NEW OPPORTUNITIES IN CENTRIFUGAL POWDER COMPACTION

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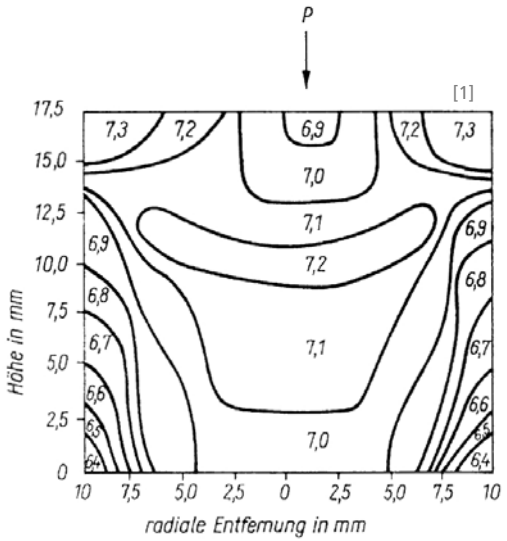
Motivation

- Factors that influence sinter components quality:
  - Heat treatment, choice of material, particle packing in green state
- Requirements for high quality sinter parts
  - High green density
  - High coordination number (particle)
  - High Packing homogeneity of green part
- Real process: inhomogeneities in green state e.g.
  - Segregation effects in MIM
  - Density gradients in pressed parts



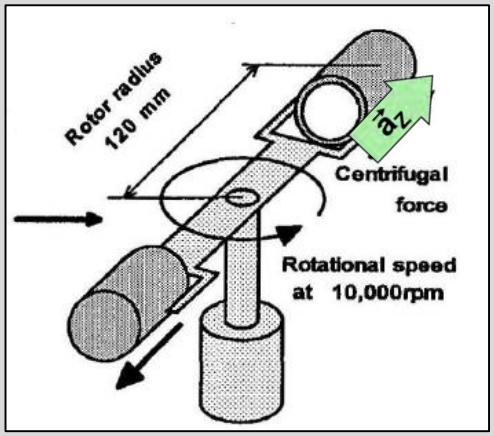
Density field in cylindric pressed green compact

[1] Schatt, Werner, Wieters, Kieback, *„Pulvermetallurgie: Technologien und Werkstoffe: Technologie und Werkstoffe"*

Manufacturing process using sedimentation

- Which manufacturing process can meet the requirements for homogenous components
  - Slurry based manufacturing techniques suitable due to low friction

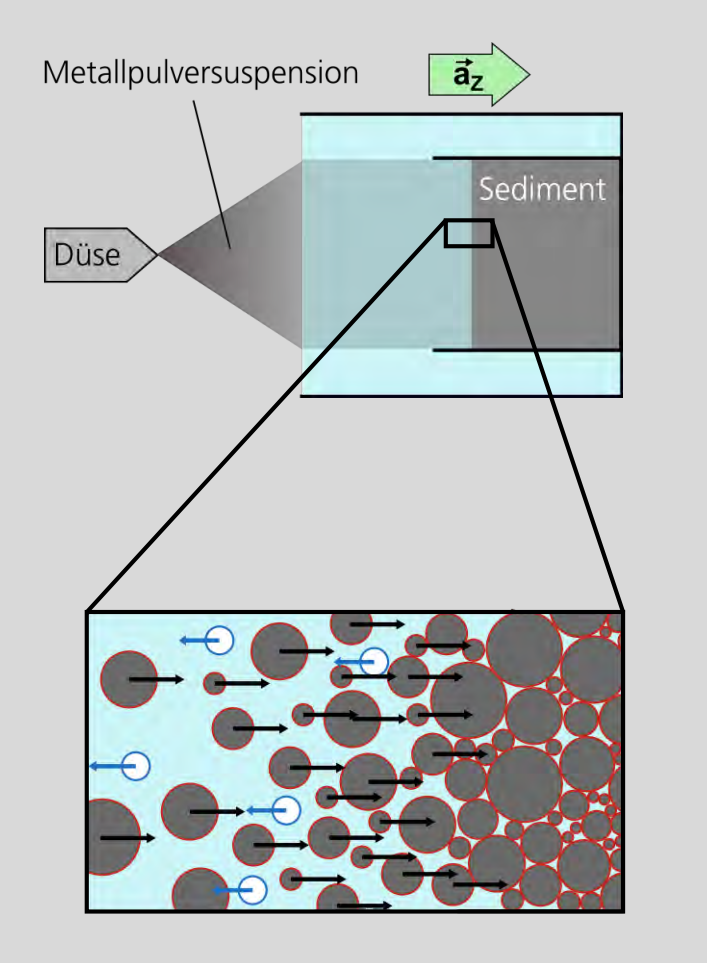
    → Sedimentation of particles
- Example: High-speed centrifugal compaction process (HCP)
  - Batchweise sedimentation small charges
  - High acceleration of 10.000 – 100.000 x g
  - → Relatively high green densities (0.55 – 0.67) and high sintered densities achievable
  - → Segregation effects – particle size > also used for producing FGM



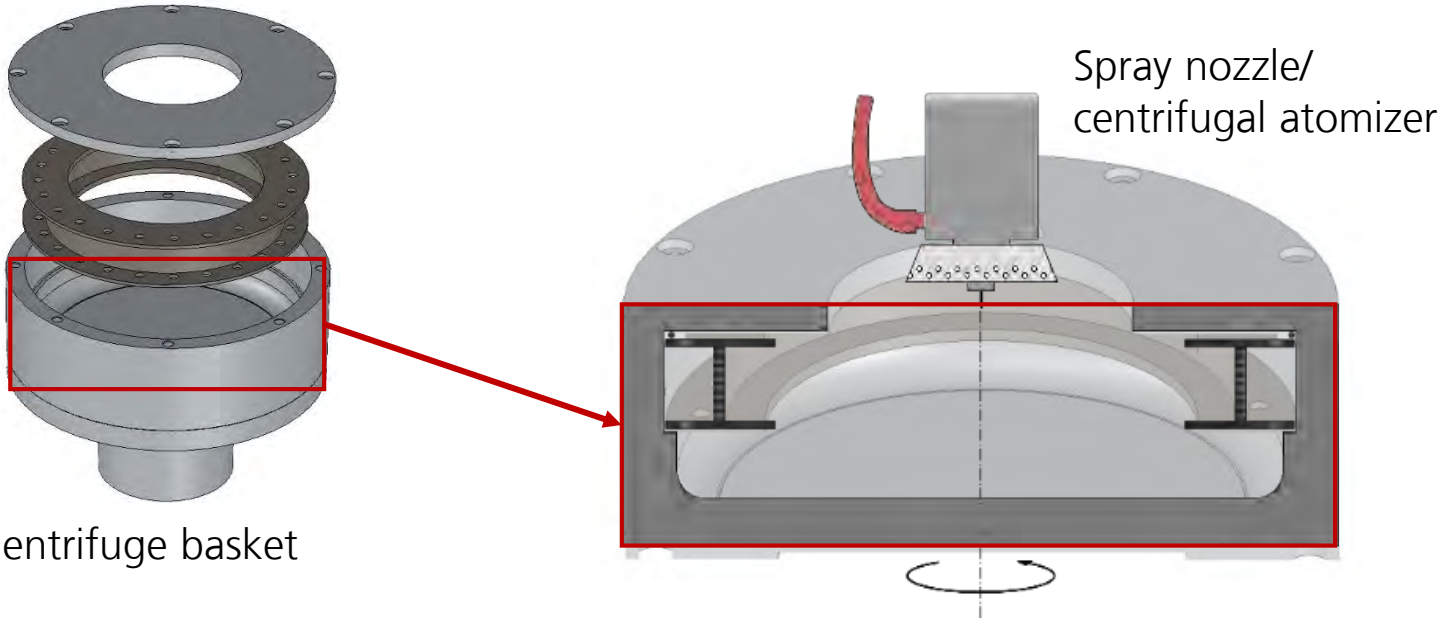
Suzuki, 2006, Development of High-Speed Centrifugal Compaction Process of Alumina

Manufacturing process using sedimentation

- Modified centrifugal sedimentation concept
  - No segregation effect by having continous suspension (particle) flow
  - Fast sedimentation due to high forces and low particle volume content
- Advantages of sedimentation process remain:
  - Homogenous forces
  - Reduced particle friction
  - Low binder content
  - Bubbles are segregated



Centrifugal sedimentation process



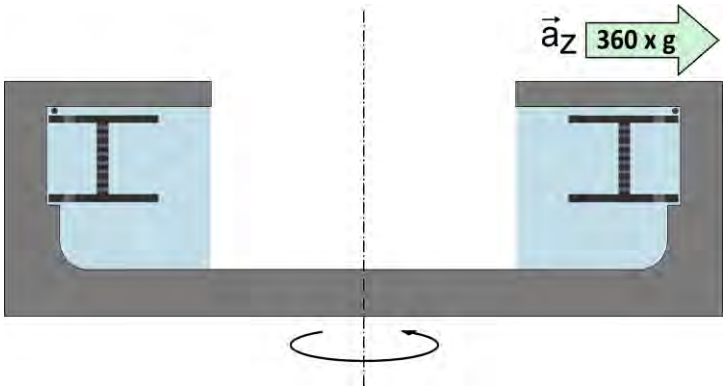
Preparation of centrifuge → Sedimentation → Dewatering → Binder-infiltration → Drying

Centrifugal sedimentation process

- Green part fabrication

Centrifugal sedimentation process

- Filling of centrifuge basket with solvent
- Rotation of centrifuge
  - Due to centrifugal forces the fluid gets pushed against cenrifuge basket walls
  - Remaining free baskret center



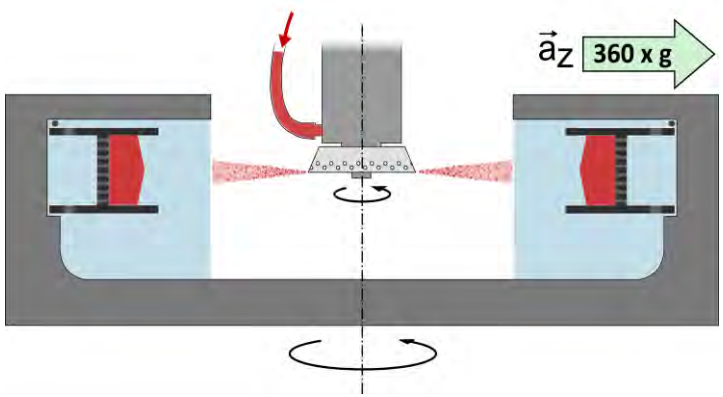
Preparation of centrifuge → Sedimentation → Dewatering → Binder-infiltration → Drying

Centrifugal sedimentation process

- Green part fabrication

Centrifugal sedimentation process

- Nozzle is brought into basket
- Spraying of powder suspension
- Particles sediment into container
- Drainage of particle-free solvent on top



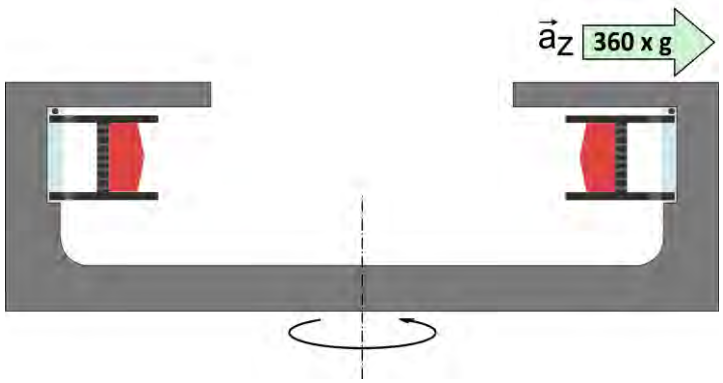
Preparation of centrifuge → Sedimentation → Dewatering → Binder-infiltration → Drying

Centrifugal sedimentation process

- Green part fabrication

Centrifugal sedimentation process

- Dewatering of centrifuge basket



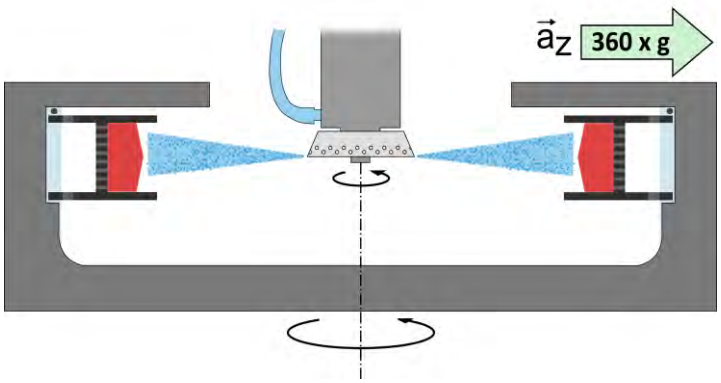
Preparation of centrifuge → Sedimentation → **Dewatering** → Binder-infiltration → Drying

Centrifugal sedimentation process

- Green part fabrication

Centrifugal sedimentation process

- Binder infiltration
- Drying and demolding of sediment



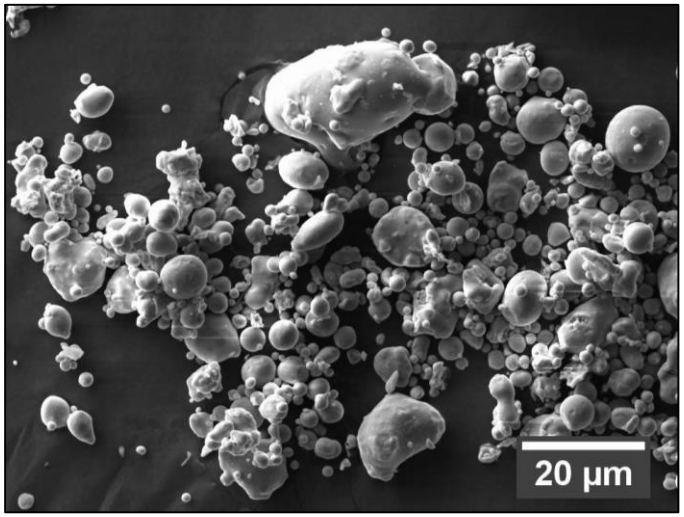
Preparation of centrifuge → Sedimentation → Dewatering → Binder-infiltration → Drying

Centrifugal sedimentation process

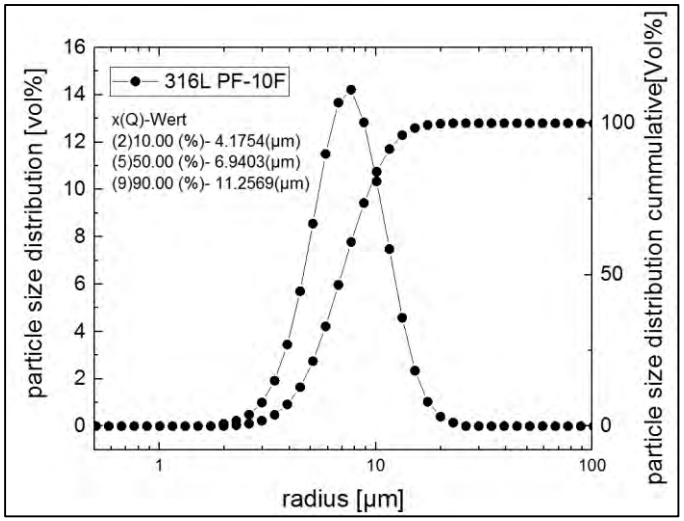
- Green part fabrication

Sedimentation experiments

- Process parameters
  - Acceleration 360 x g
  - Particle mass flow 50 - 500 g/min
  - Particle volume loading of spray suspension 4 – 6 vol%



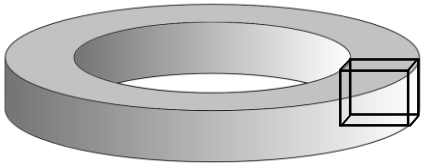
- Model powder: stainles steel powder 316L
  - Spherical particles
  - D_{50} = 6,9 µm, D_{90} = 11,3 µm
  - Few bigger particles >15 µm with irregular shape

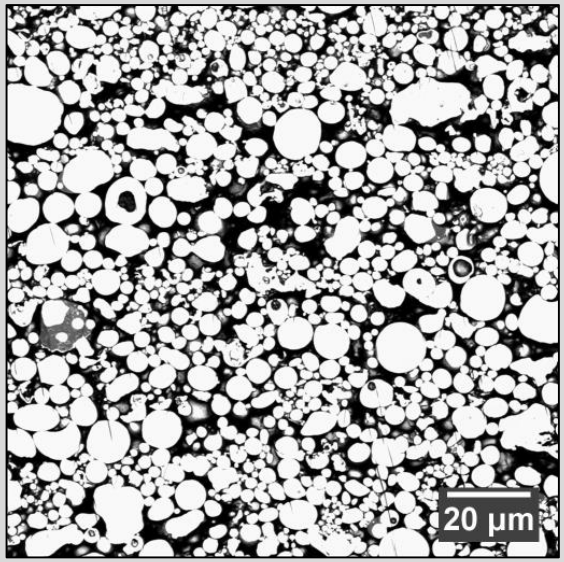


Fraunhofer IFAM Branch Lab Dresden

Analysis of sediments

- Cross sections of sediments show possible defects:
  - Layering in particle packing
    - Thin wall effect (1 – 2) mm
    - Layering due to processing parameters
  - Process-know-how: defects can be minimized
- Green density analysis
  - Preparation: cross section polishing CSP
  - Confocal laser scanning microscopy (CLSM)



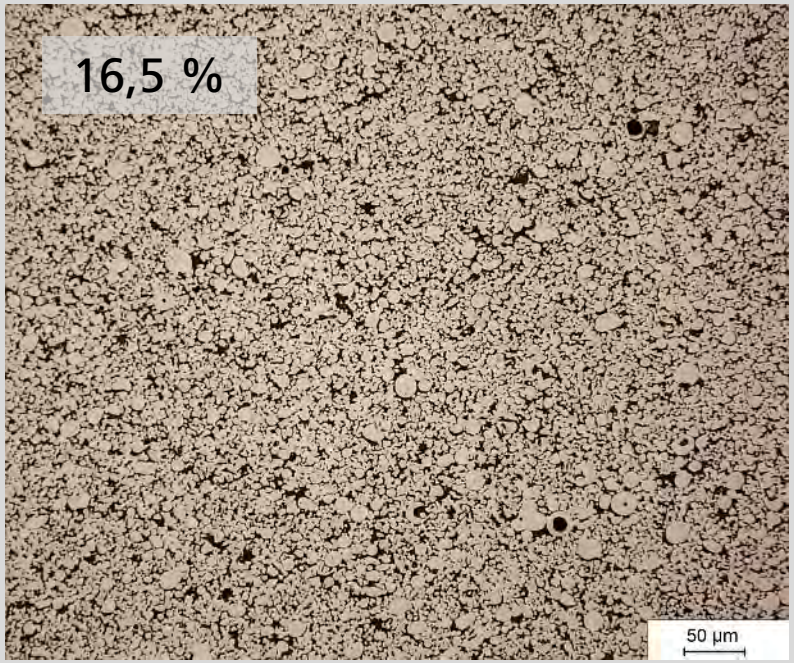


Particle packing

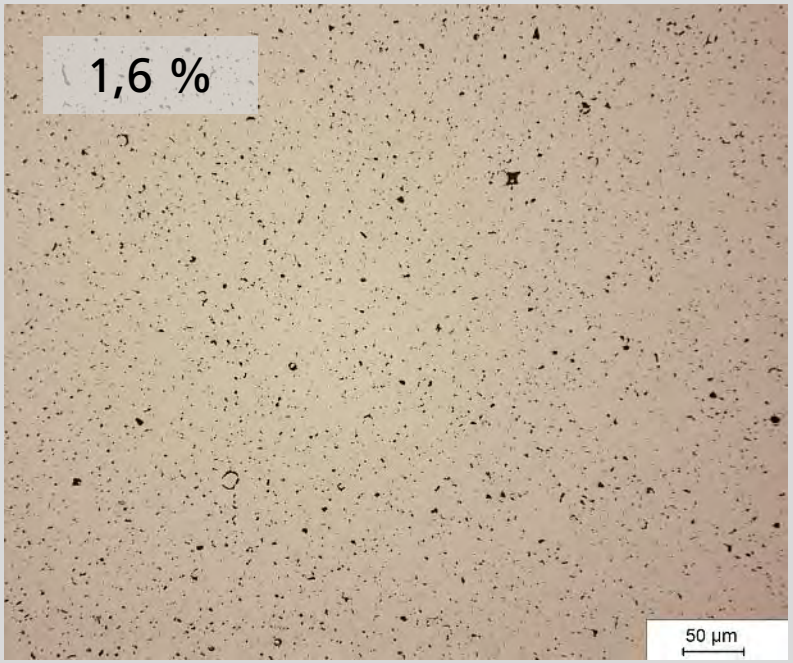
- Average green density of 66 %
- Uniform packing

Analysis of sediments

- Sintering result: homogenous with high density



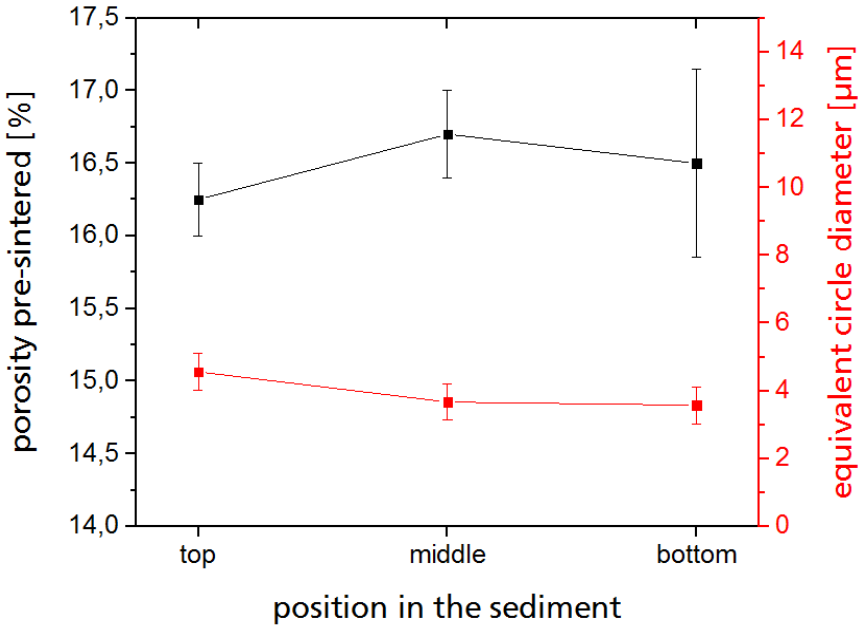
Sintering step 1000°C, 5min

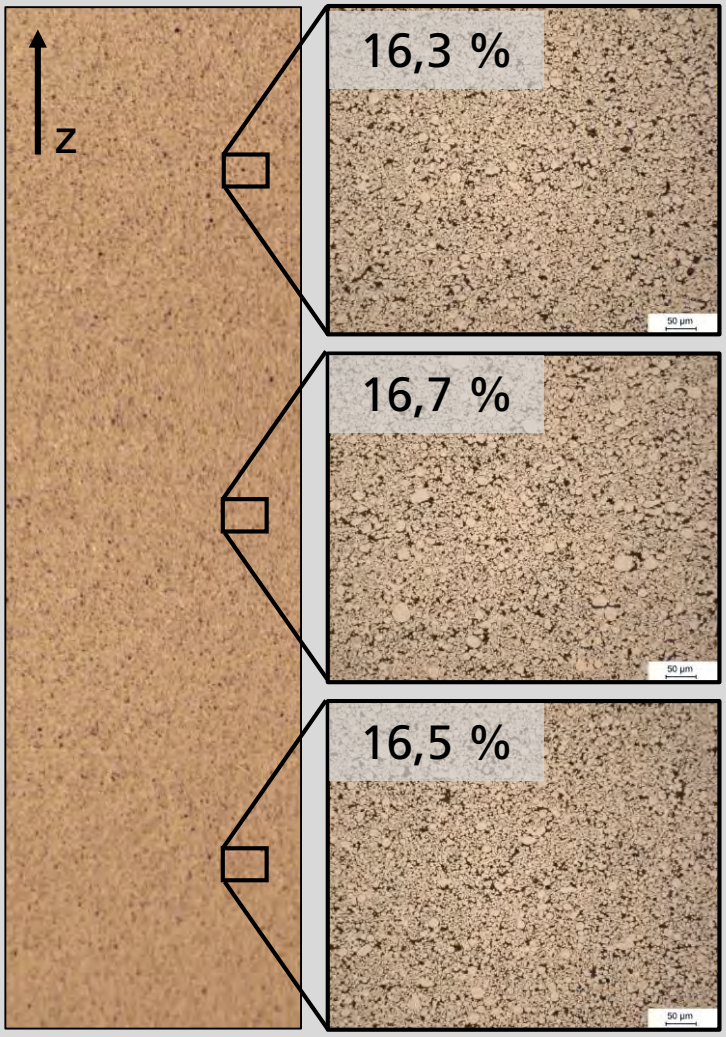


Sintering step 1250°C, 5min

Analysis of sediments

- Homogeneity of sediments
  - Homogenous porosity in z-direction
  - No significant segregation due to particle size distribution



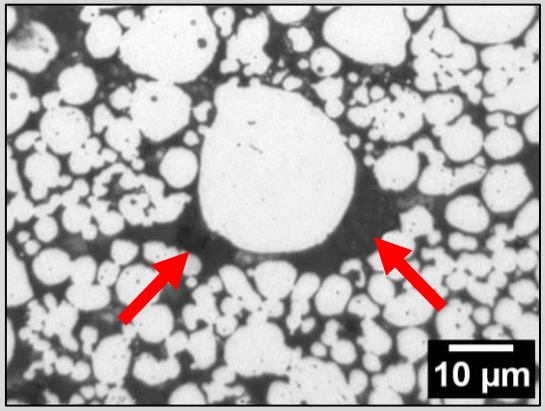


Pre-sintered sediment (1000°C)

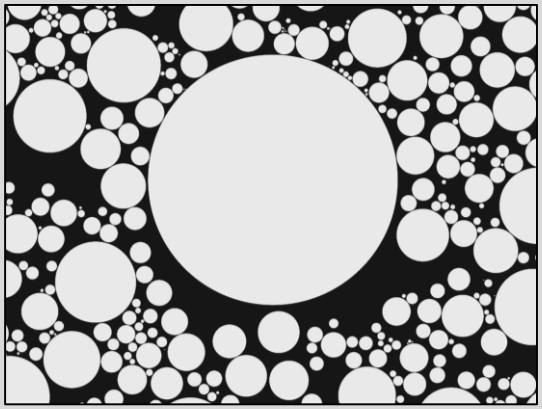
Analysis of sediments – large particles

- Few large particles can lead to inhomogeneity and low density
- Voids in the „shadow“ of large particles

- Defect reproduced in Packing simulation
  - „Drop and Roll“ - algorithm
  - Input: measured particle size distribution
  - Systematic defect for sedimentation? > True for low particle loadings
- Voids can be avoided using higher particle mass flow > higher sedimentation rate



Large particles within sediment



Packing simulation

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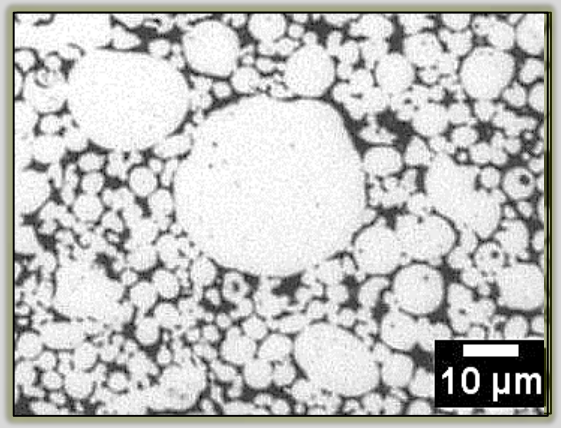

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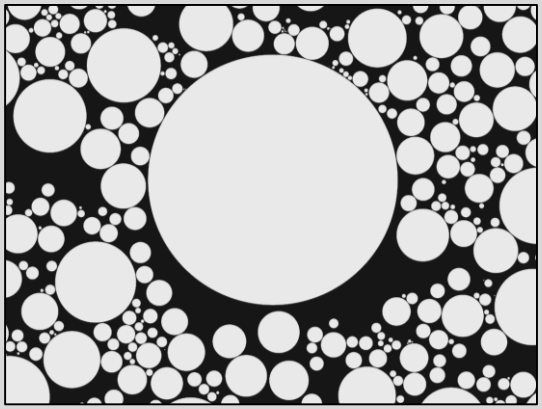
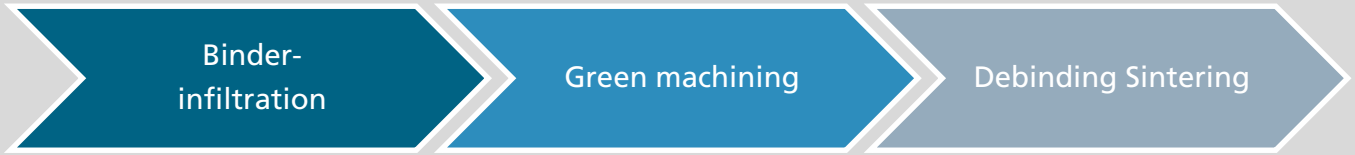


Packing simulation

Shaping by green machining

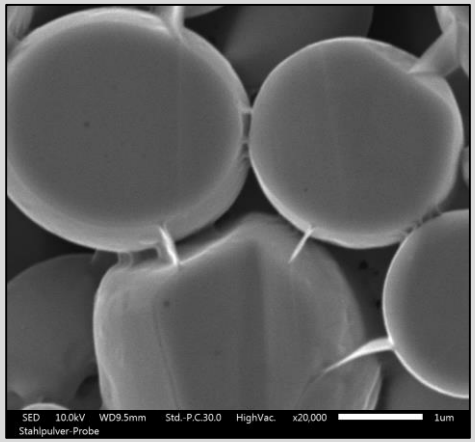
- Sediments - semi-finished product (ring geometry)
- Shaping step necessary
  - Green machining

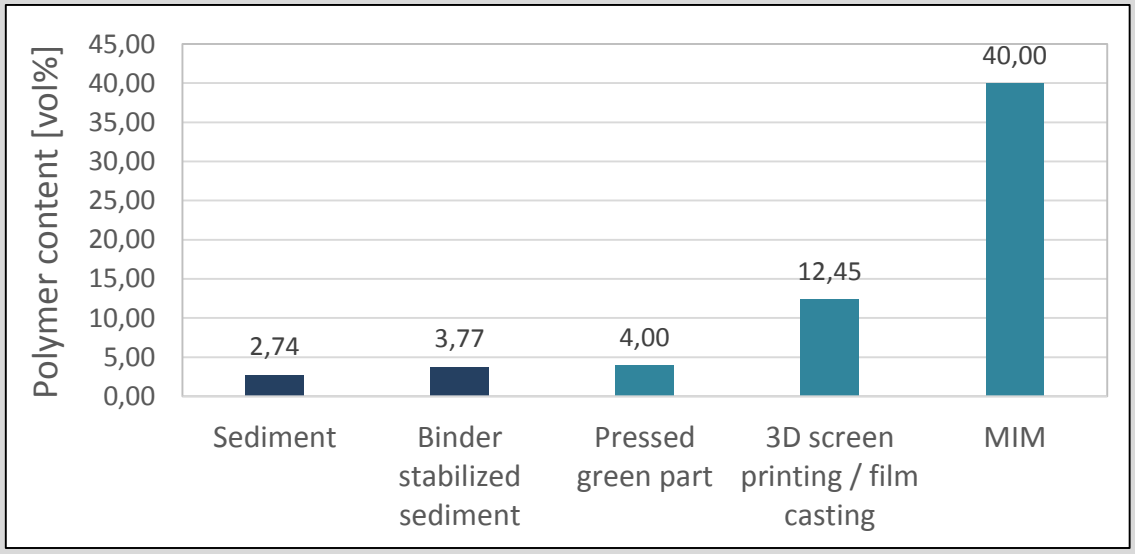


- Binder-infiltration of sediment under vacuum
- Green machining
  - CNC-machining, drilling, turning
  - Debinding, sintering

Green machining – Binder content

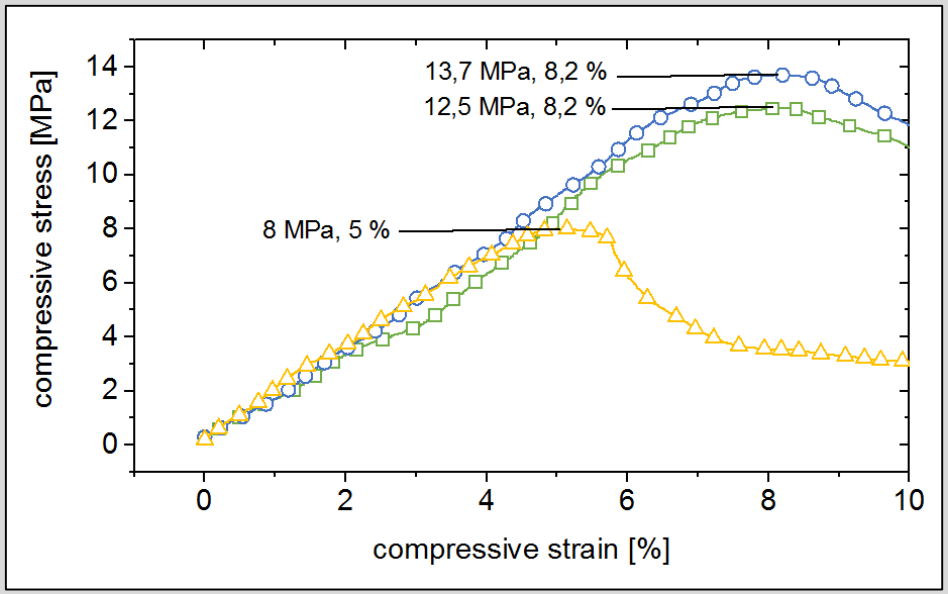
- Binder solution development:
  - Viscosity, wetting behaviour, mech. strength
- Low binder content of ~4 vol%
  - Thermogravimetric analysis:

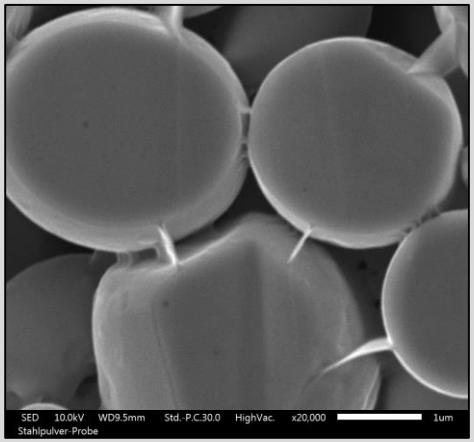




Green machining – Green strength

- Shear forces during machining require sufficient green strength
  - Compression test

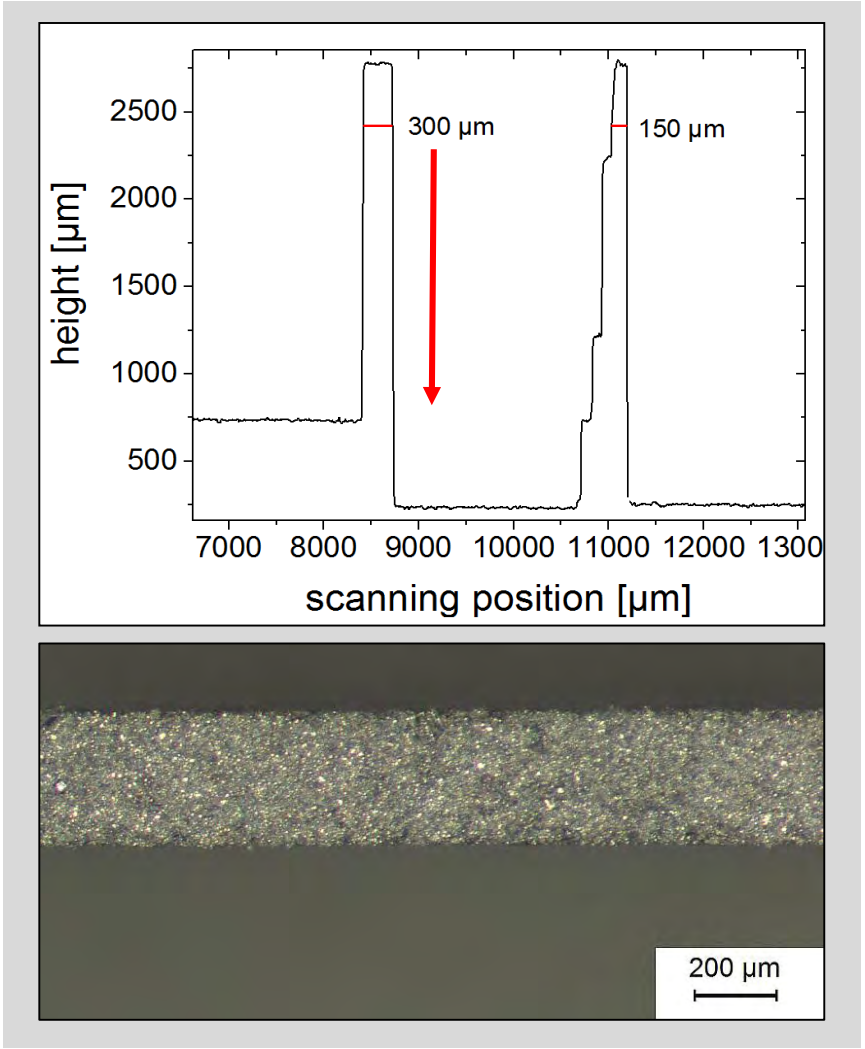




- Compressive strength ~11 MPa
- Max. compressive strain of ~7 %
- Literature values: 18 – 150 MPa

Green machining - Experiments

- Green machining of sediment samples:
  - Process parameters
    - Tool: HSS 12 mm, 2 mm
    - < 1800 rpm
    - 125-160 mm/min feed speed
- Geometry
  - Face milling > cuboid
  - Line profile,
    line width 100-300 µm
  - Aspect ratio h/w = 6
  - 2 mm holes



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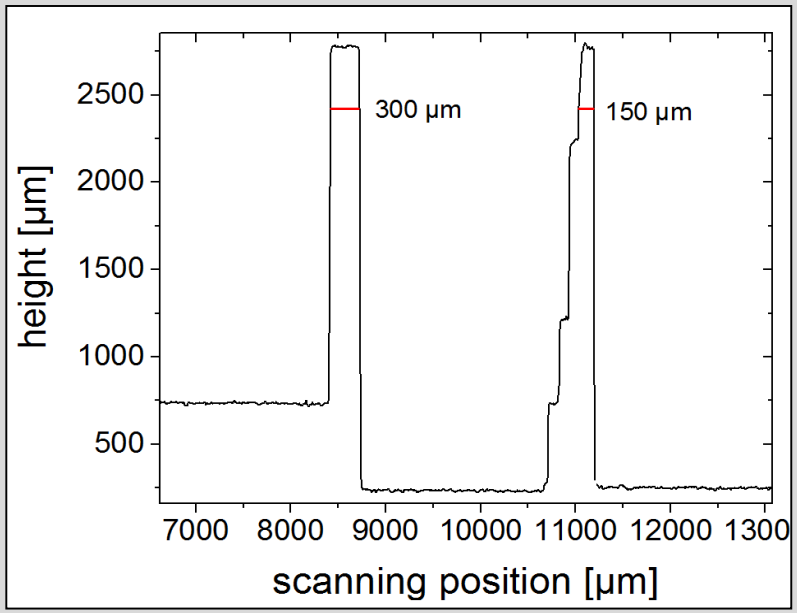
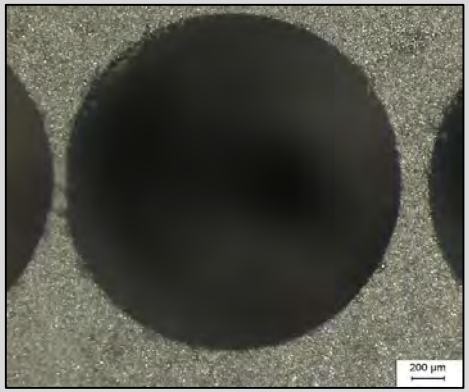
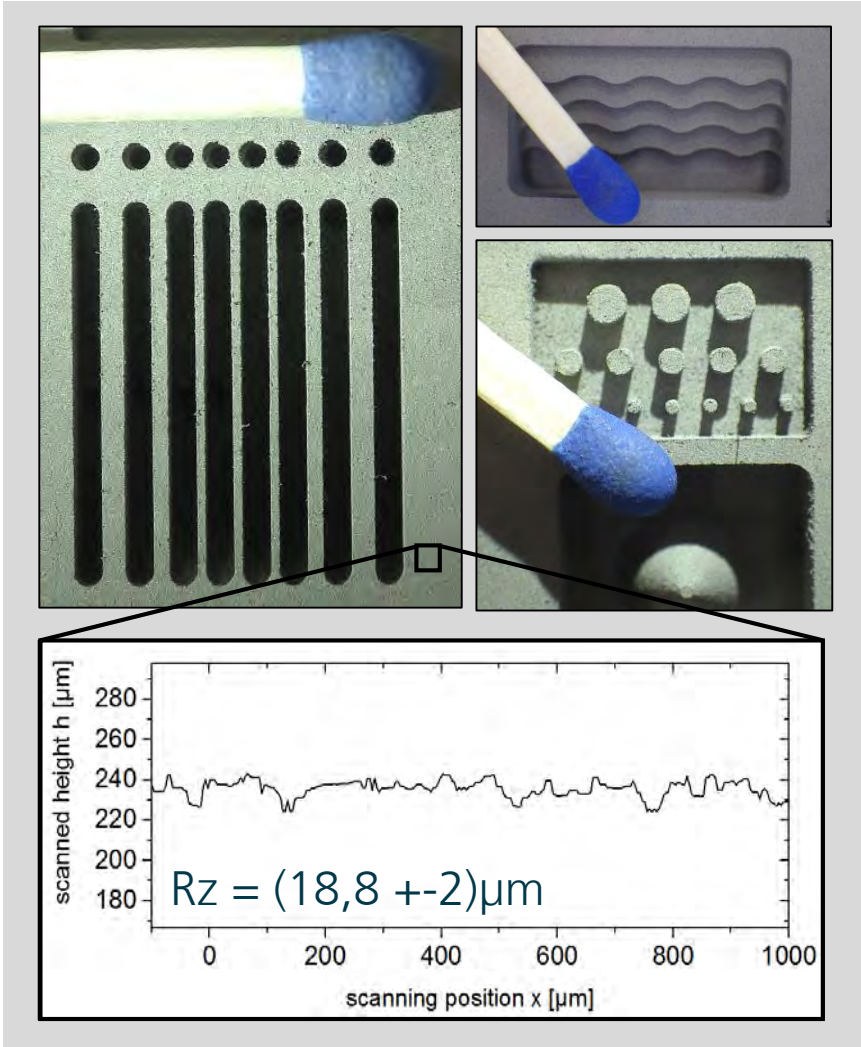




Green machining - Experiments

- CNC-Green machining of sediment samples:
  - Process parameters
    - Tools: 0.2 mm, 5 mm
    - 25.000 - 40.000 rpm
    - 120 – 160 mm/min feed
- Generic structures
  - Face milling
  - Line structures dist. 0.5 – 1 mm
  - Text and wave structures
  - Cylinders und Coboids
    D,a = 0.5, 1, 1.5 mm
    d = 1 – 3,5 mm



Summary and Outlook

- ✓ Centrifugal sedimentation as manufacturing process for machinable green parts tested
- ✓ Fabrication of homogenous green parts possible – no segregation due to particle size and good sintering dynamic
- ✓ Large particle defects can be avoided – also bimodal powders can be used
- ✓ Green machining with minimum resolution of ~ 200 µm at high aspect ratio
- ✓ Good machinability with very little defects

Next steps:

- o Production of gradients possible by using multiple dispense systems
- o Repeatability for sediment results
- o Optimization of milling strategies and evaluation of processing guidelines

Thank you for your attention !

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