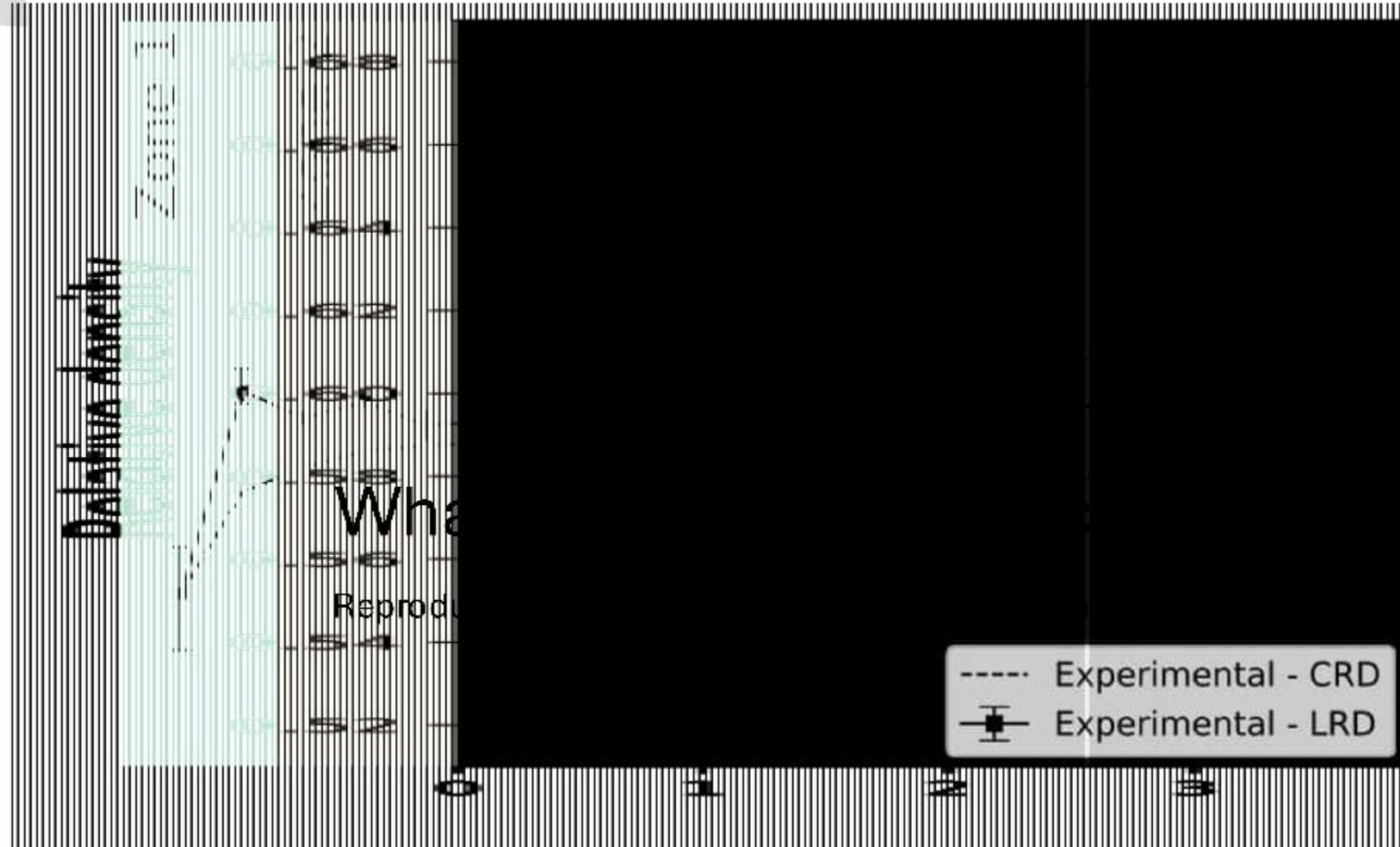
3 zones can be seen:

**Zone 1:** First layer effect

**Zone 2:** Plateau

**Zone 3:** Densification

Ti-6Al-4V: 45-106  $\mu\text{m}$   
 $V = 10 \text{ mm/sec}$   
 $L_t = 100 \mu\text{m}$



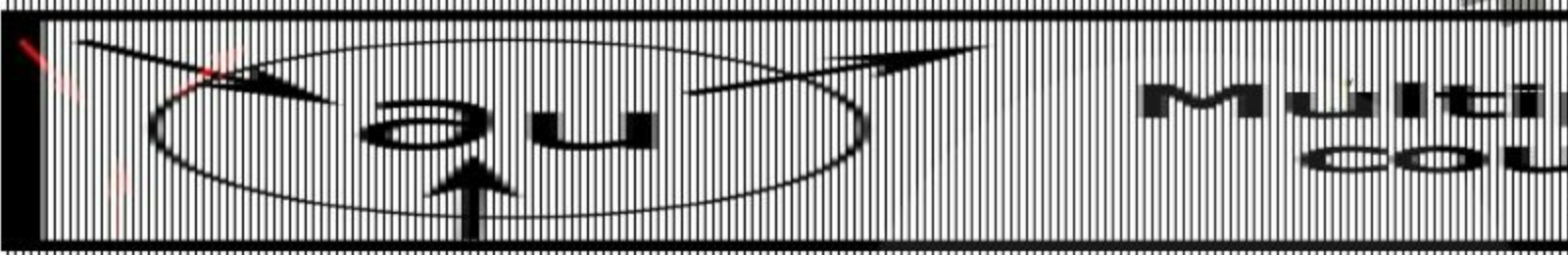
# Presentation outline

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

# 1. Proposed solution



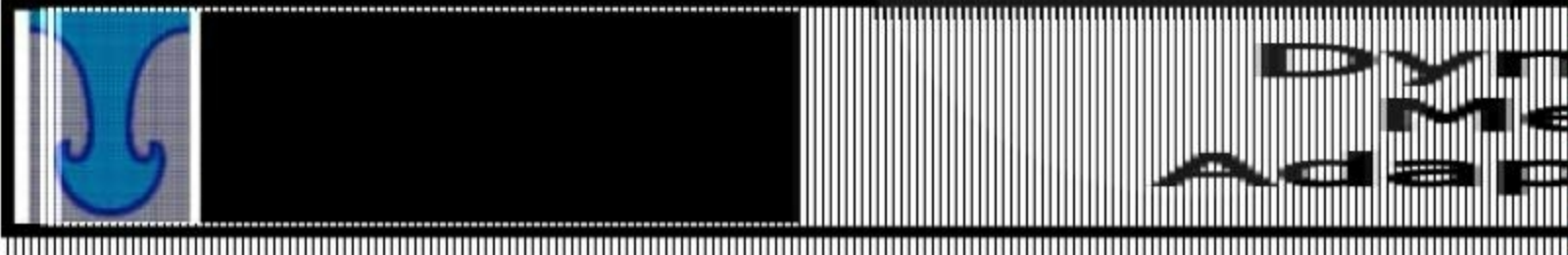
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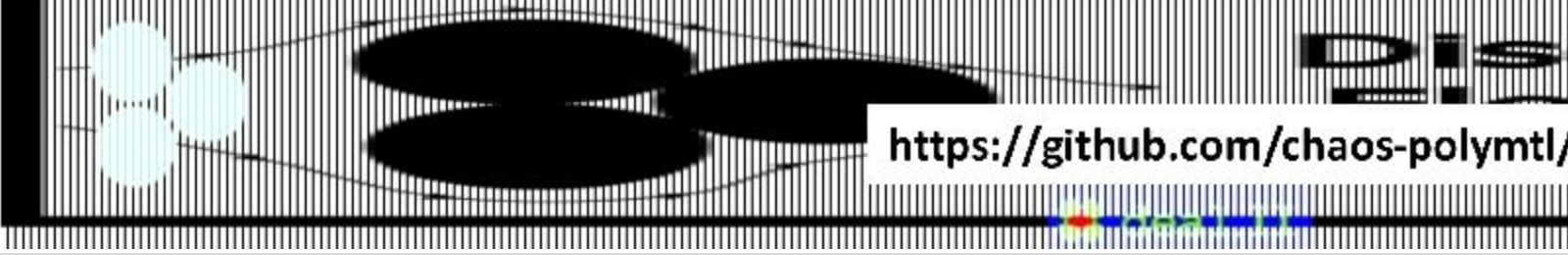
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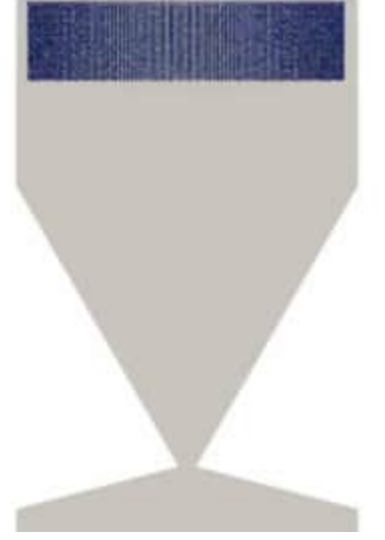
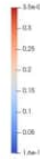
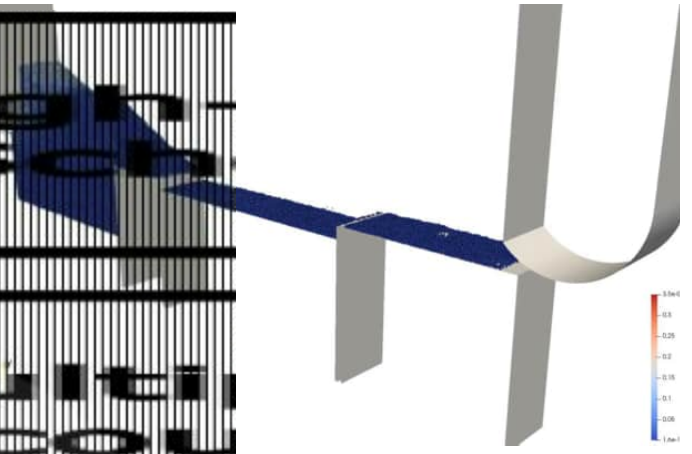


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<https://github.com/chaos-polymtl/lethe>



# 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:

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

## Euler's law of angular motion:

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

$m_i$ : 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

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

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

# Additive manufacturing powders

Particle size distribution generally between 10 and 100  $\mu\text{m}$

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

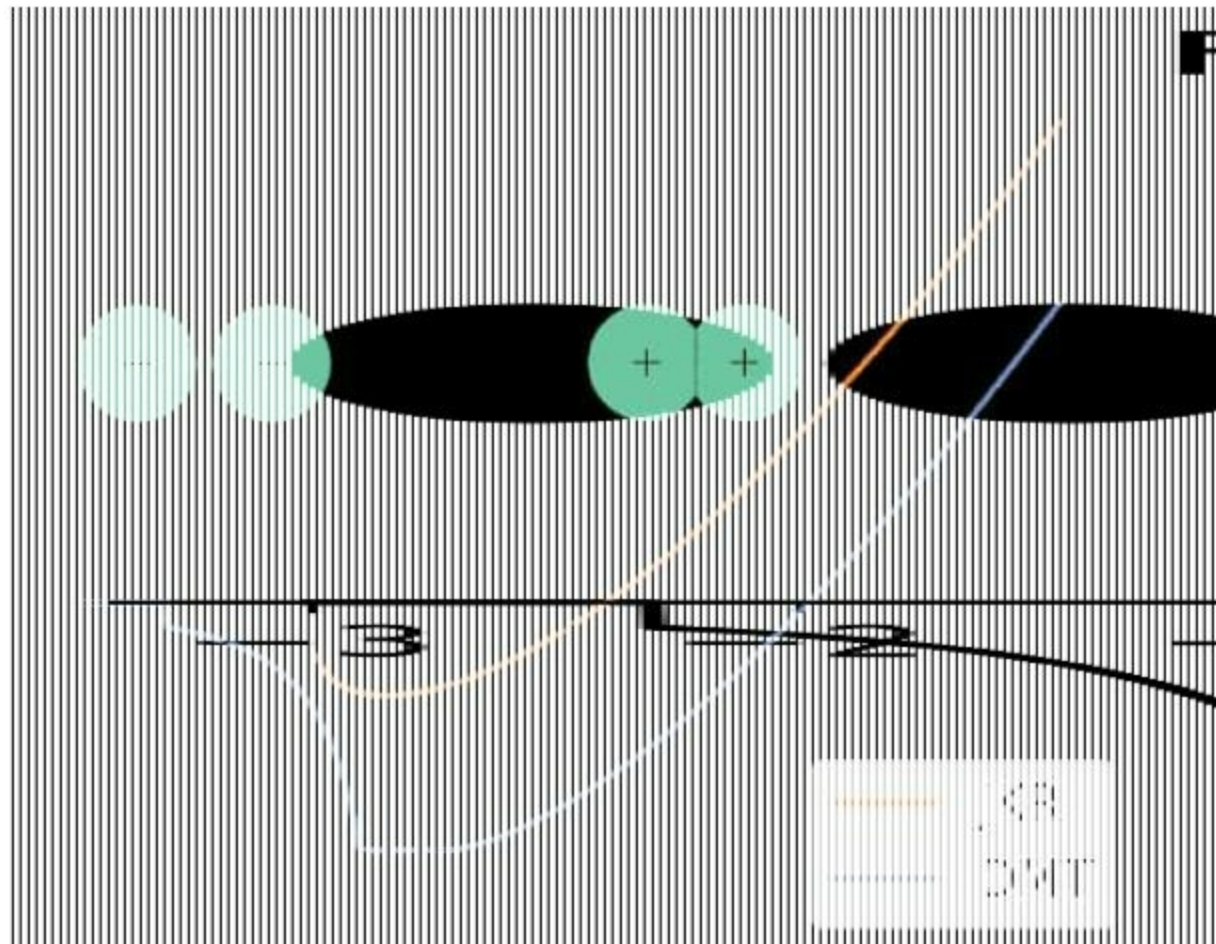
## Need to consider cohesive forces:

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

Particle properties need to be calibrated:

- Friction coefficient ( $\mu_T$ )
- Rolling friction coefficient ( $\mu_R$ )
- Surface energy ( $\gamma$ )

**Note:** Results shown today use the JKR model.



$R_e$ : Effective radius       $F_{s0}$ : DMT Pull-off force

$\delta_n$ : Normal overlap

# Simulation set-up

DEM simulation can be computationally expensive.

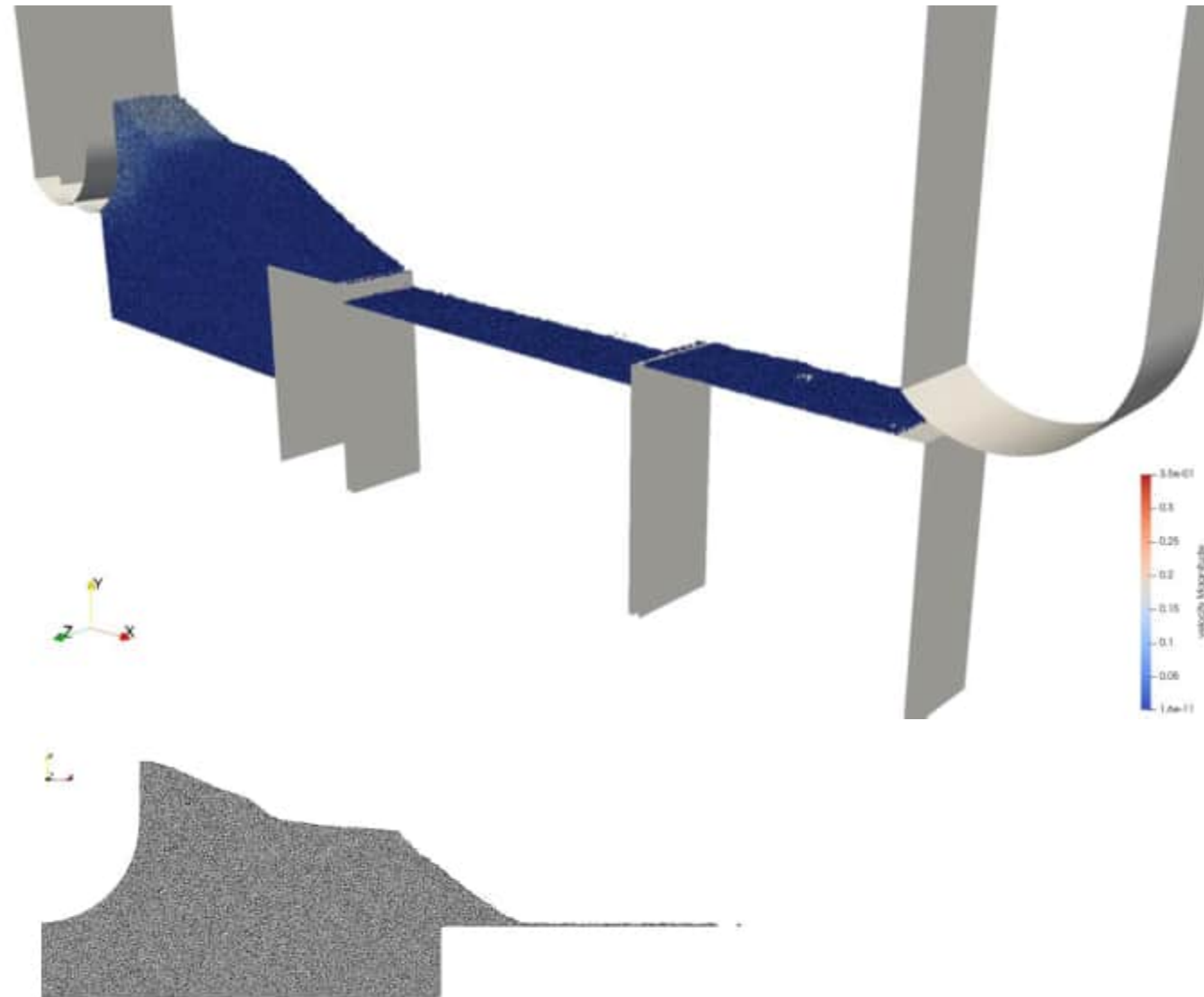
- Number of particles ( > 1 million)
- Process duration
- Time step ( $< 3e-7$ )

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 ( $\mu_T$ )

First simulation (1) :

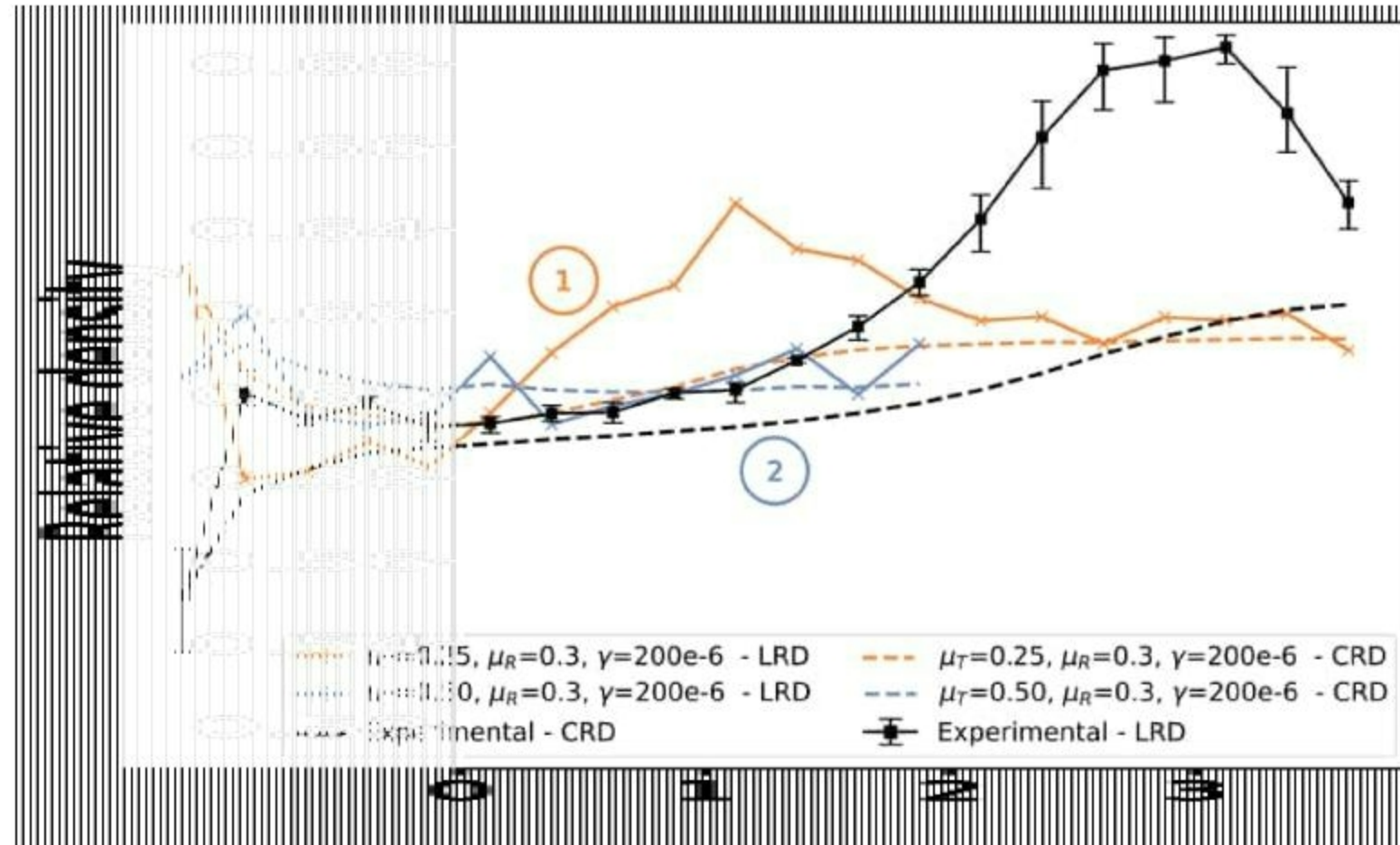
- Small densification phenomenon starts at layer #7.

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

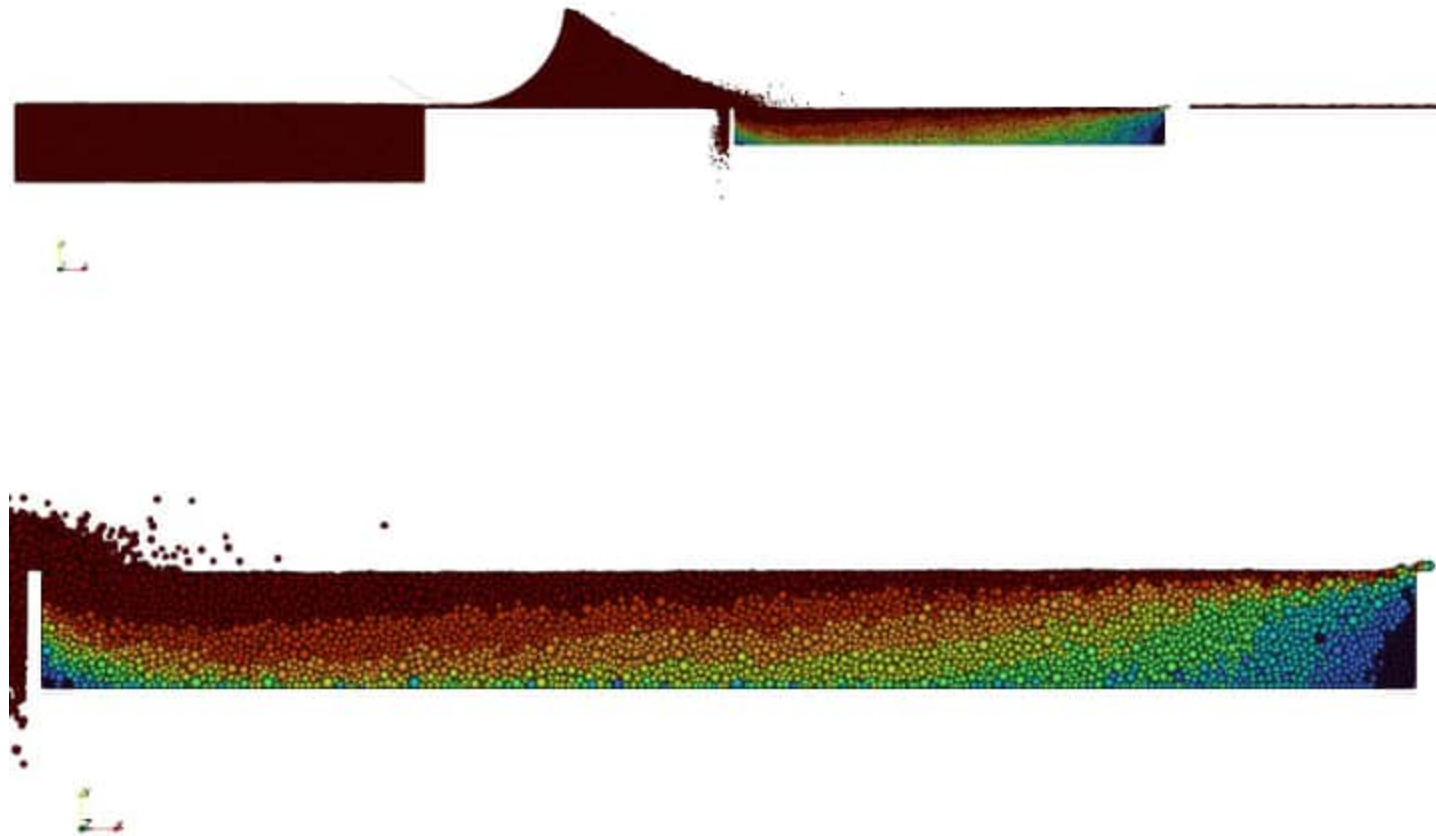
CRD: Cumulative Relative Density

# Build plate side view

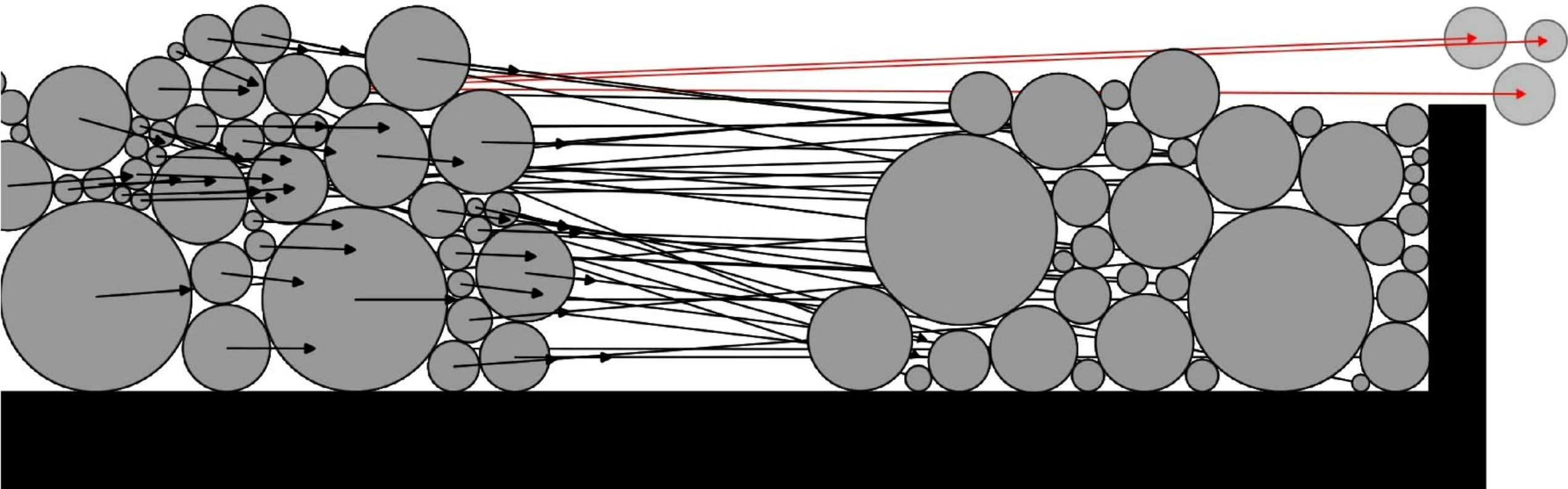
Each particle has been colored according to its layer number.

- 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

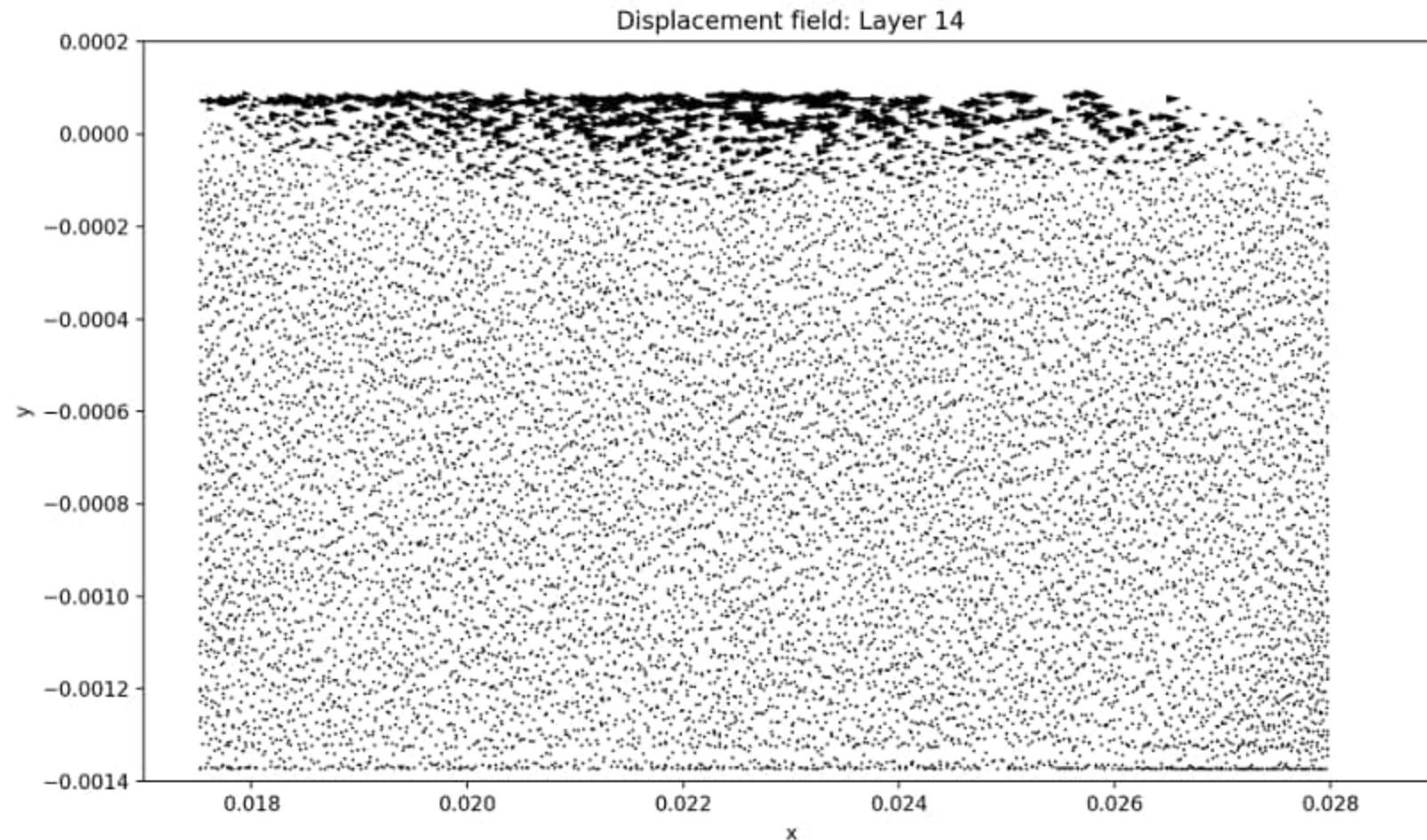
First set of surface properties:

- Densification starts at layer 7.
- Peaks at layer 9 to 11.
- 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

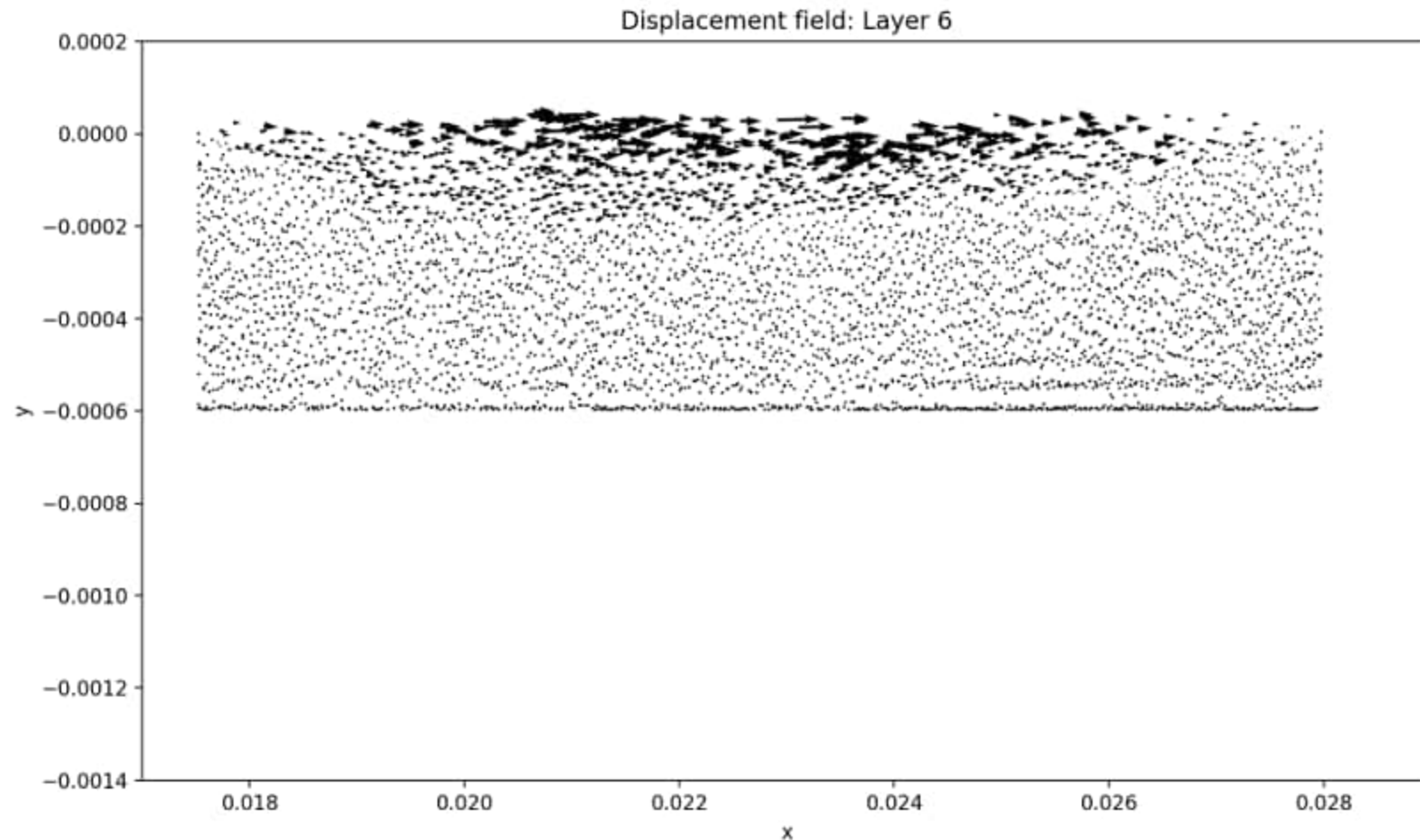
Second set of surface properties:

➤ 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:

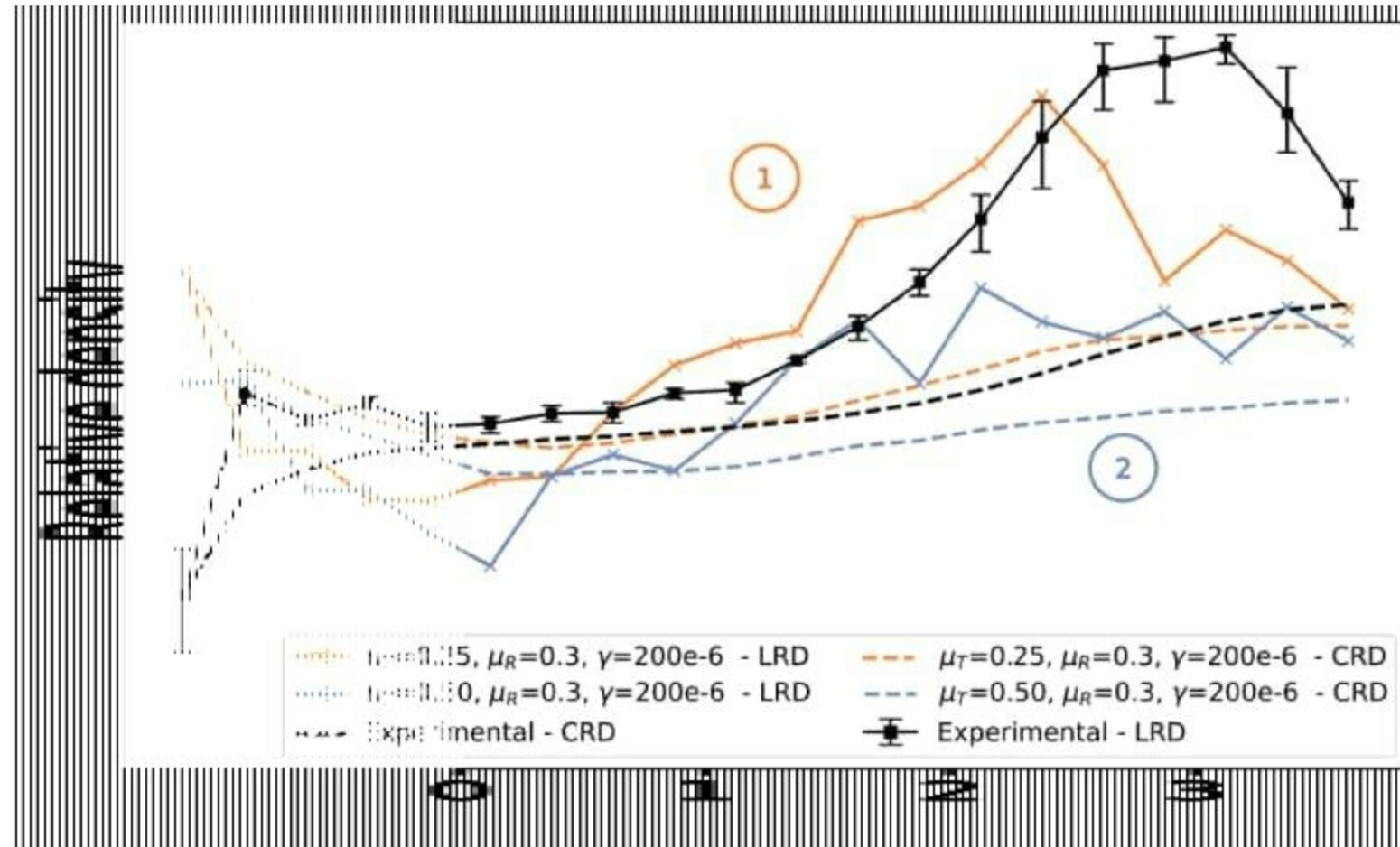
- 2 centimeters instead of 1.

## First simulation (1)

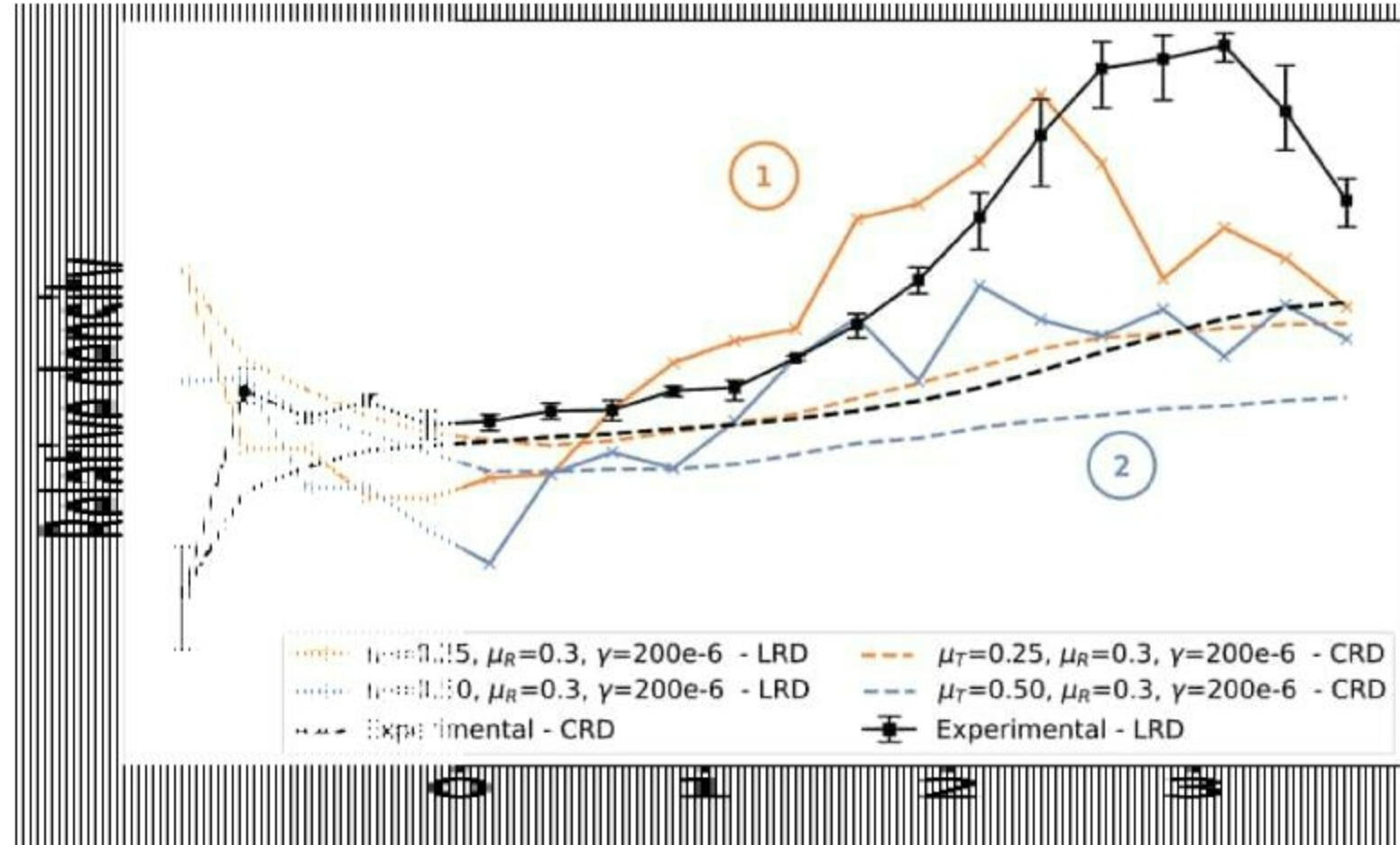
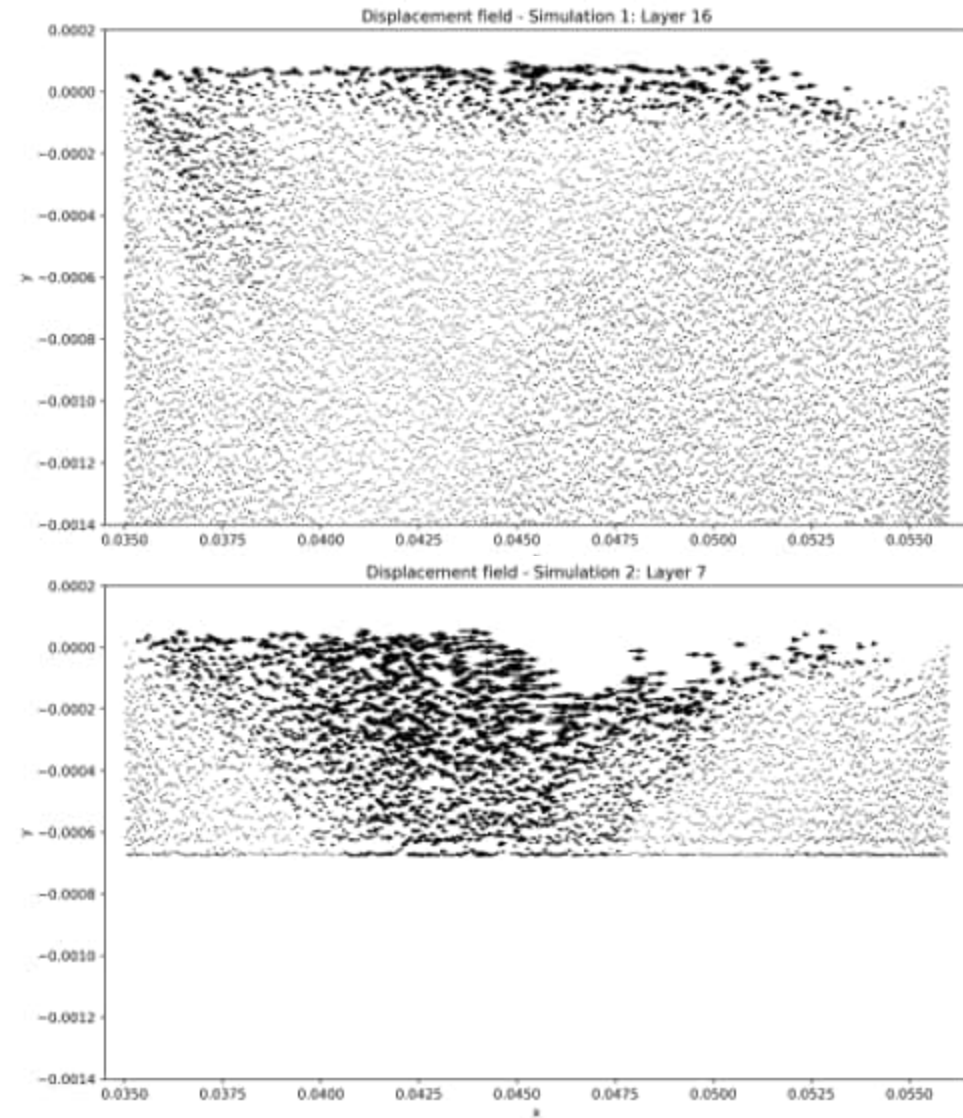
- Better agreement with experimental results.

## Second simulation (2):

- Densification occur at layer 10.



# Increase the length in spread direction

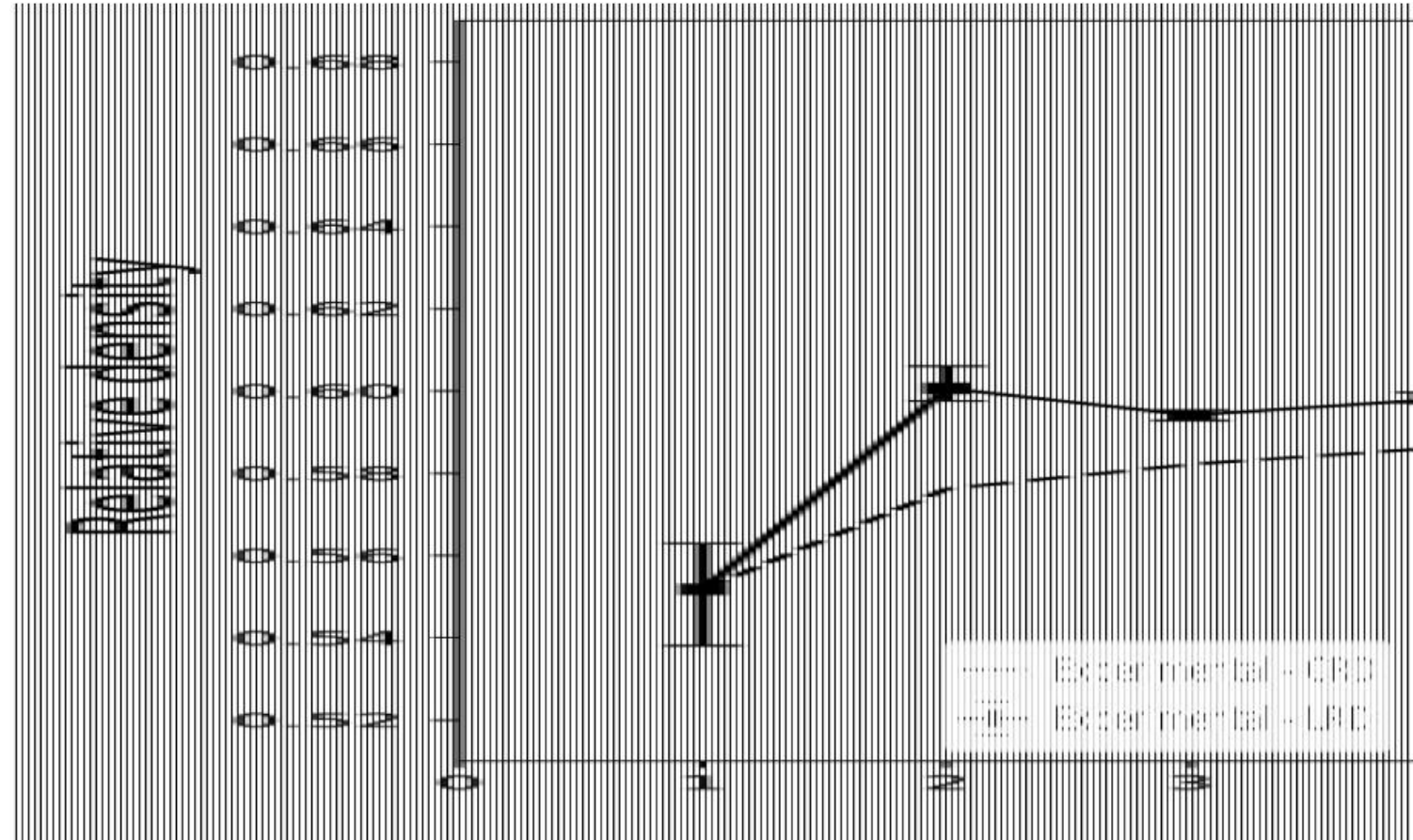


# Concluding remarks

- 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

*olivier.gaboriault@polymtl.ca*

