Precise prediction of NNS HIP components through DEM and FEM modelling

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Introduction

- **Purpose of the study**
- **Process description**

Simulation of HIP Process with “Image Analyzed” Densities Distribution

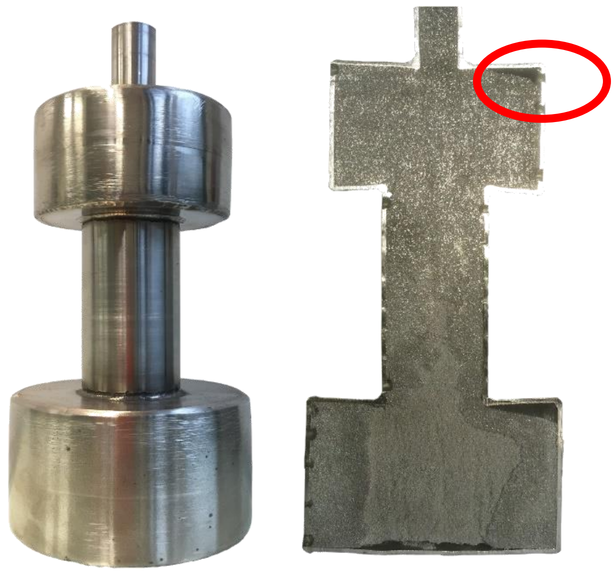
- “Image Analyze” for investigation of initial density distribution
- FEM Simulation

Simulation of HIP Process with DEM simulated Densities Distribution

- Introduction of DEM and Modelling Approach
- Validation, Simulation and Comparison

Summary and Outlook

Purpose of the study



Welded Capsule (SS304) filled with powder (SS316L) before HIP Process

T_{HIP} = 1125° C
p_{HIP} = 110 MPa
$t_{Holding}$ = 2 h

Capsule (SS304) filled with powder (SS316L) consolidated to full dense after HIP Process

- **Anisotropic shrinkage of capsule during PM HIP:**
  - **Inhomogeneous powder densities distribution in the capsule**
  - **Temperature gradients and inhomogeneity in the HIP Unit**
  - **Imperfection of material**

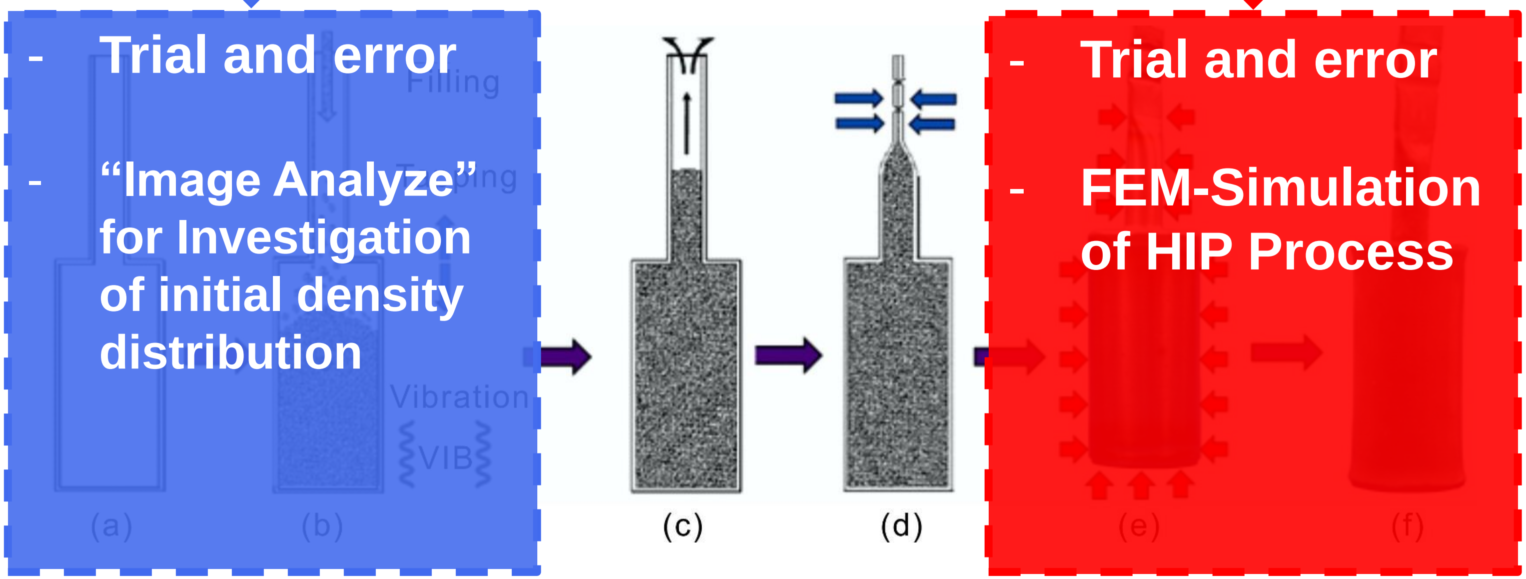
Process description

- Capsule design
- Particle size
- Initial relative density and distribution

- Material properties
- Process parameters
  (Time, Pressure, Temperature, etc.)

- Trial and error
- “Image Analyze” for Investigation of initial density distribution

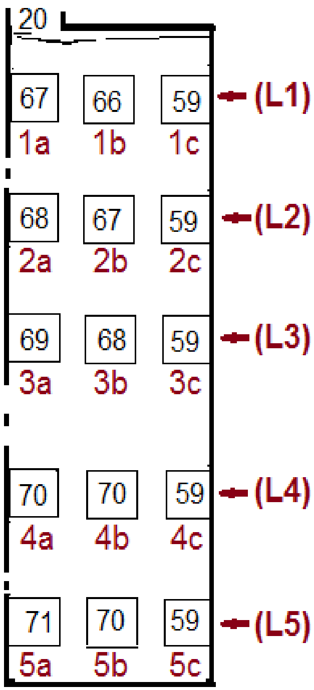
- Trial and error
- FEM-Simulation of HIP Process



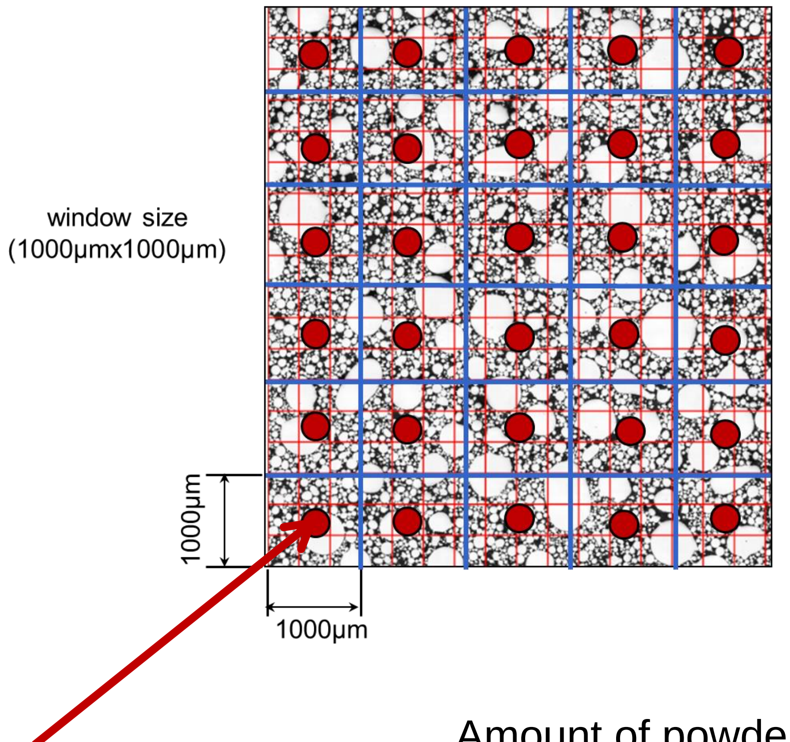
HIP process in general: (a) Capsule production; (b) Filling powder, tapping and vibration; (c) Evacuation; (d) Sealing capsule; (e) Applying high temperature and high pressure; (f) Full density HIPed component

Content

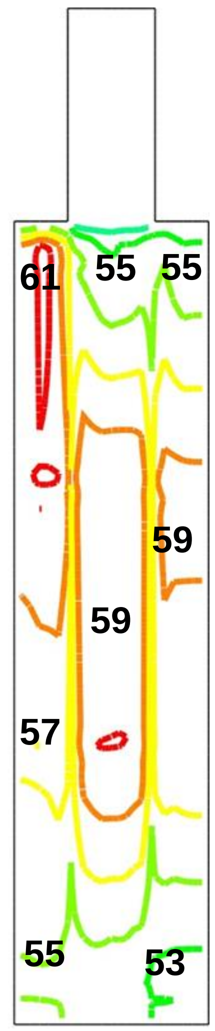
“Image Analyze” for investigation of initial density distribution



Microstructure photos of a subarea

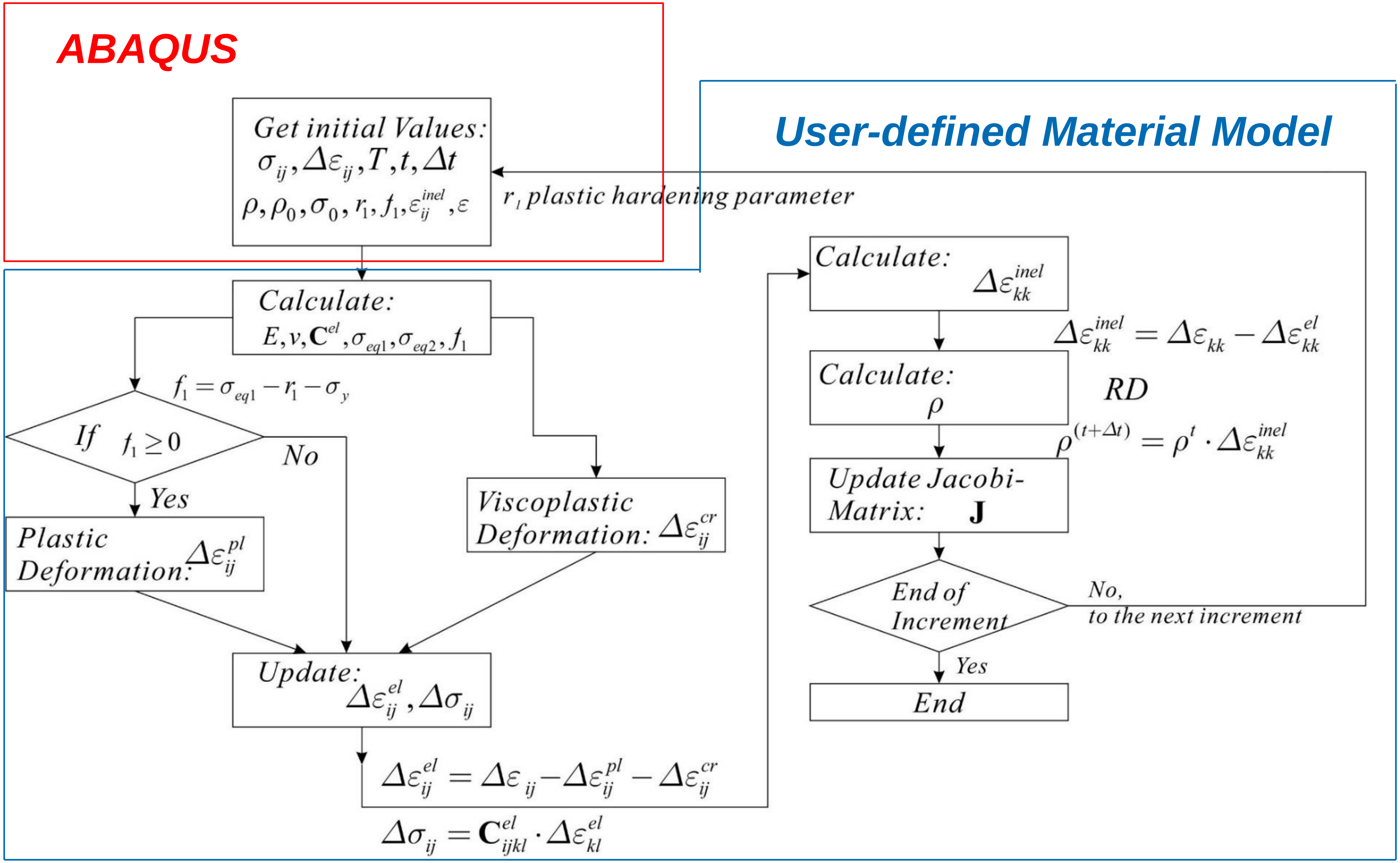


RD [%]

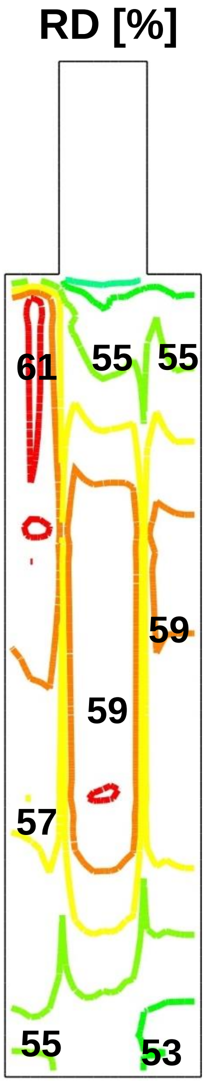


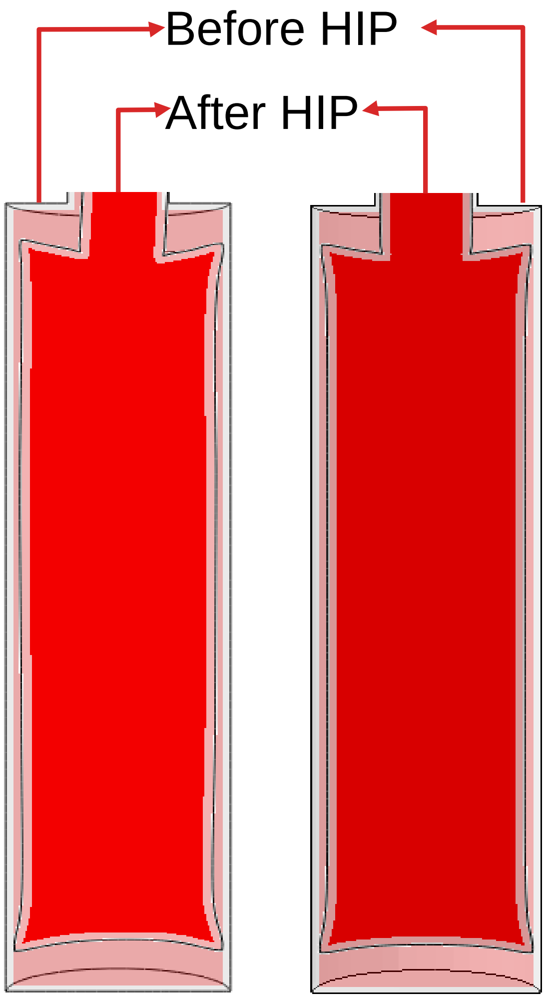
$$\text{Relative Density (RD) of each window} = \frac{\text{Amount of powder}}{\text{Total area of the window}}$$

FEM densification model



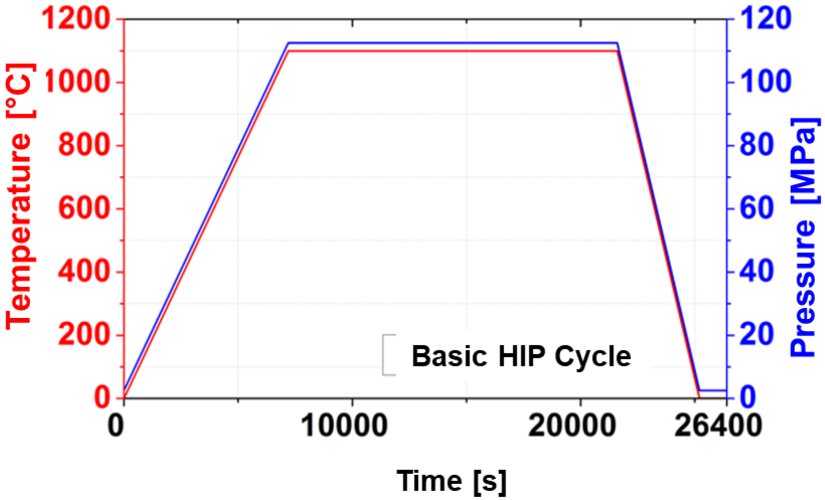
HIP Simulation with determined densities field in the capsule

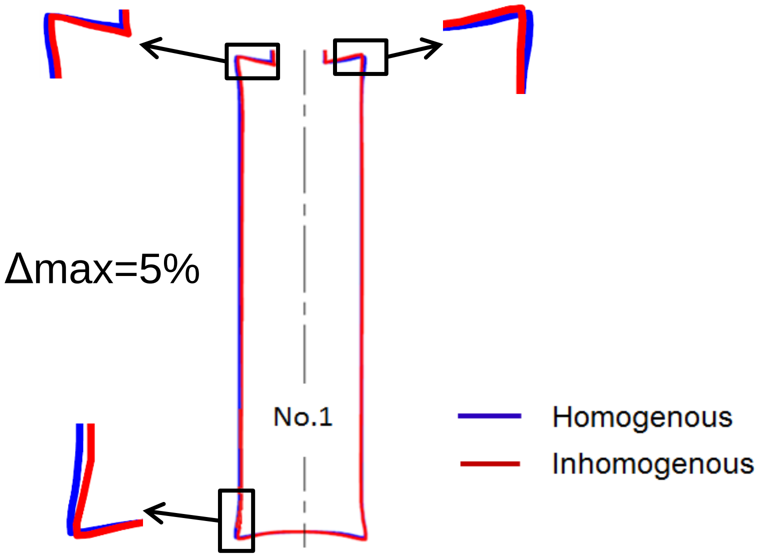




RD determined from experiment

Mean RD value





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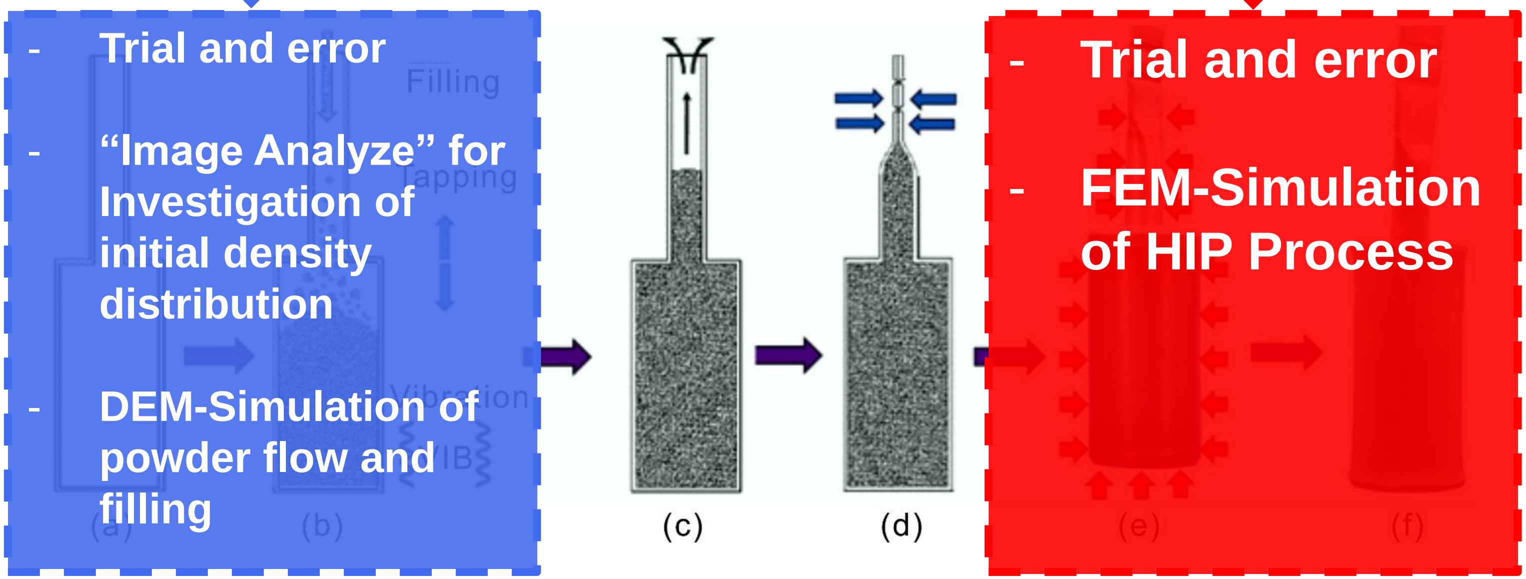
  (Time, Pressure, Temperature, etc.)

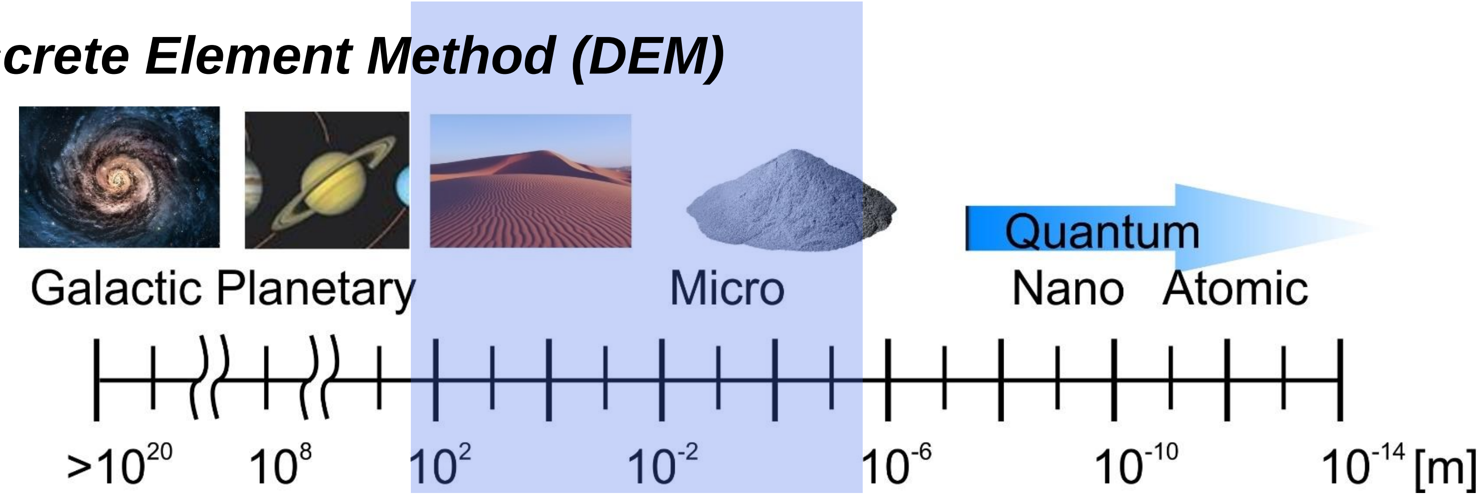
- Trial and error
- “Image Analyze” for Investigation of initial density distribution
- DEM-Simulation of powder flow and filling

- Trial and error
- FEM-Simulation of HIP Process



HIP process in general: (a) Capsule production; (b) Filling powder, tapping and vibration; (c) Evacuation; (d) Sealing capsule; (e) Applying high temperature and high pressure; (f) Full density HIPed component

Discrete Element Method (DEM)



- mathematical description of single objects / particles / granules
- meshless method compared to FEM
- interactions between objects only at contact points

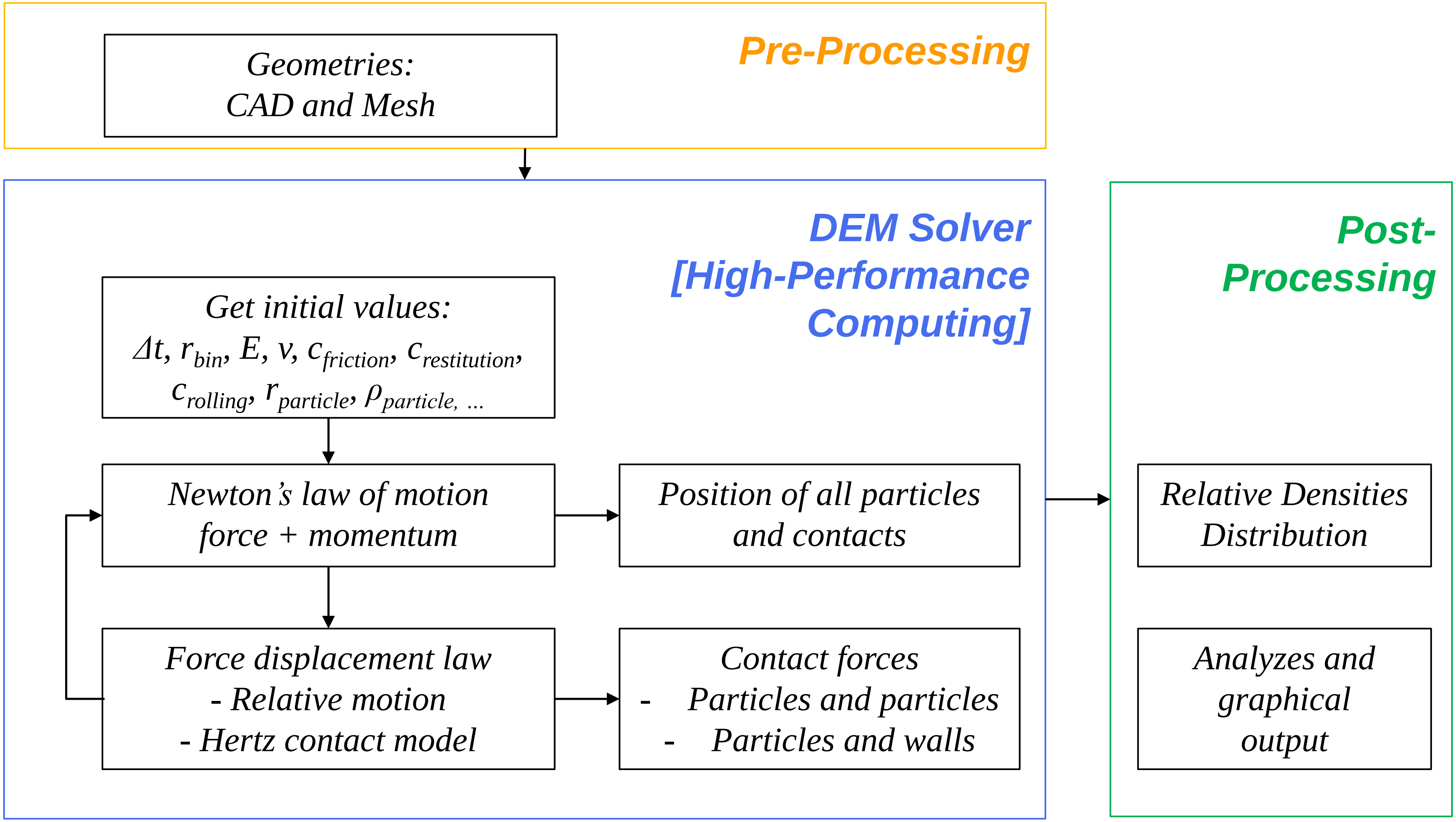
Advantages:

- Few equations which have to be solved for each object
- Forces and motions can be investigated for each single object, which are usually not measureable

Limits in usage:

- Computing time-consuming for real particle systems consists of billions of elements

DEM Modelling Approach



Materials and Model Parameters

Materials:

- Stainless Steel 316L (Powder)
- SS304 (Underlayment)

Particles: radius 250 µm

Density ρ 7800 kg/m³

Particle radius r 250 µm

Young's modulus E

Poisson's ratio v

Coefficient of restitution $c_{restitution}$

Coefficient of static friction $c_{friction}$

Coefficient of rolling friction $c_{rolling}$

Capacity: 10^9 Particles

- Iron powder 500 kg
- Ti-Alloys powder 300 kg

Rayleigh time increment:

$$\Delta t_R = \frac{\pi r \sqrt{\rho / G}}{(0.1631\, v + 0.8766)}$$

Hertz time increment:

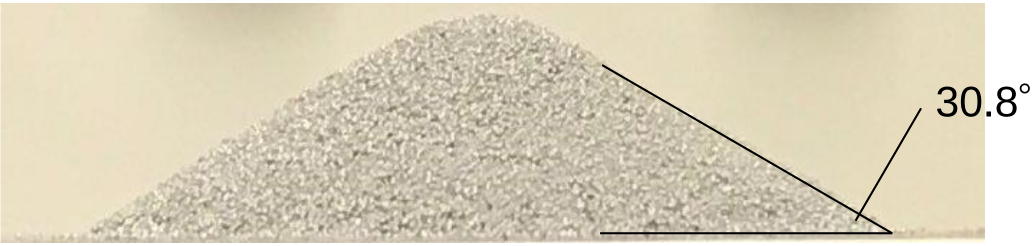
$$\Delta t_H = 2.87 \left[\frac{(\rho (4/3) \pi r^3)^2}{r E^2 v_{max}}\right]^{0,2}$$

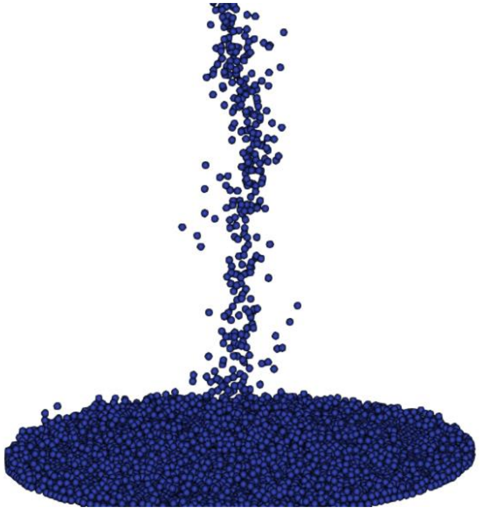
$$\Delta t = 0{,}20\, min(\Delta t_R, \Delta t_H)$$

Time increment 0.000001s

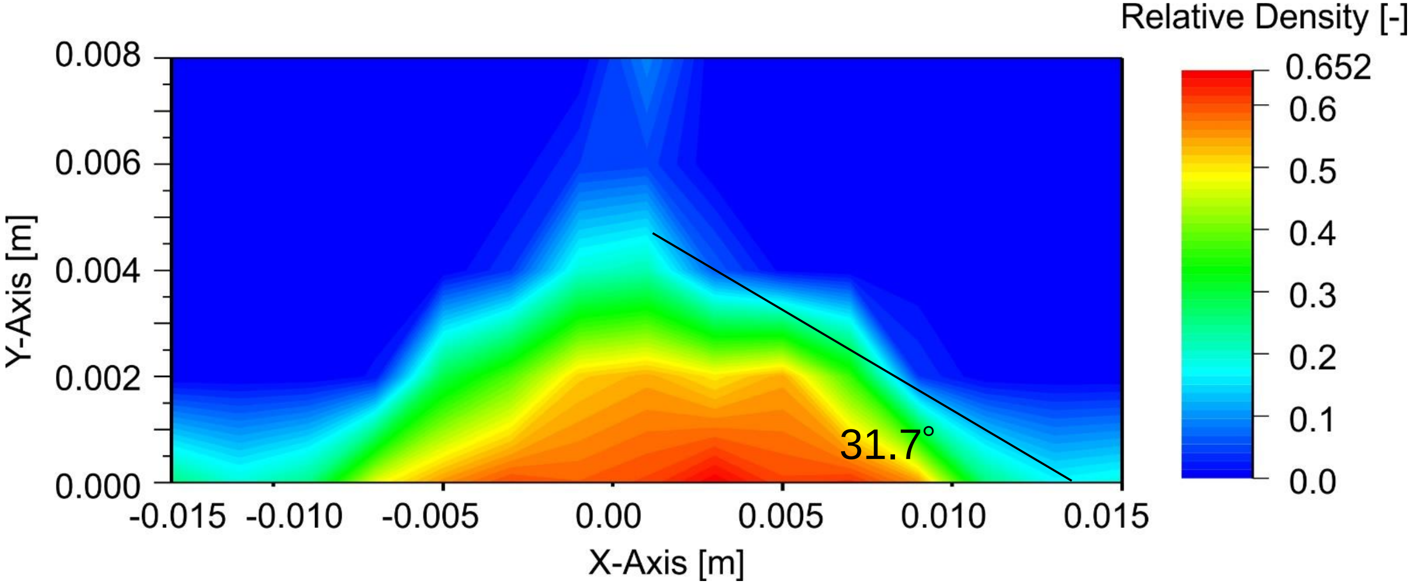
Validation - Flow test

Angle of repose





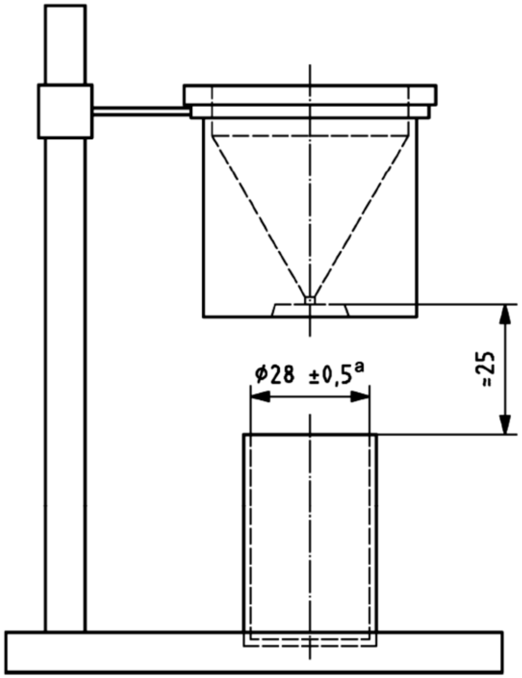
Deviation: 2.9%



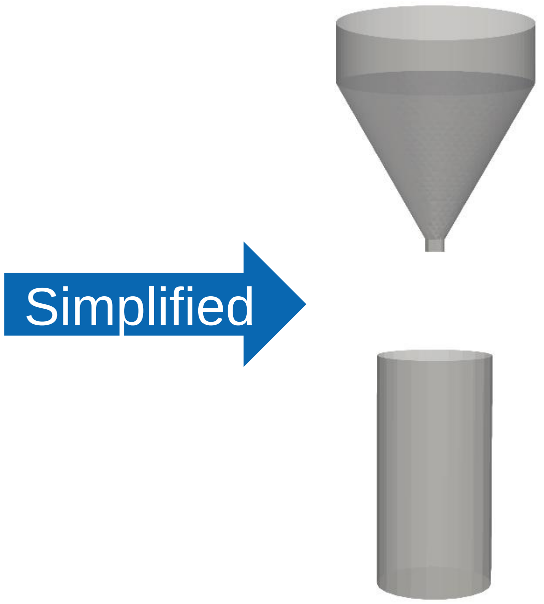
Validation - Flowmeter

Flowmeter

Experiment

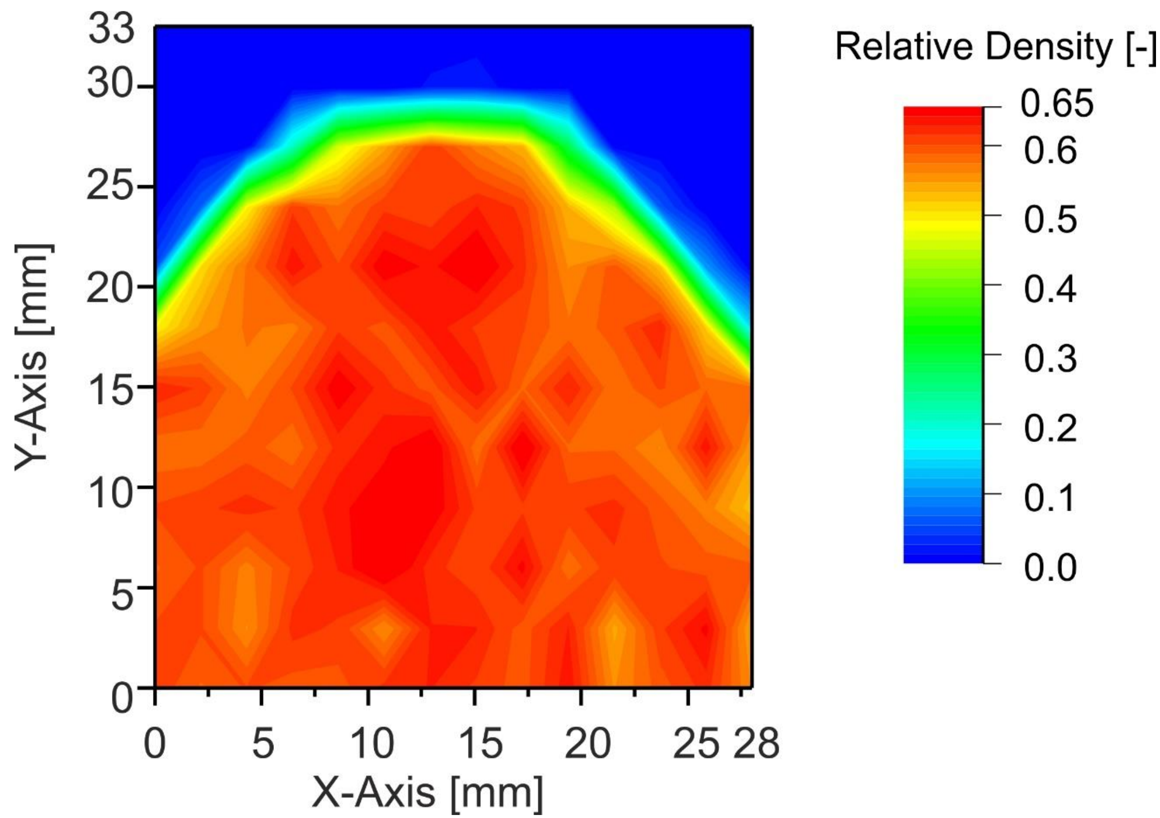


Simulation Model

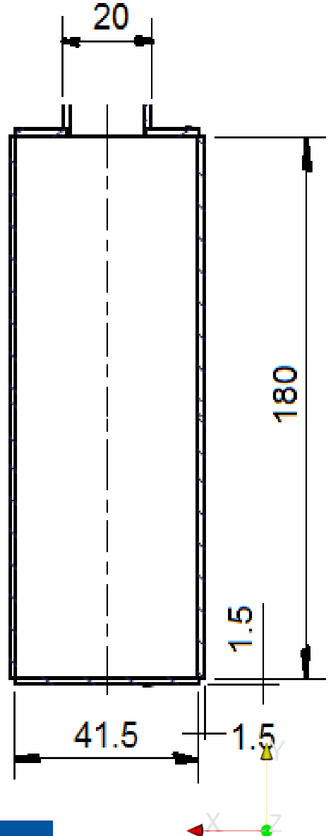


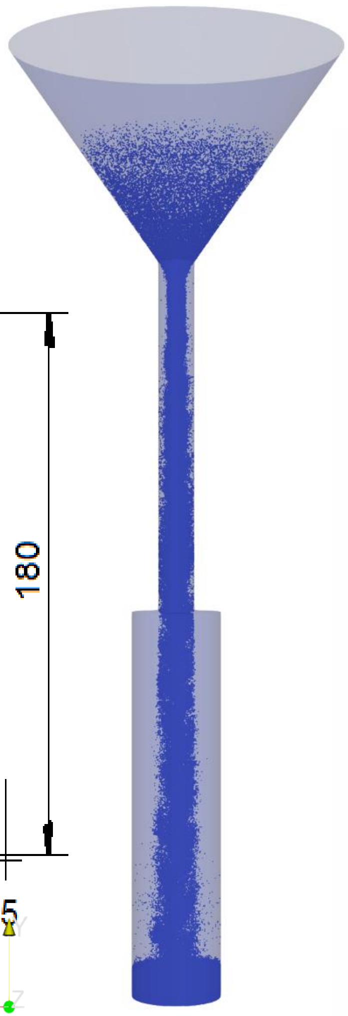
Validation - Flowmeter

SS316L Powder
Time: Exp. 18.5 s / 50g, Sim. 20.1s / 50g
Deviation: 1.6 s , 10.2 %

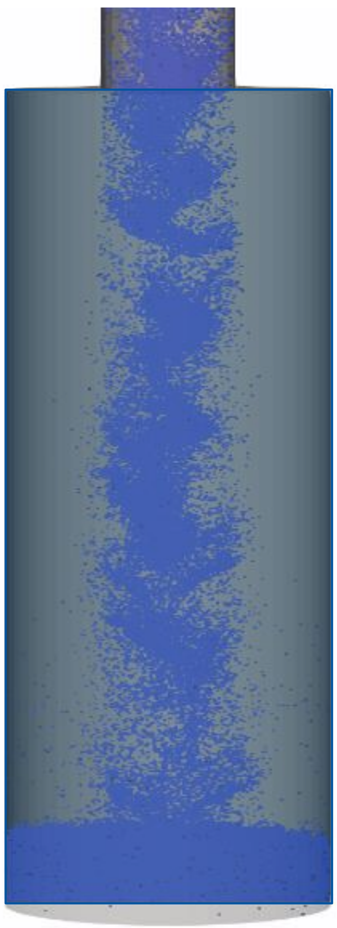


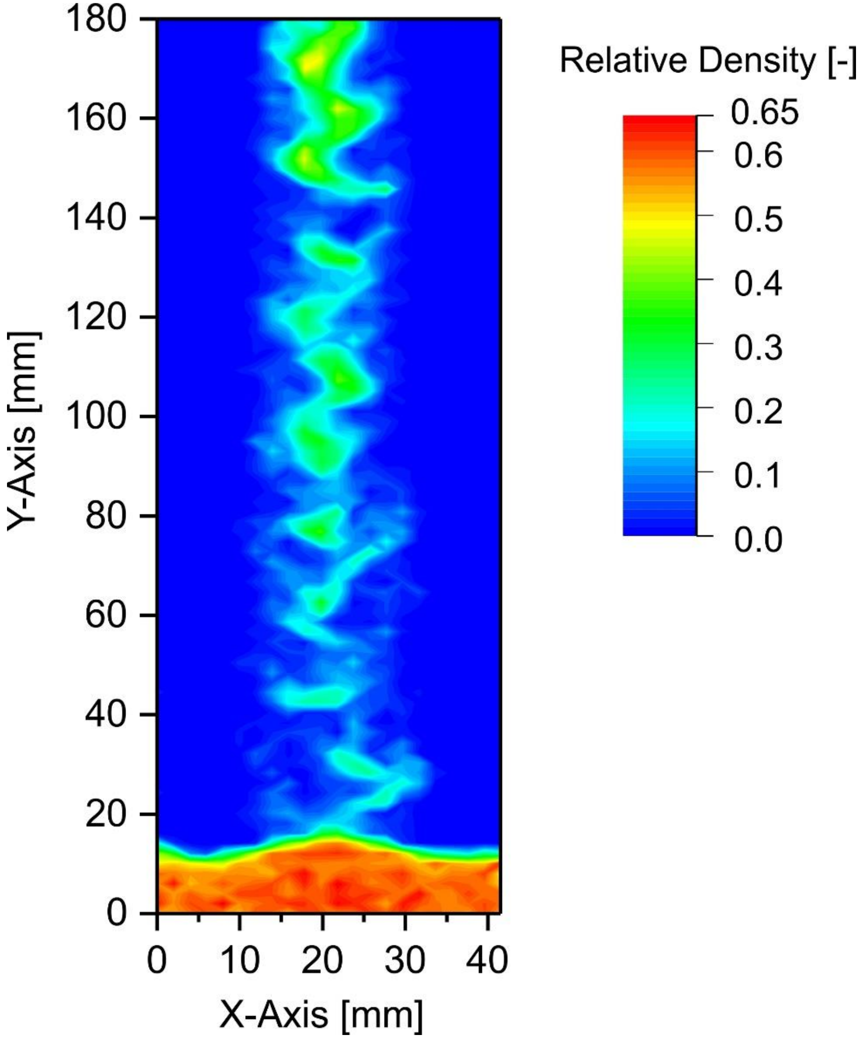
Filling process using DEM Simulation





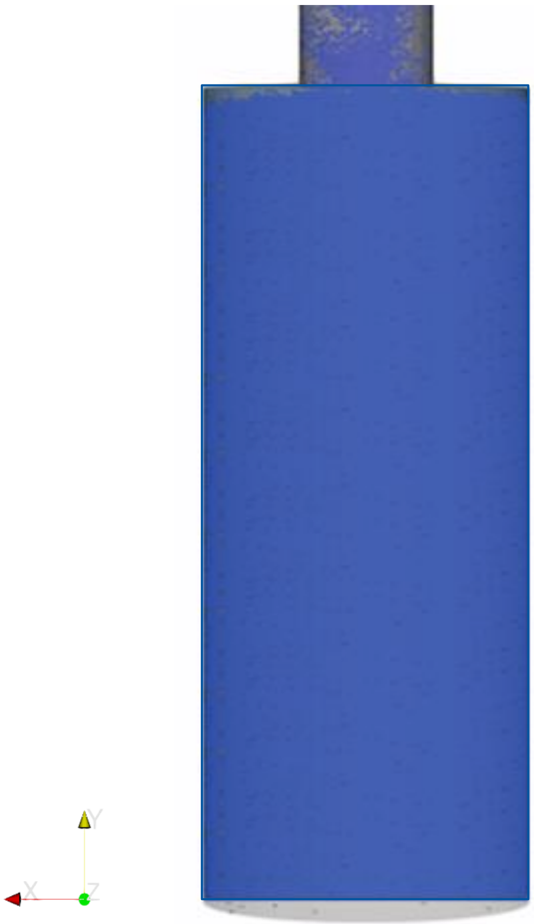
Z = 0

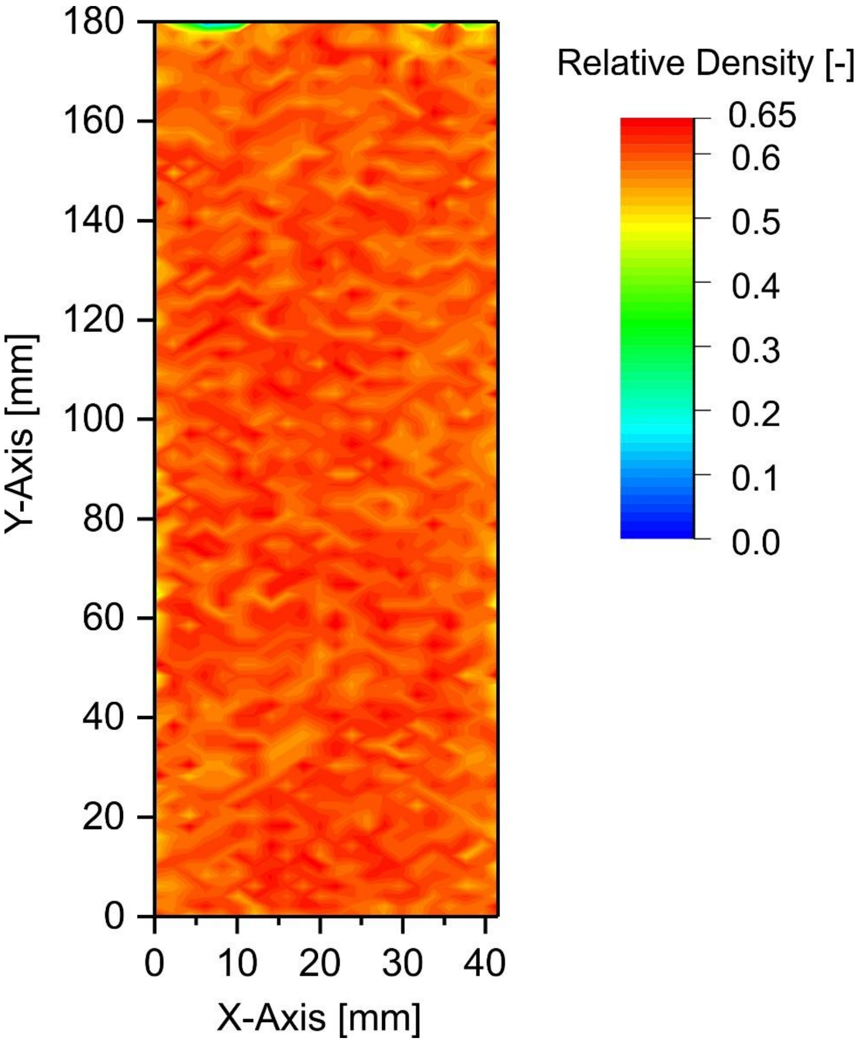




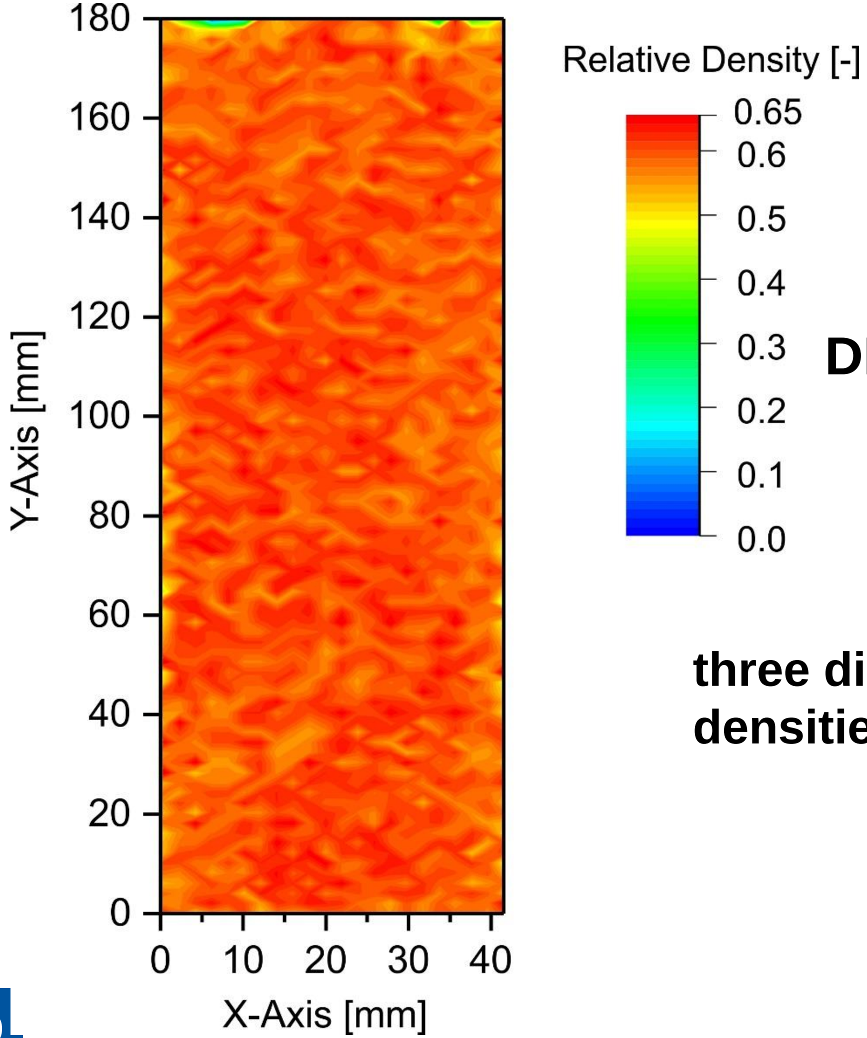
Filling process using DEM Simulation

Z = 0



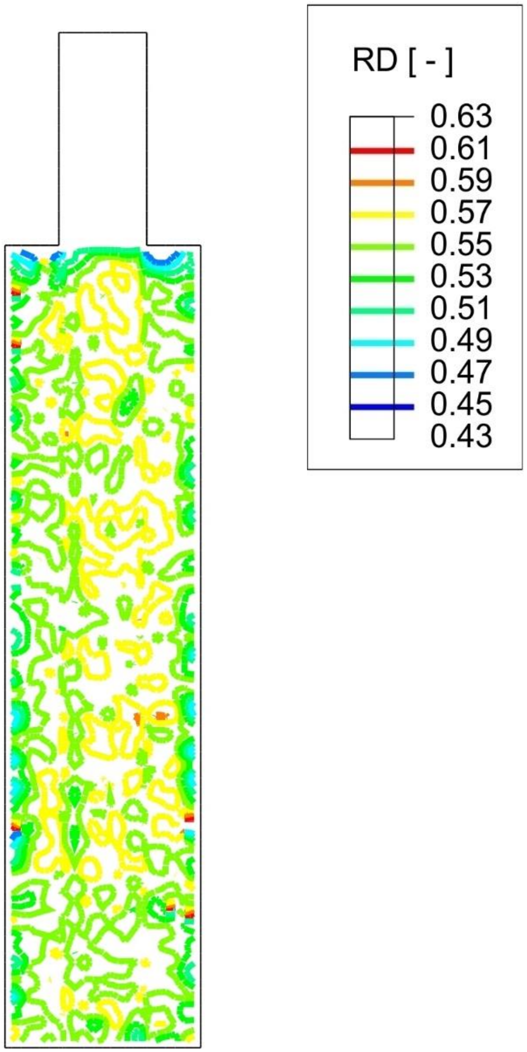


HIP Simulation with determined densities field in the capsule



DEM -> FEM

three dimenstional densities field



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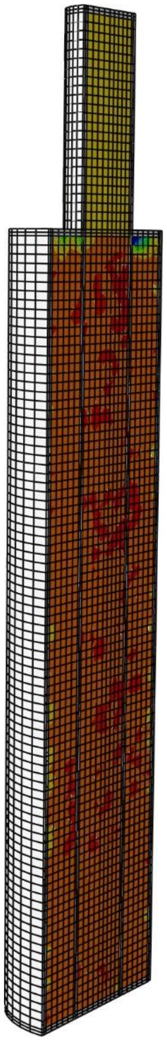
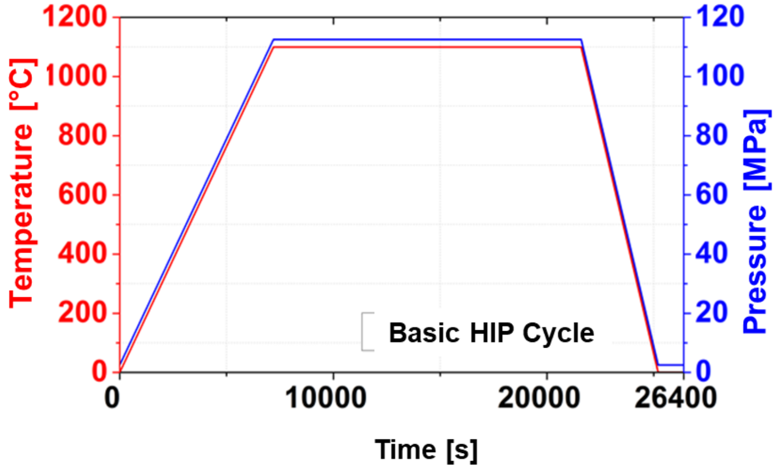
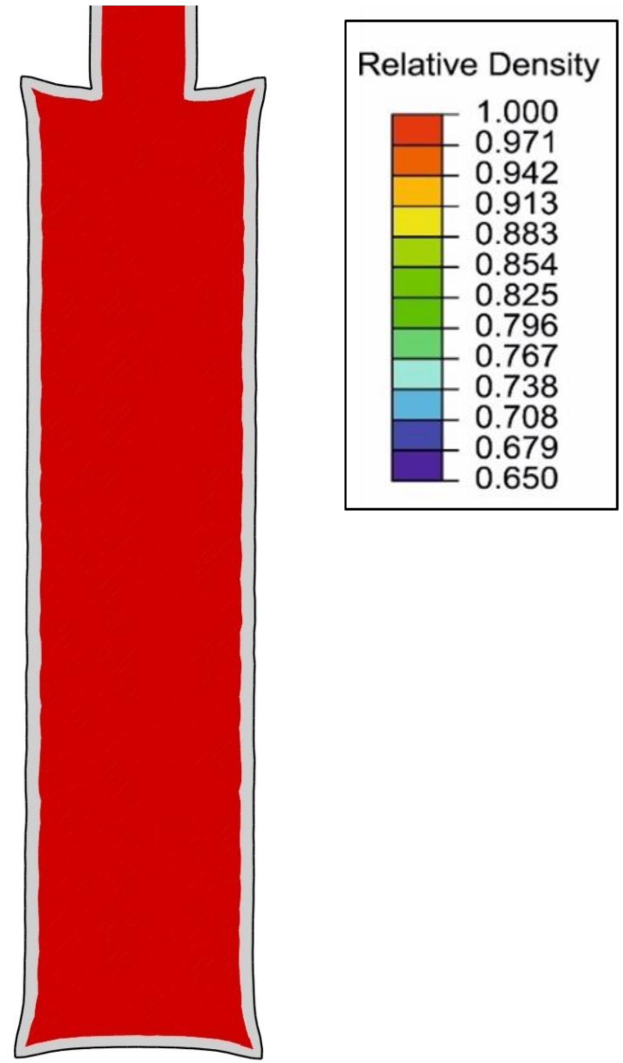


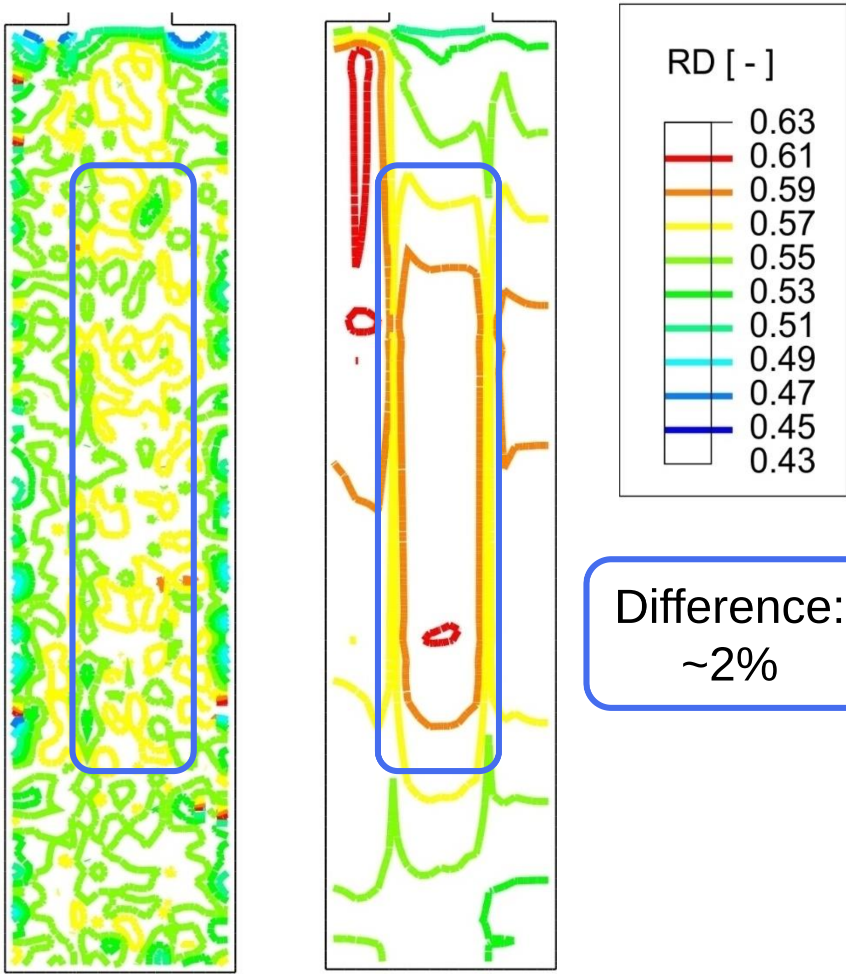


Cylinder Capsule
Thickness: 1.5 mm
Element size~2mm
Capsule material: SS304
Powder material: SS316L



Comparison of initial and final shapes

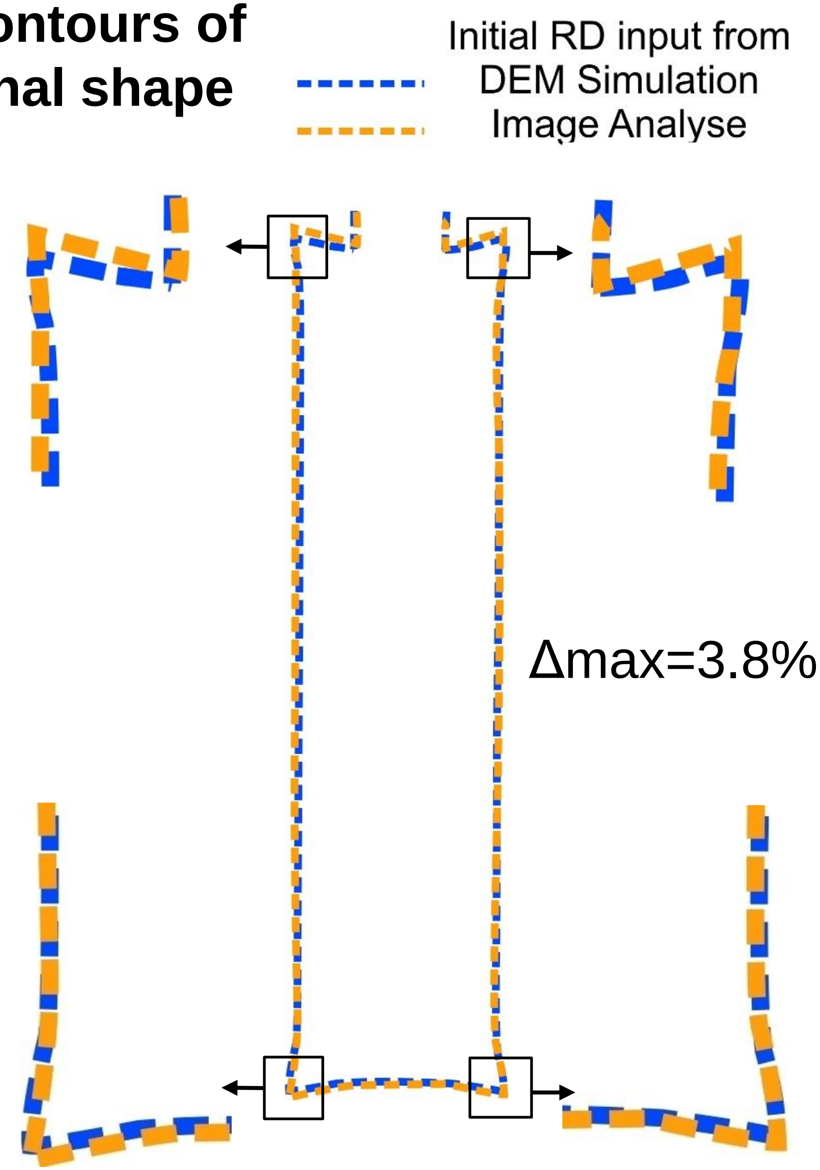
DEM Simulated | **„Image Anlyse“**



Difference: ~2%

Initial Relative Density (RD)

Contours of final shape



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Summary and Outlook

Conclusion and Outlook

- **Summary**

  - Simulation approach with coupled DEM and FEM Modelling has been used to calculate the capsule filling densities and predict the densification behavior of HIP Process.
  - The simulation results correspond well with the experimental measurement.

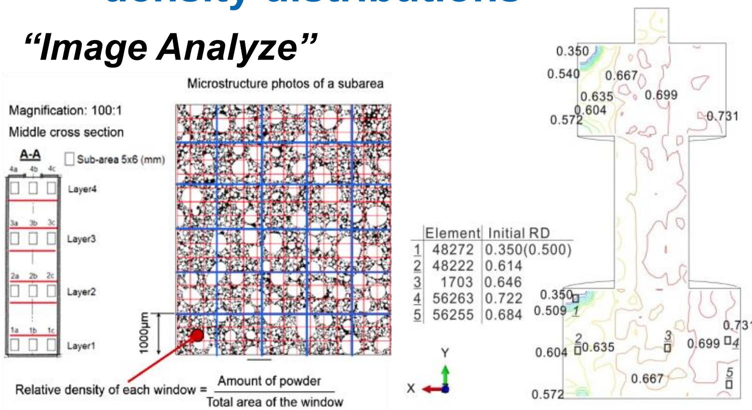
- **Outlook**

  - Influences of particle size distribution
  - Influences of pre-desification process, vibration and tapping
  - Influences of more complex shape

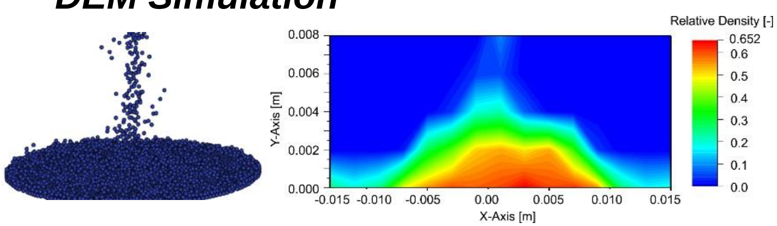
Sim. and Exp. of HIP Process chain

Inhomogeneous initial density distributions

"Image Analyze"



DEM Simulation



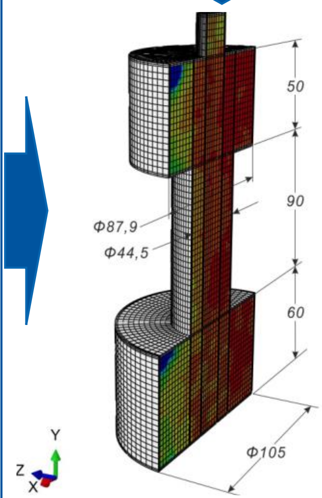
Temperature gradient on the capsule surfaces

Capsule thickness

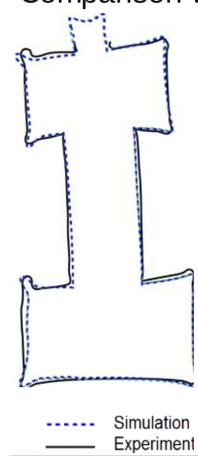
Properties of powder and capsule materials

Temperature and pressure profile

Kuhn-Donwey and Abouaf-Chenot Model

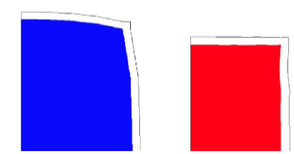


Comparison with experiments



Capsule shape optimization

Opimized capsule



Before and after HIP

Acknowledgement

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Thank you very much for your attention!

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