FUSED DEPOSITION MODELING – OPPORTUNITIES FOR CHEAP METAL AM

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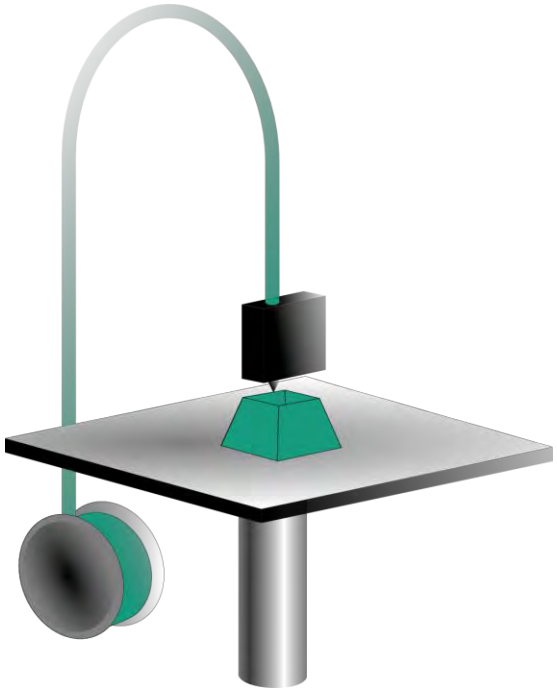
S. Riecker, J. Clouse, T. Studnitzky, O. Andersen, B. Kieback



Fraunhofer IFAM Branch Lab Dresden

Motivation

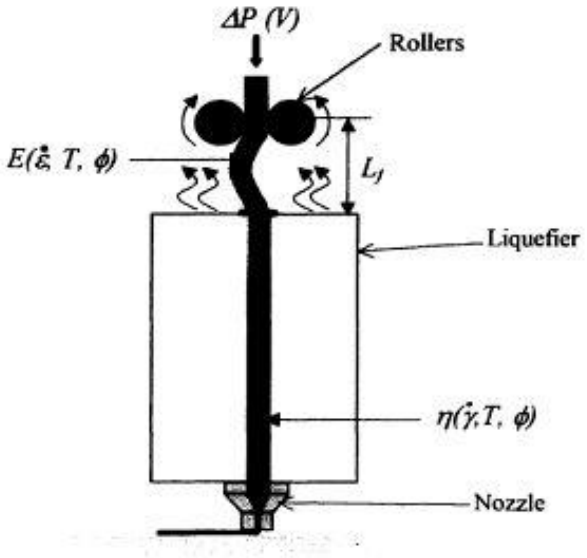
- Great variety of different AM-technologies – FDM more and more popular
- FDM-Printer application ranges from desktop printers for private use to professional series for design studies, prototyping and even for industrial manufacturing
- Low complexity of printing machine: easy to use and to maintain
- Low investment costs, starting at 800 € for self built systems, 2000 € for desktop printers

www.chip.de

http://www.stratasys.com

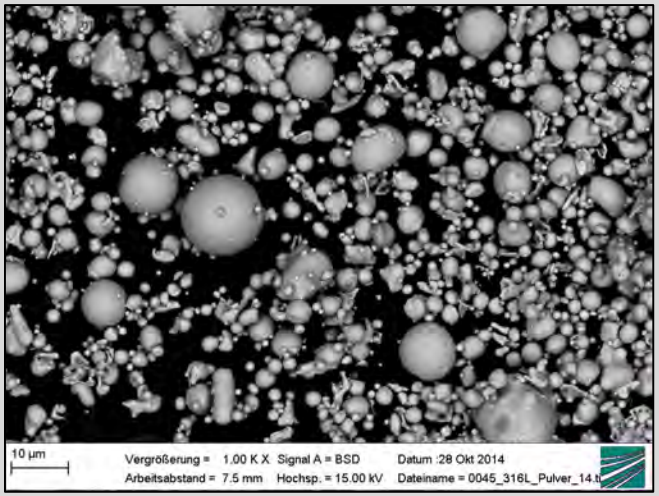
Goal of Studies: Development of a “Metal” Filament

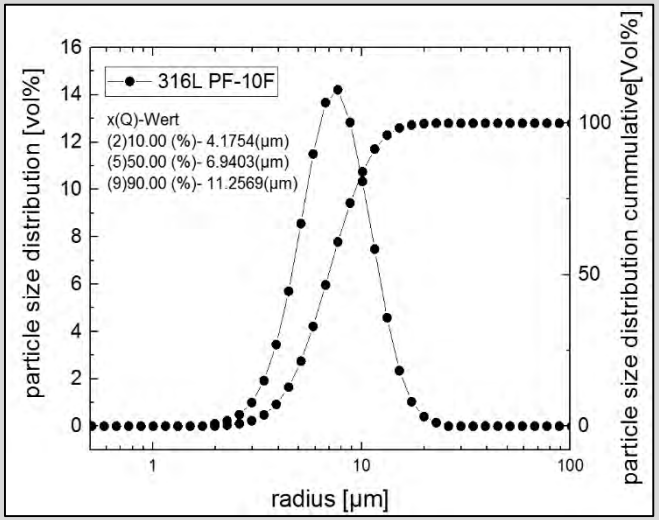
- Sinterable and “suitable” for use in a low-cost desktop printer
- Requirements for the metal filament?
- Metal filling of more than 45 vol.%
- Polymer matrix: Thermoplastic carrier system and organic additives (plasticizer, dispersing agent)
  - Low viscosity (100 – 1000 Pas) at
    - working temperature of about 180-280 °C and
    - shear rates of about 100 – 1000 s^{-1}
  - Flexibility and Strength
  - Good layer adhesion during printing
- Aiming for thermal debinding, no solvent or acidic atmospheres



Project Goal: Development of a “Metal” Filament

- Model powder: 316L MIM powder
  - Spherical
  - D_{50} = 6.9 µm



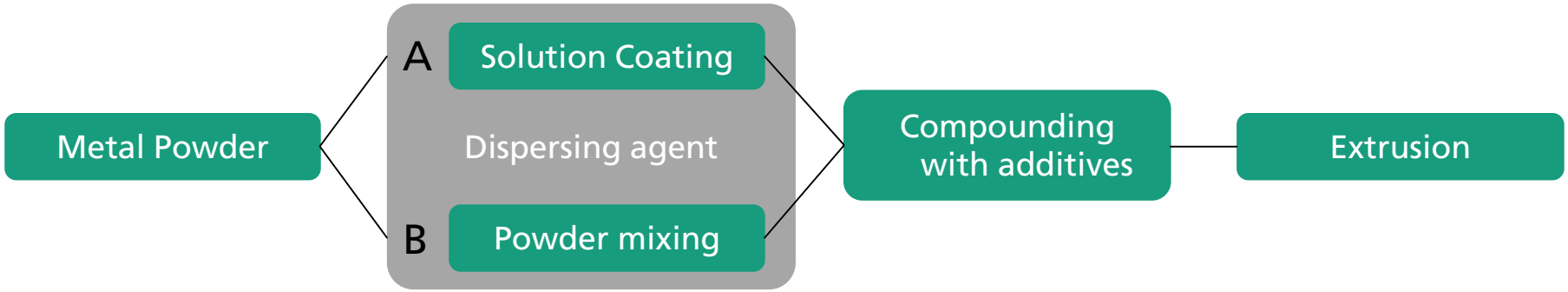


- Thermoplasts

FDM Filament Materials	MIM Feedstock Materials
ABS	PP
PLA	PE
PPSU	PMMA
PET	POM
PA	Paraffin Wax
PC	EVA

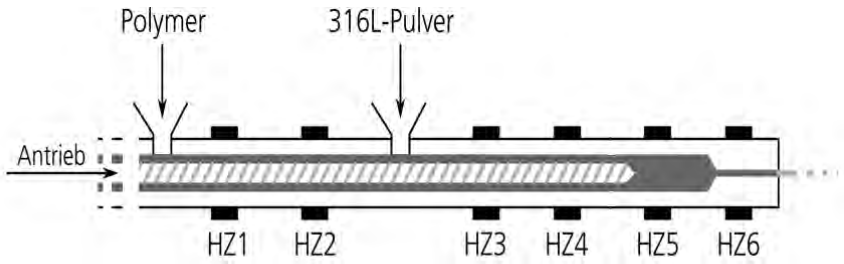
Filament Preparation

- Metal powder is mixed with dispersing agent in two different ways
  - Route A: Solution coating
  - Route B: Powder mixing
- Compounding of additives in extruder
  - Powder Content 0 – 65 vol.% (reference and maximum loading)
- Extrusion of filament
- 12 different feedstock mixtures for filament extrusion experiments



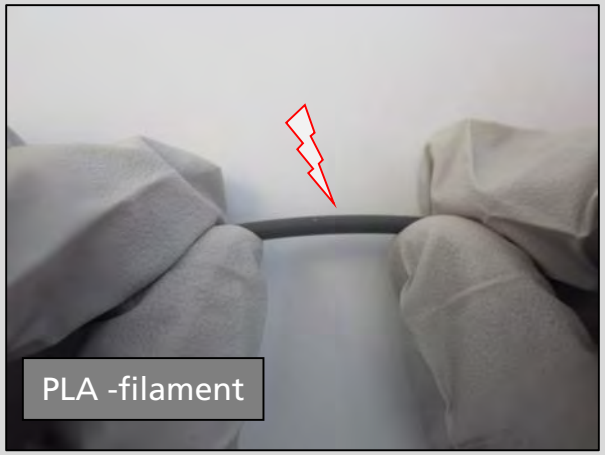
Filament Extrusion

- Brabender TSE 20/40 Extruder
  - Double screw setup
  - 6 Heating zones 210-280 °C
- Die drooling/bearding caused by certain additives
- Oval cross section - soft filament
- Clogging at high particle loadings
- Smoke development

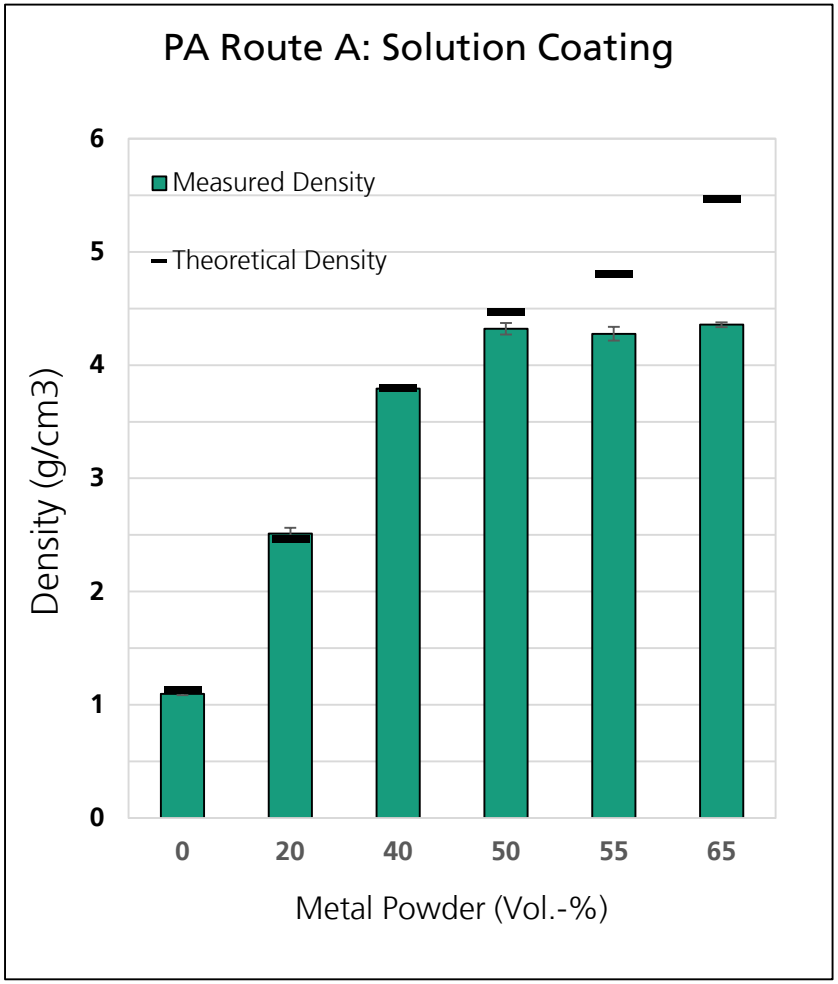


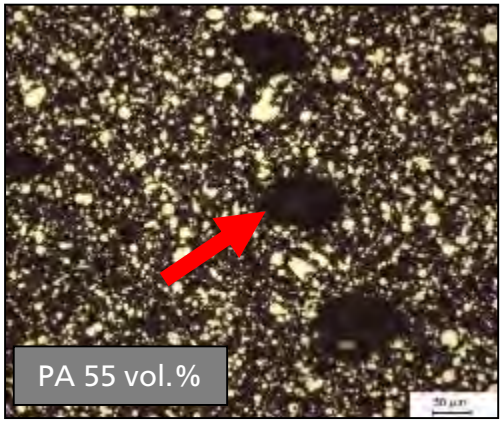
Filament Properties

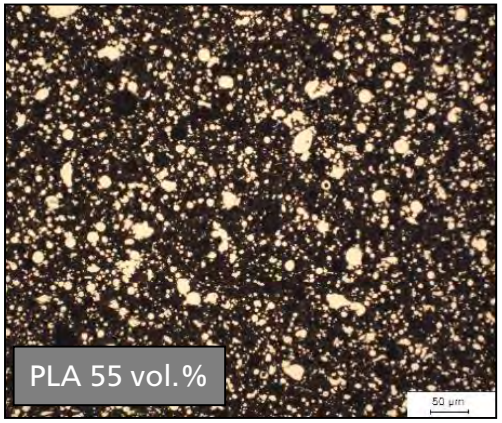
- PLA filaments remain relatively brittle
- Best results for PA-filaments:
- Flexible filaments > coilable
  - particle loadings up to 55 vol.%
  - filaments strong enough for printing
- Circular cross section
  - Diameter (2.6 ±0.2) mm
- Compounding inhomogeneities - surface color inconsistencies in some filaments
  - Important issue when printing through nozzle (0.4 mm)



Filament Characterization







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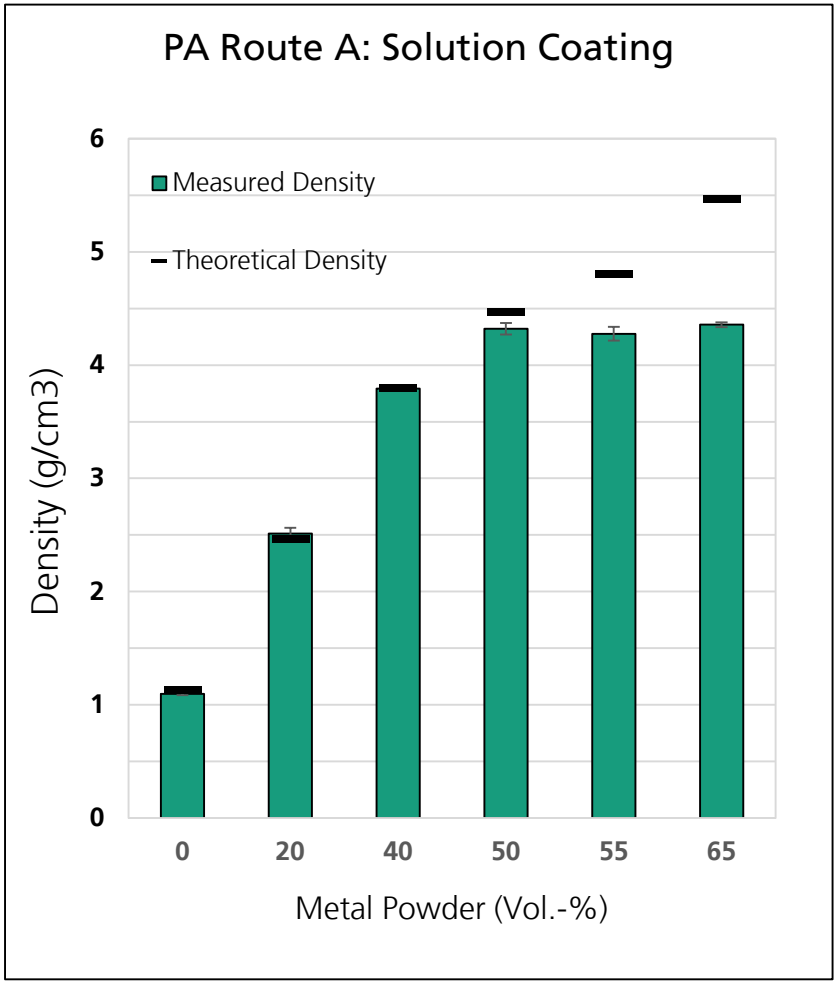

- Filament density lower than expected
  - Critical powder loading
  - Decomposition of some additives
  - Moisture content
  - Compounding – processing issue

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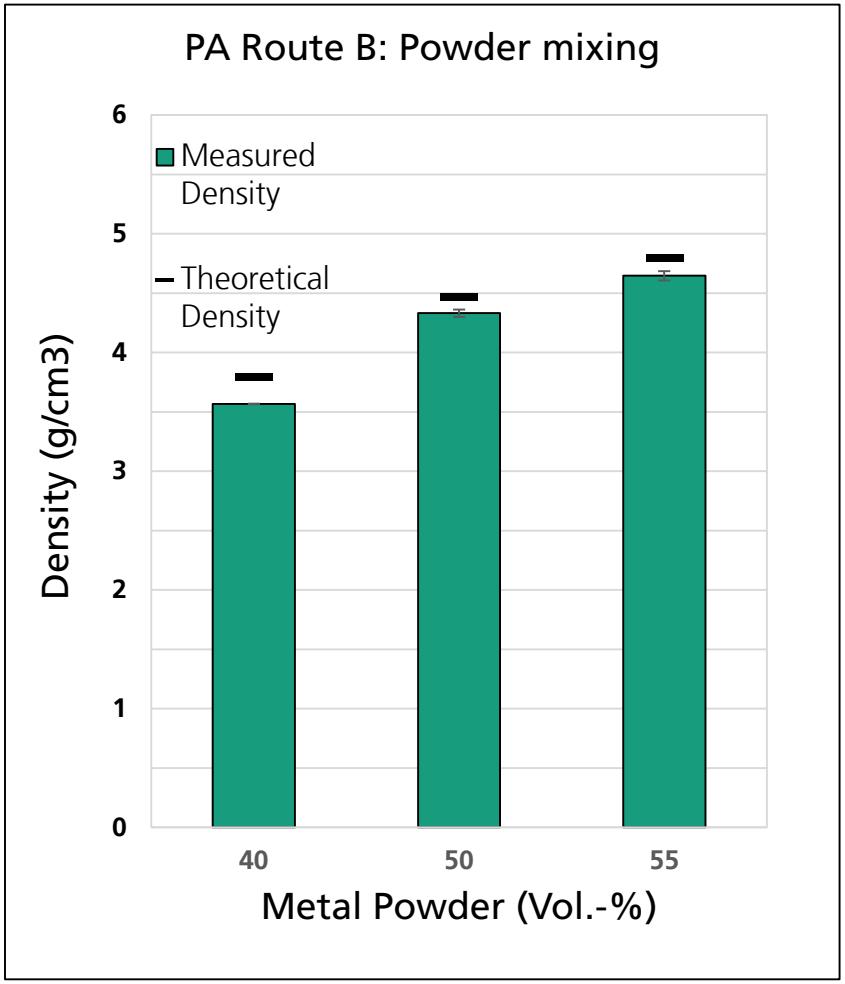

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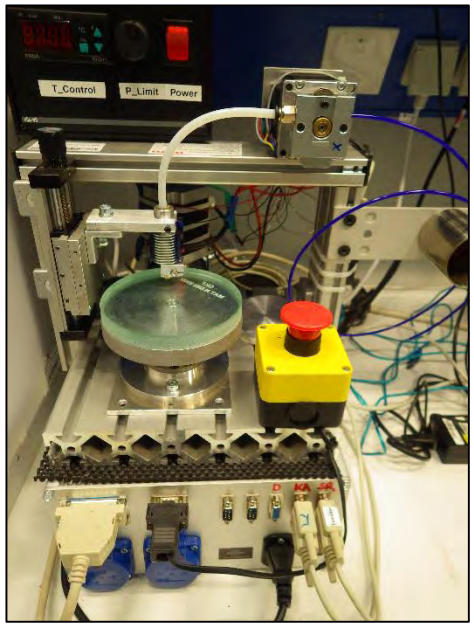
Printing Trials

- Desktop Printer - Ultimaker 2
- Filament extruding setup
- Process parameters:
  - Filament extruding Setup:
    - Nozzle Diameter (0.8, 0.6, 0.4) mm
    - Feed Speeds (0.5 – 7) mm/s
      - Extrusion speeds of about (5 – 100) mm/s
      - Built rates (0,62 – 5) mm³/s
    - Temperature (220 - 290) °C
  - Desktop Printer:
    - Adjustment of Printing Speed, Nozzle Temperature, Fan Speed, Material Flow, Retraction length, Layer Height



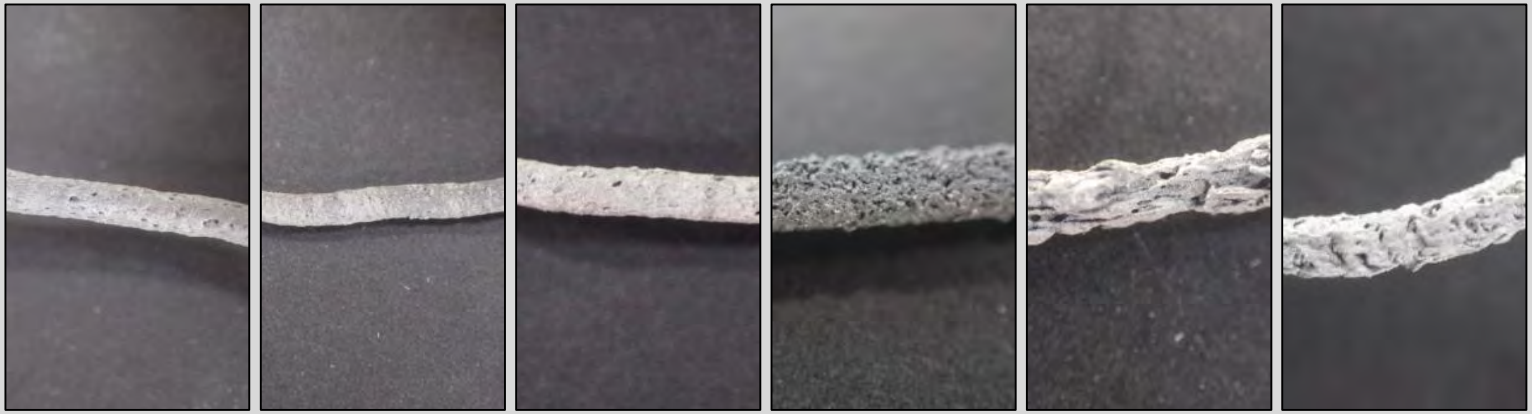
Printing Trials – Setup: Printing Speed

- PA-filament, 50 vol.%, T = 250 °C, nozzle 0.8 mm
- Low speeds: inconsistent extrusion and unstable melt contact with the walls of the nozzle, strand breaks and occasional clogs, voids
- High speeds: higher flow stability for speeds [14 mm/s; 70 mm/s]
- Decent quality for speed around 20 – 25 mm/s

PA Route B: Extrusion Speeds from left to: 7 mm/s [0.88 mm³/s], 14 mm/s [1,76 mm³/s], 42 mm/s [5.3 mm³/s], 70 mm/s [8.8 mm³/s], 98 mm/s [12,37 mm³/s]

Printing Trials – Setup: Printing Temperature

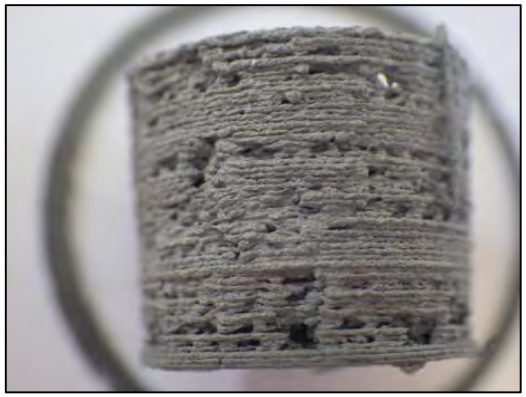
- PA-filament, 50 vol.%, 14 mm/s extrusion speed, nozzle 0.8 mm
- Low temperature: more consistent extrusion, no strand breaks
- High temperature: strand breaks, increase in surface roughness
- Decent quality for 235°C – 240°C with low surface roughness and defects



PA Route B: Temperatures extruded at 14 mm/s from left to right: 225 °C, 235 °C, 250°C, 270 °C, 280°C, 290°C

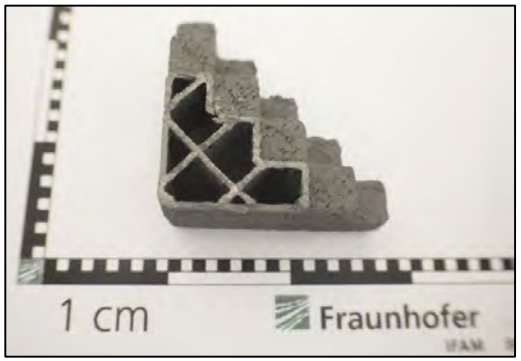
Printing Trials – Common Defects

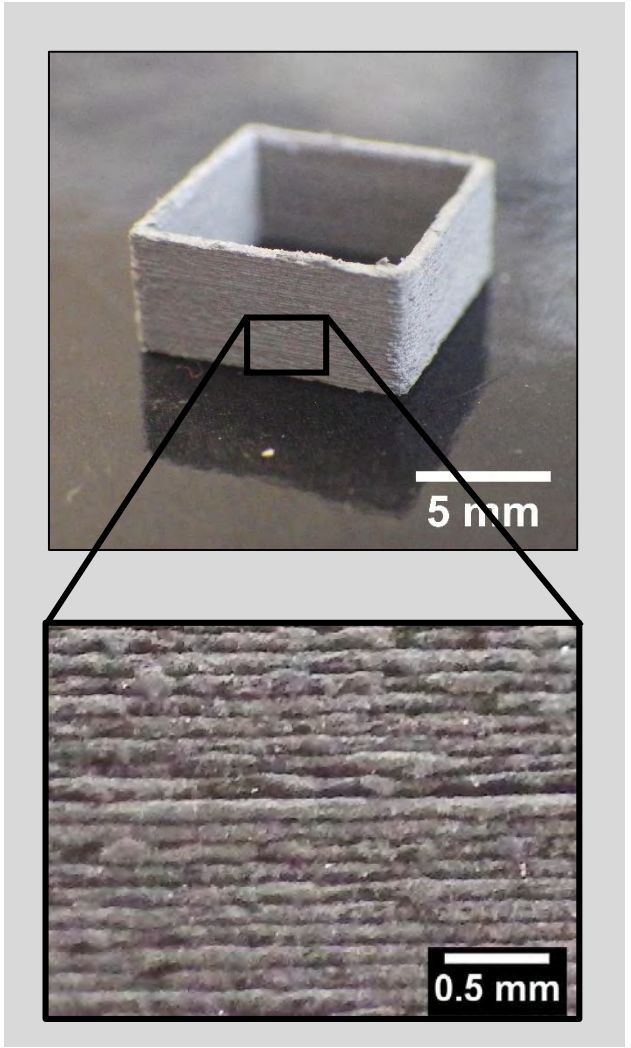
- Filament-nozzle-combination: sweet spot
  - Feed speed
  - Temperature
  - Speed of printhead
- Inconsistant flow
- Under- and Overextrusion



Printing Trials – Desktop Prints

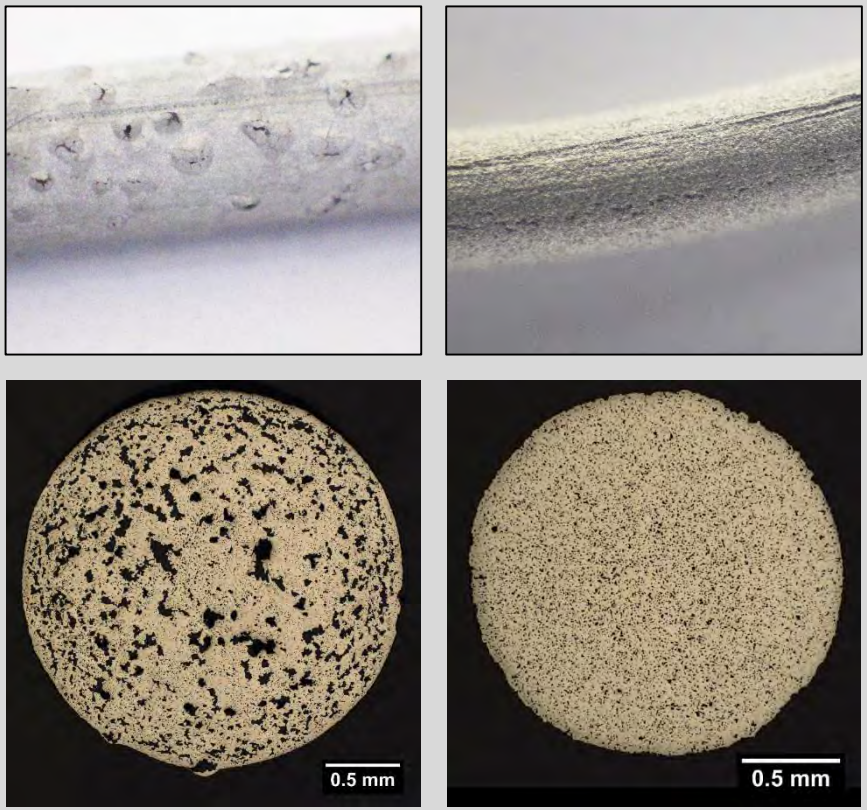
- Printing of generic structures on desktop printer
  - Filament with 50 vol.% (≈ 88 wt.%) powder loading
  - 0.1 mm layer height
  - 0.4 mm standard nozzle
  - Good layer adhesion





Debinding and Sintering of the Filaments

- Debinding/Sintering
  - T = 200 – 450 °C, 1250 °C
  - Hydrogen atmosphere
- Great difference in sintering result:
  - Filament composition
  - Thermal debinding route
- PA-filament with 55 vol.% powder content (right)
  - Porosity ~11 %
  - Carbon content 0.011 wt.%
    - 316L limit = 0.03 wt.%



Sintering results for PA filaments with different dispersing agents

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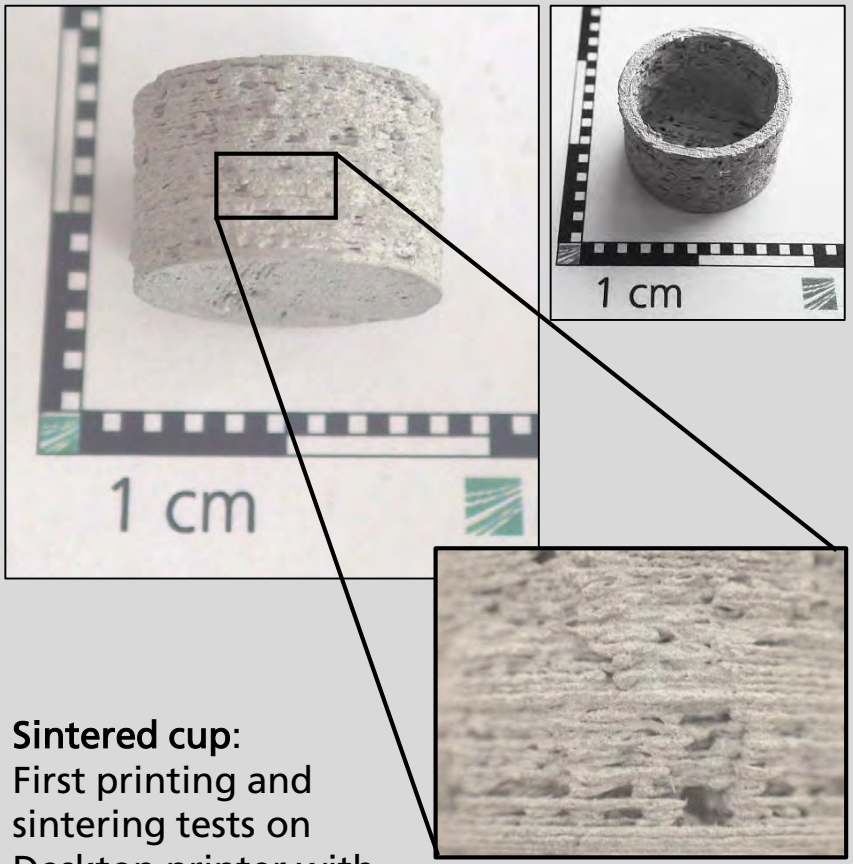

Sintered cup:
First printing and sintering tests on Desktop printer with poor surface quality

Summary and Outlook

- First results of internal studies of metal FDM-process
- Printable filament (0.4 mm nozzle, 0.1 mm layerheight)
  - flexible, mechanic strength, printable up to 55 vol % loading
  - Low cost desktop systems can be used without reconstruction to manufacture green parts
- Sinterable filament
  - Thermal debinding step
- Printing and sintering needs quality improvements
- Focus on the development of the metal filament in upcoming project:
  - Filament composition with increased particle loading
  - Printing parameters for better surface quality and less defects
  - Sintering regime for high density sintered parts

Invitation for symposium

Non beam-based Additive Manufacturing Approaches for Metallic Parts

at Materials Science & Technology 2017

The meeting will be held 10/8/2017 - 10/12/2017,

Pittsburgh PA, USA.

Thank you for your attention !

Dipl.-Ing. Sebastian Riecker

Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM, Branch Lab Dresden

Winterbergstraße 28 | 01277 Dresden | Germany

Phone +49 351 2537-429

Mail sebastian.riecker@ifam-dd.fraunhofer.de