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Additive manufacturing of stainless steel via fused deposition

Marius Wagner

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Frank Clemens

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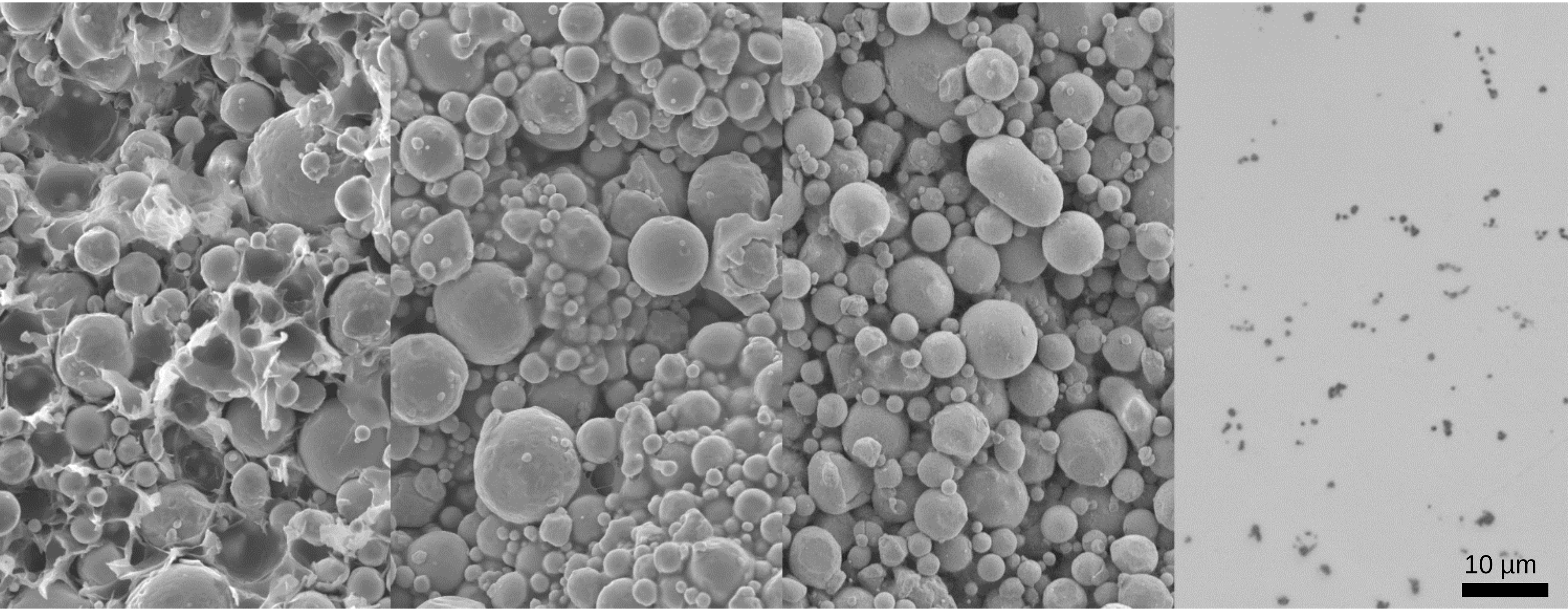

Additive Manufacturing of Stainless Steel via Fused Deposition

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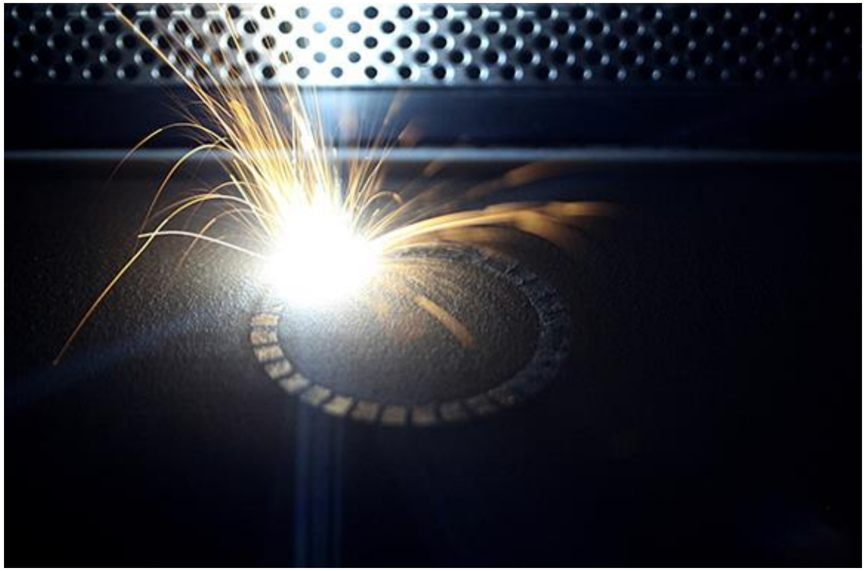
AM of Metals

Powder Bed Fusion



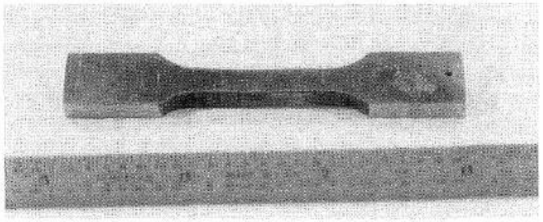
https://www.cetim.fr/en

Handling of open powder

Large quantities of material required

Fused Deposition of Metals

- Based on the Fused Deposition Modeling (FDM)
- FDMet was first introduced in the early 90s at the Rutgers University
- Patent of FDM expired in 2009, prices for FDM printers dropped from over 10,000 $ to less than 1000 $
- Many open research questions
  - Recent years research interest grows



Agarwala, et al. *1996 International Solid Freeform Fabrication Symposium*.

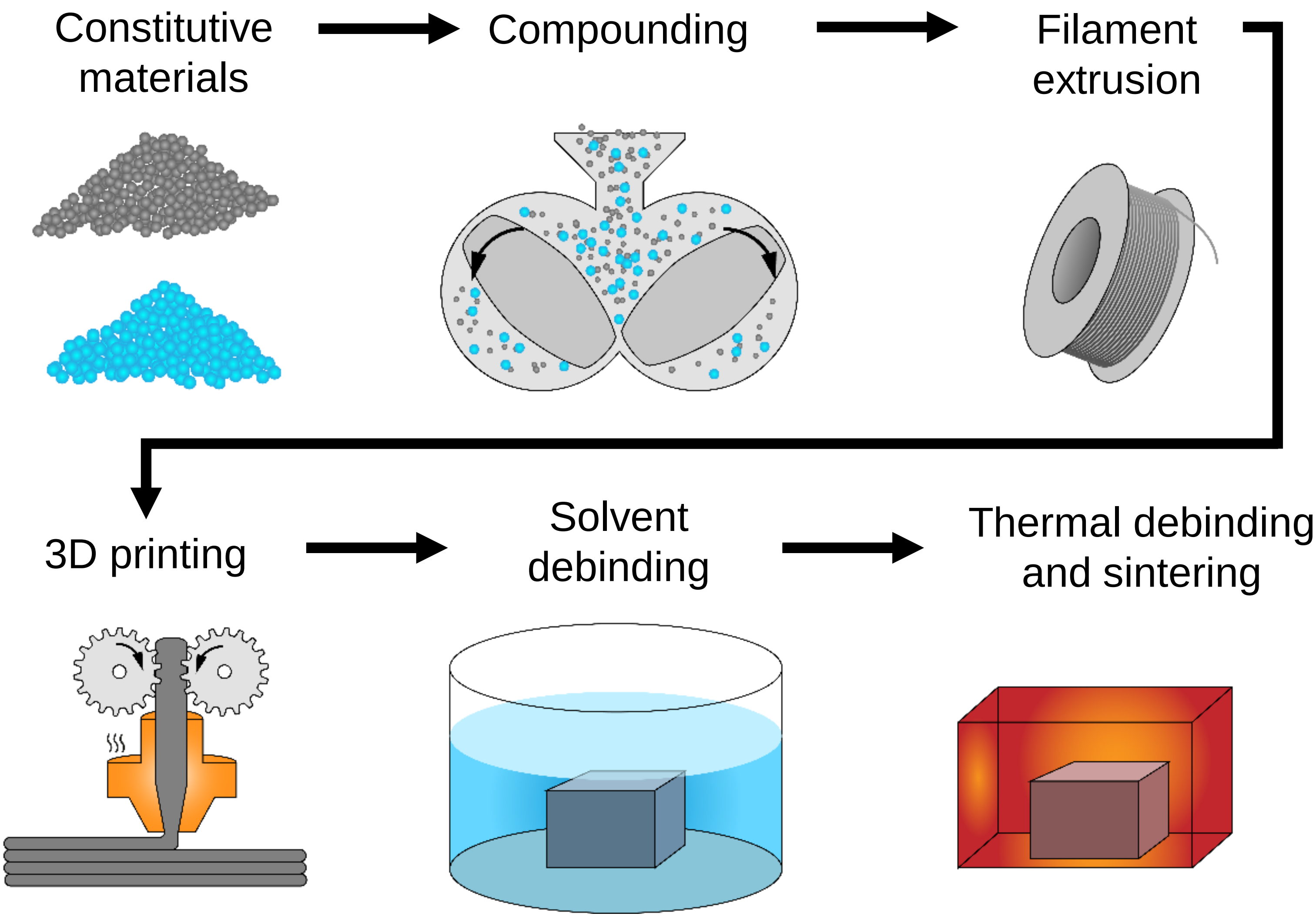
Fused Deposition of Metals

- Markforged, Desktop Metal, BASF
  - Closed proprietary systems
  - Limited materials available

Ultrafuse 316LX filament, BASF

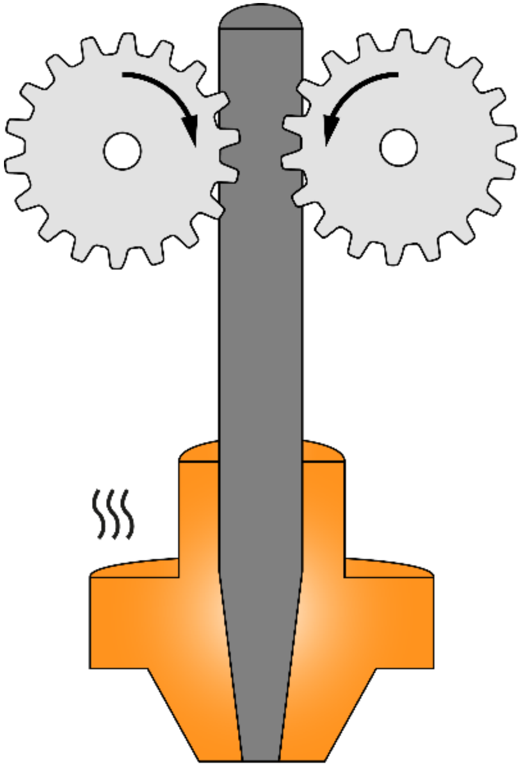
- Development of own filaments
  - Gain knowledge about all processes involved
  - Freedom in material selection

Fused Deposition of Metals

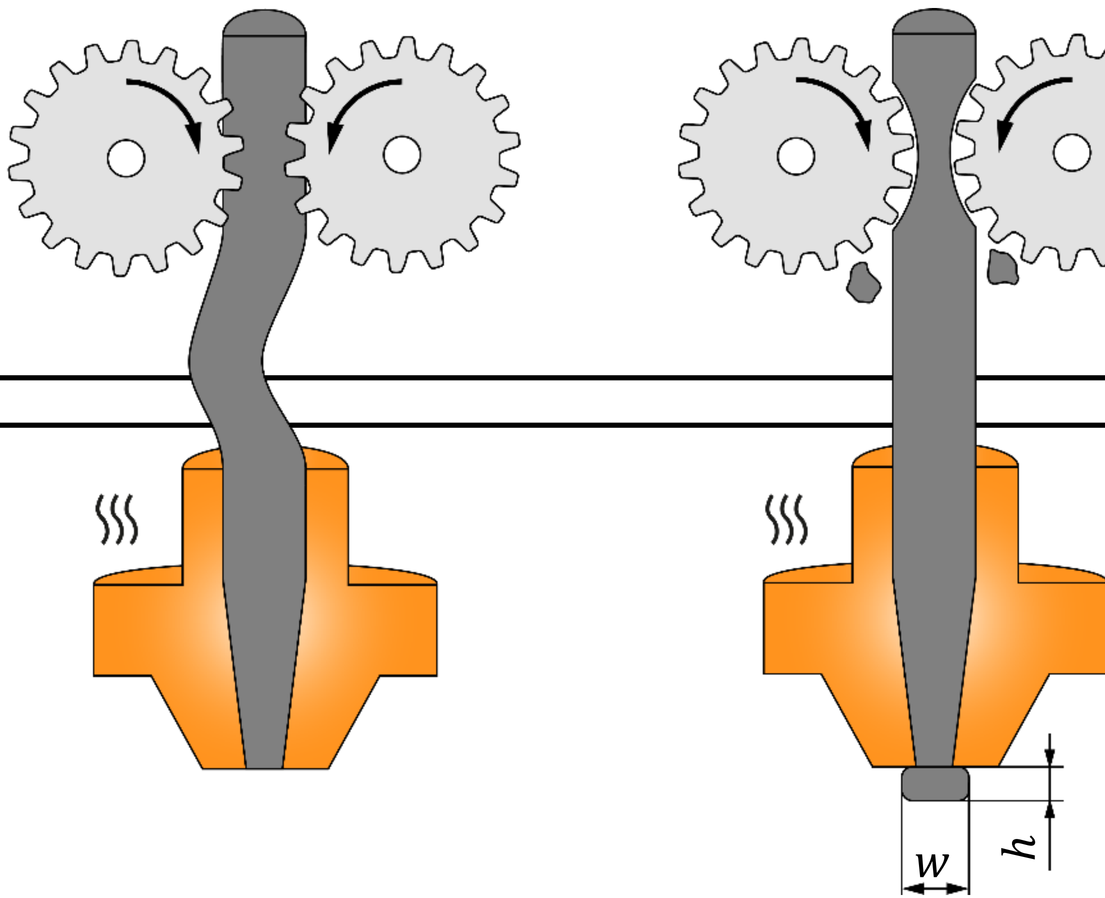


FDM 3D Printing

bq Hephestos 2 - 3D printer



Extrusion of Filaments



$$P_{max} = \mathrm{F}_{\mathrm{max}} / A$$

$$Q = w \cdot h \cdot v$$

$$\dot{\gamma}_{apparent} = \frac{4\,Q}{\pi\,{R_n}^3}$$

$$\tau = \eta \cdot \dot{\gamma}$$

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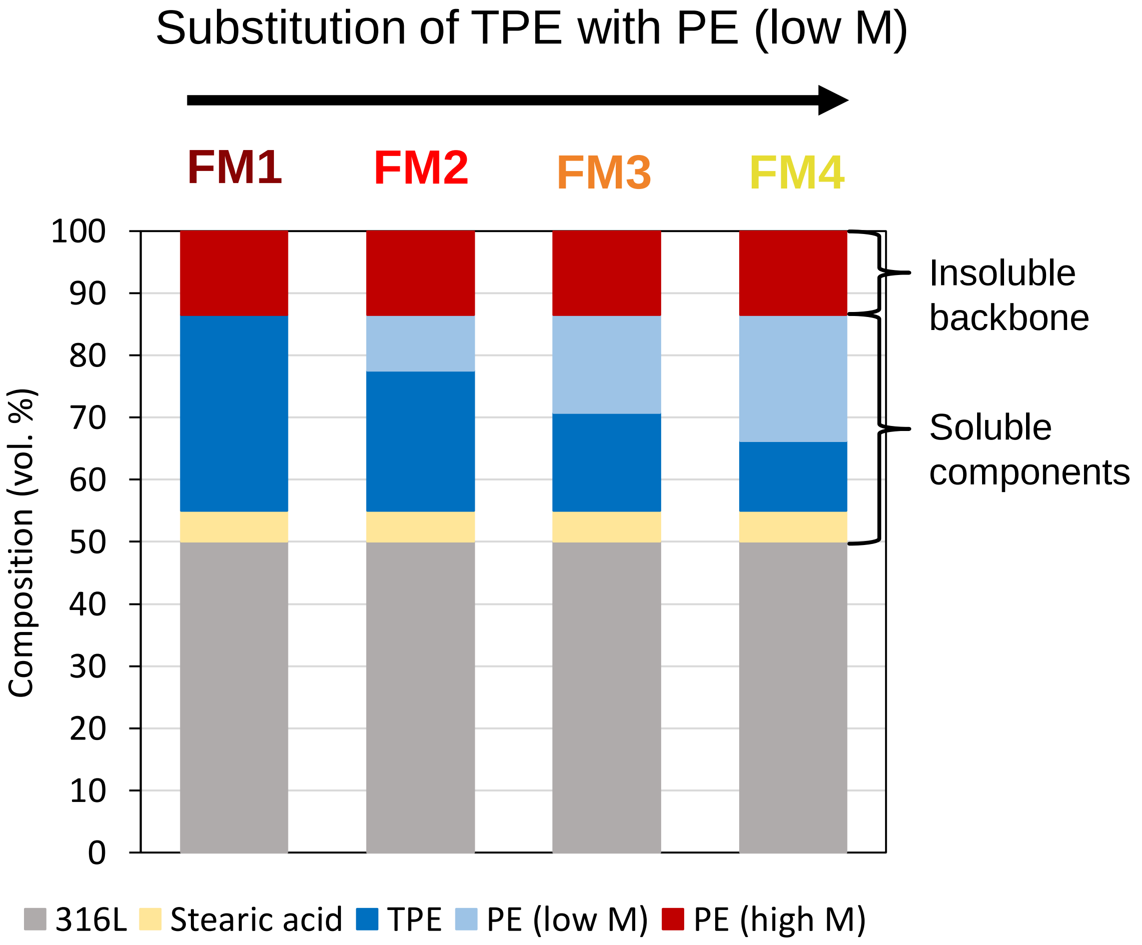
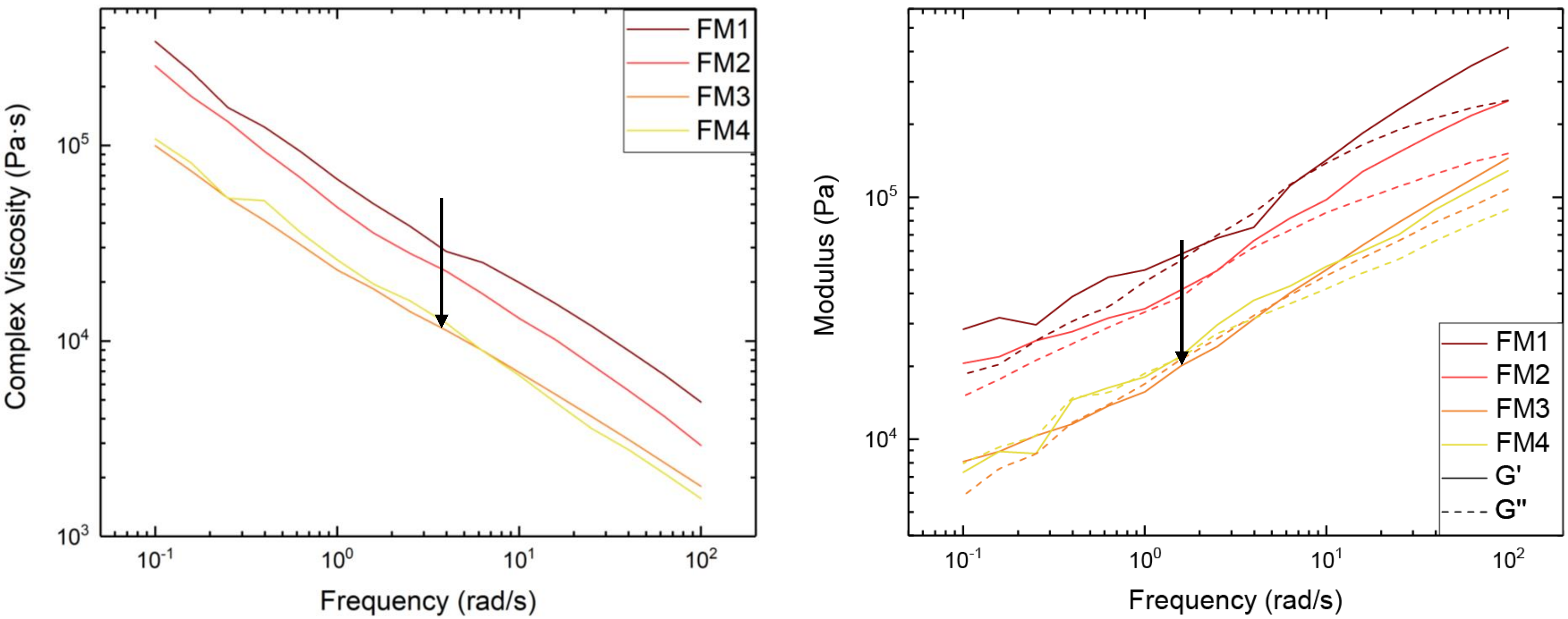
w h

FDMet Binder Composition



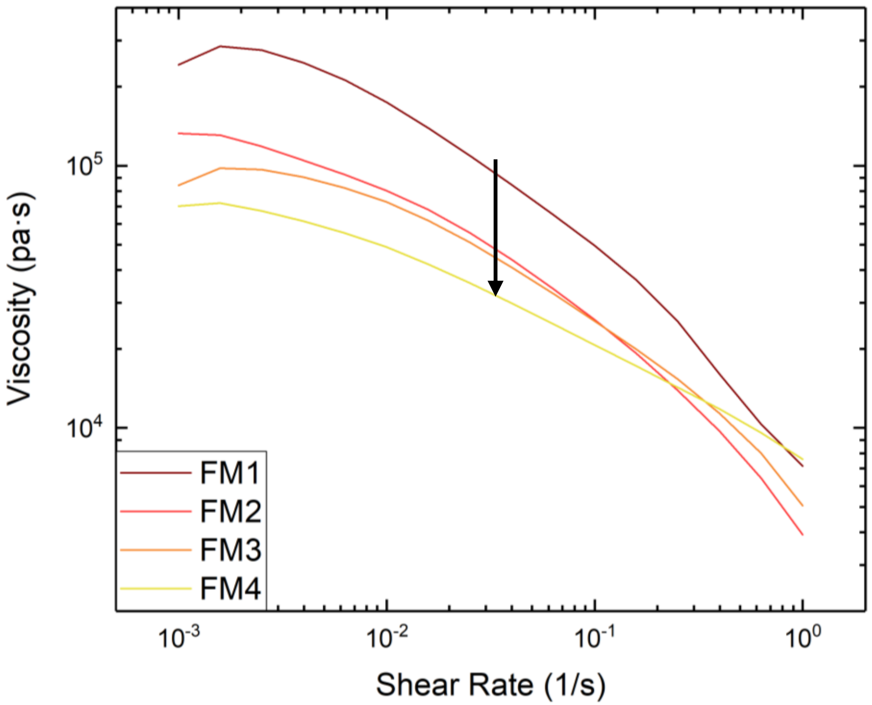
- Increasing stiffness
- Decreasing viscosity
- Increasing brittleness

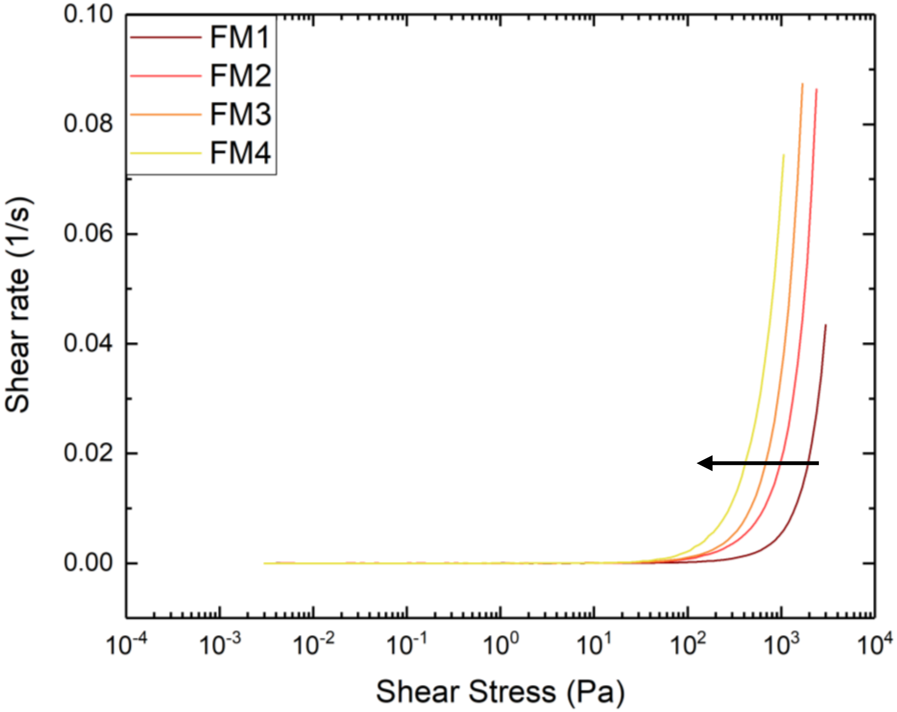
FDMet Binder Composition



- Rheological behavior governed by particle–particle interactions
- Matrix viscosity affects the interaction times

FDMet Binder Composition

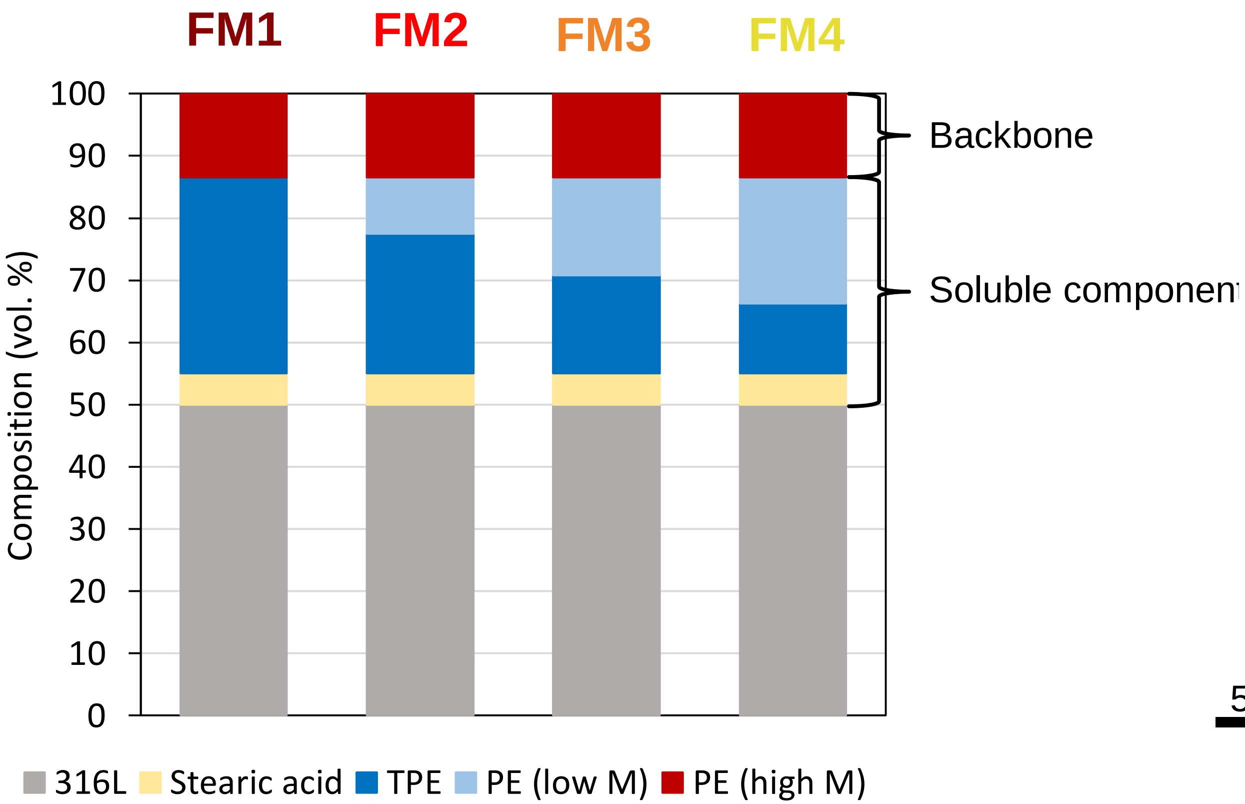


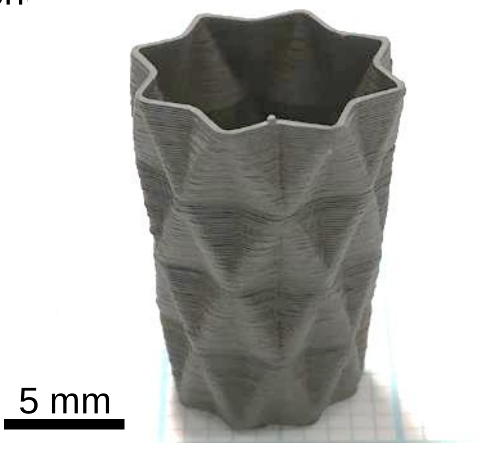


Yield stress:

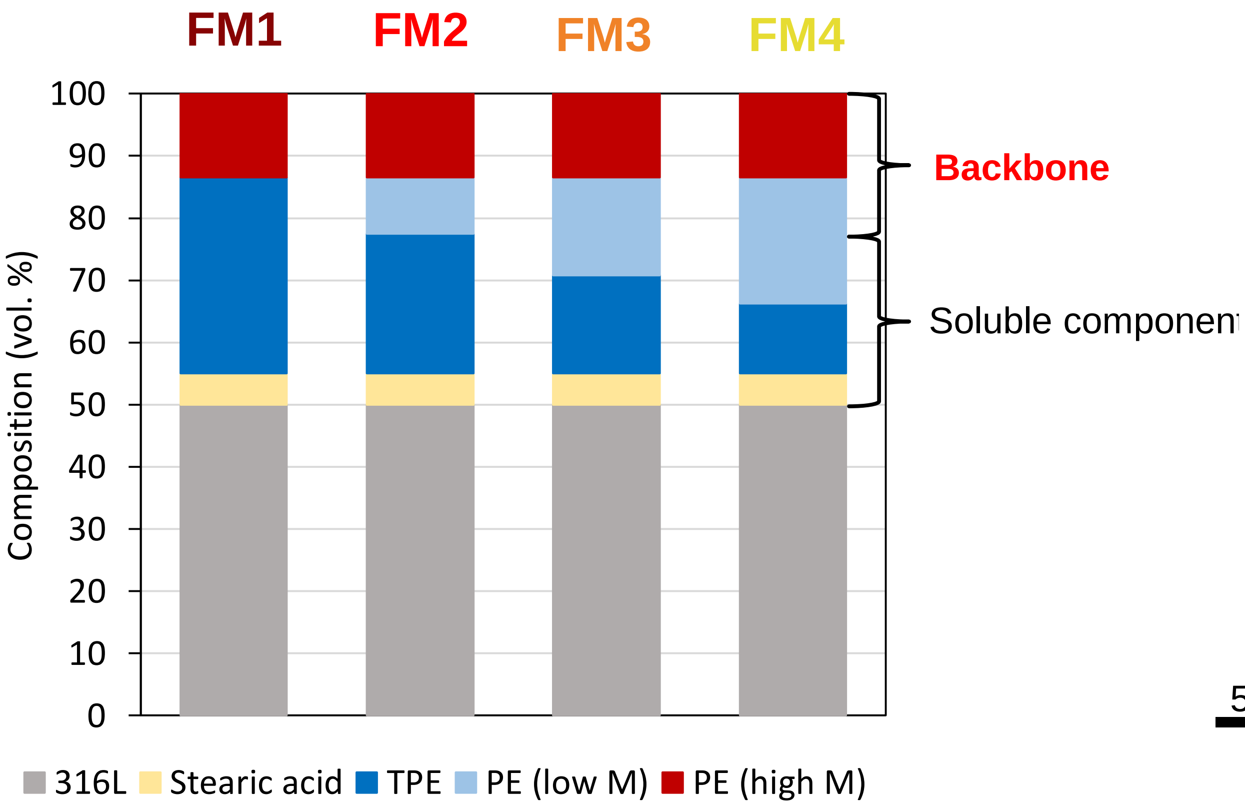
- No deformation in the printing process
- Shape retention during thermal debinding

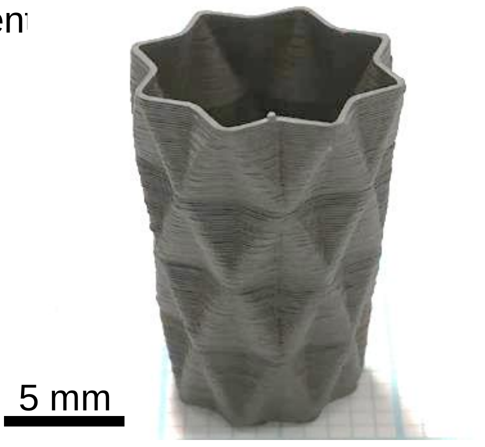
FDMet Binder Composition





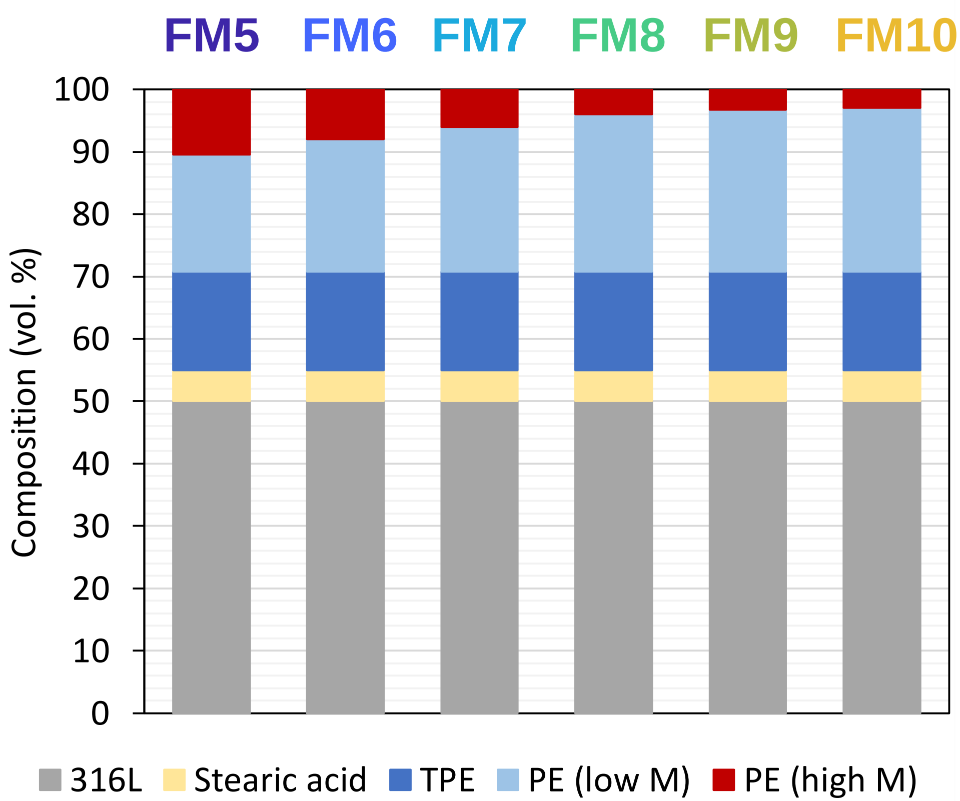
FDMet Binder Composition

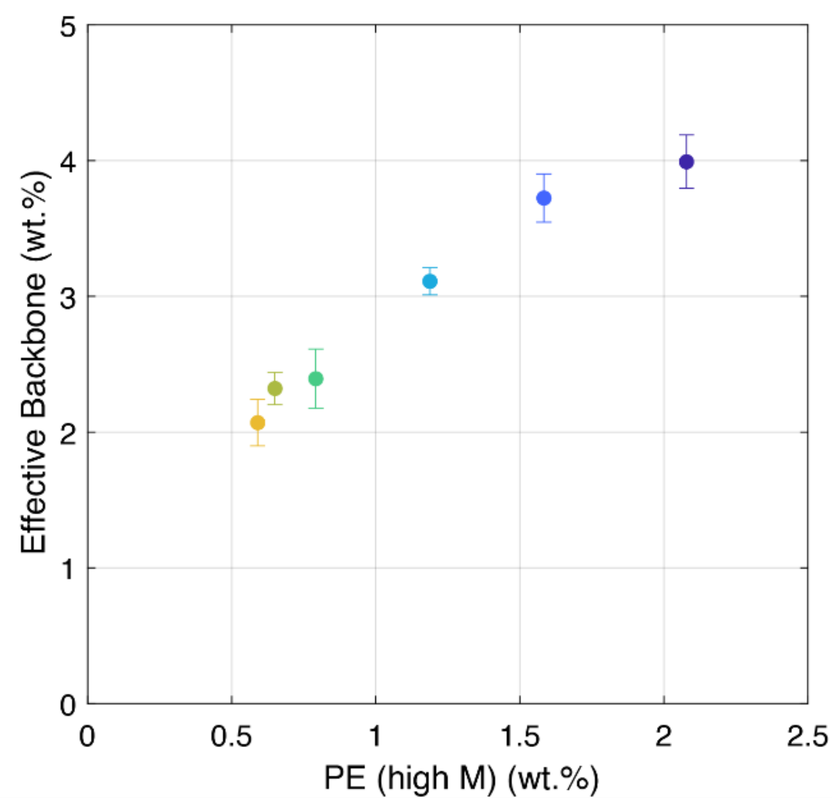




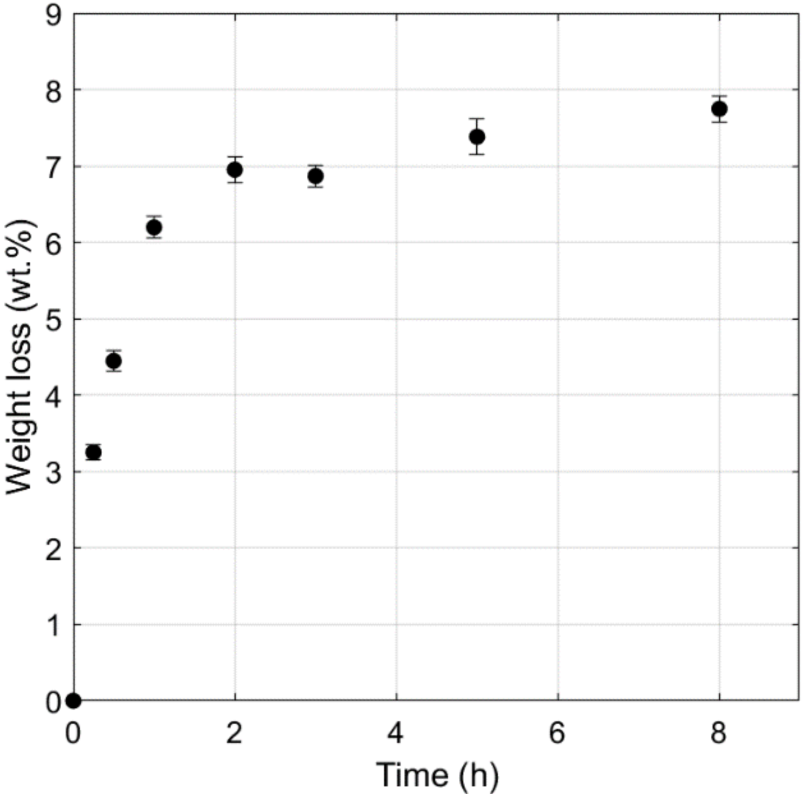
Solvent Debinding

Effective backbone as a function of high M PE:



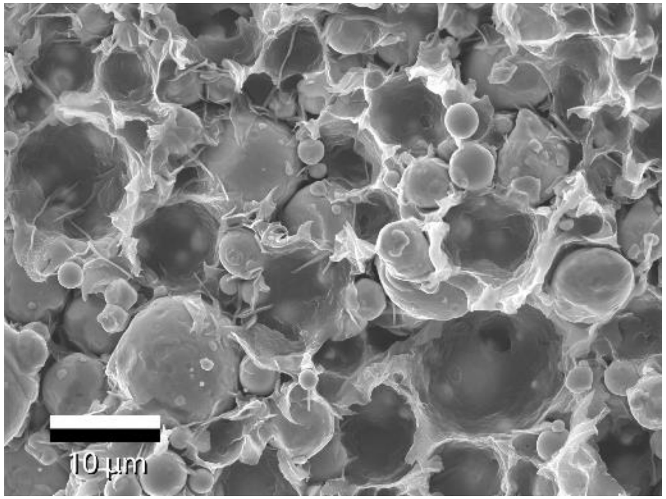


Solvent Debinding

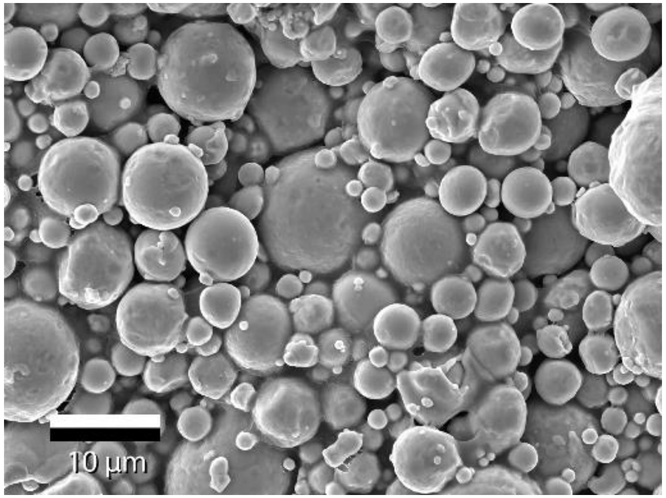


- Removal of TPE, PE (low M), and stearic acid
- Cyclo-hexane at 60°C

Before solvent debinding

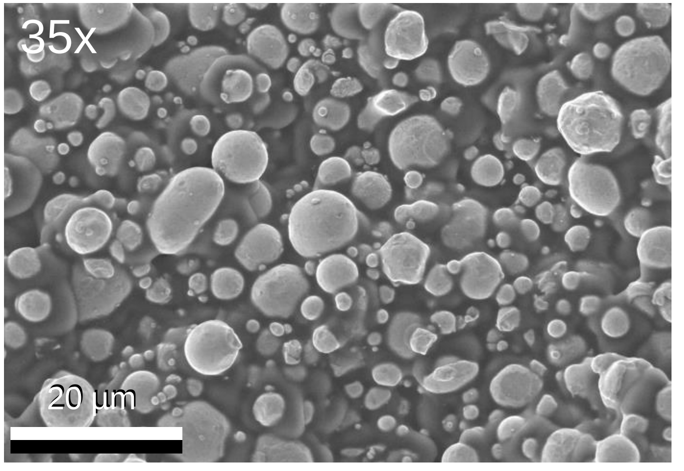


After solvent debinding



Thermal Debinding

In-situ environmental SEM investigation

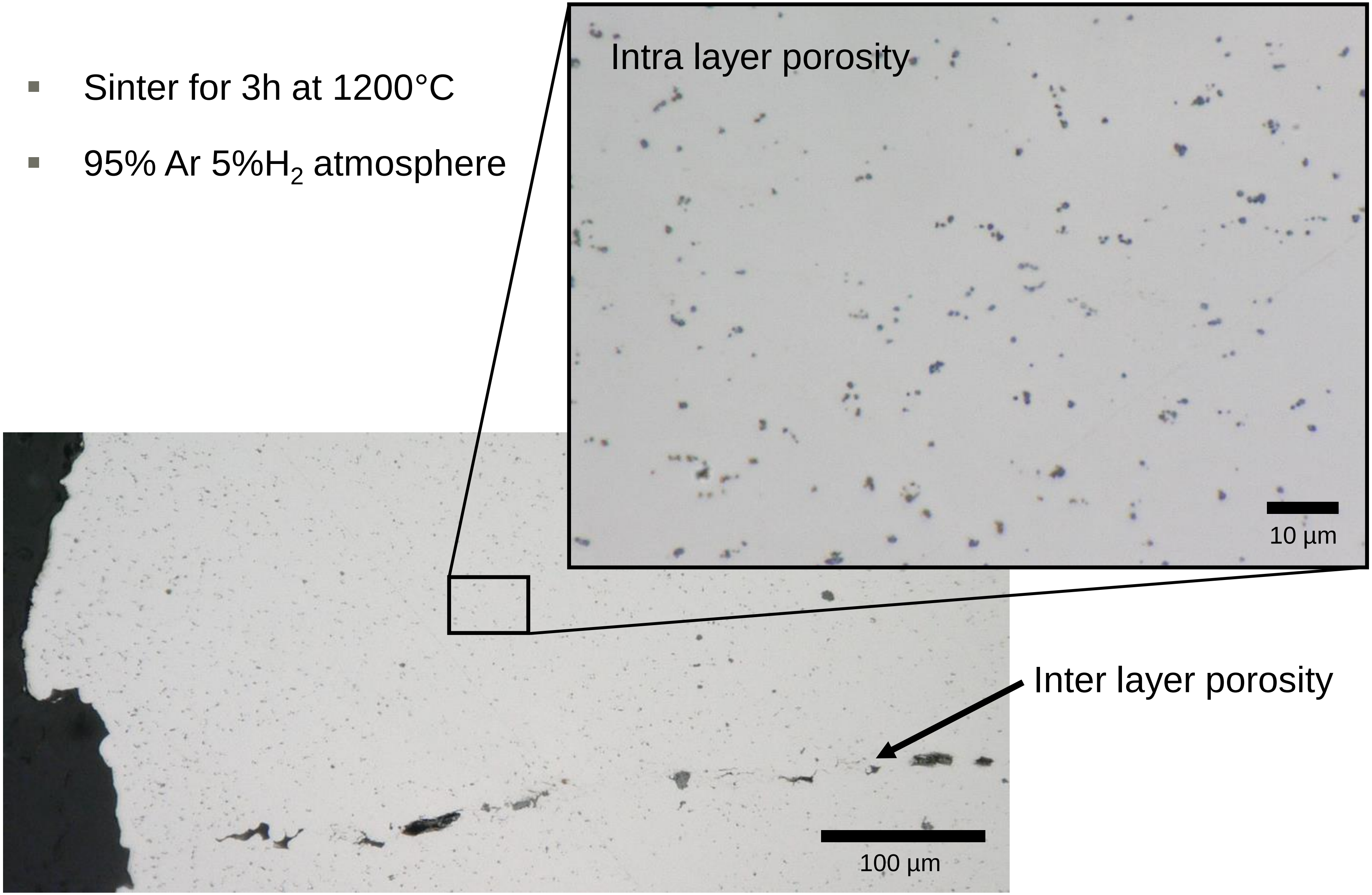


Decomposition of the PE backbone between 340°C and 560°C

- H_2 atmosphere
- P = 25 KPa

Sintered Microstructure

- Sinter for 3h at 1200°C
- 95% Ar 5%H_2 atmosphere



High Speed Nanoindentation Mapping

- Load and penetration depth are measured, which allows calculation of hardness and modulus
- iNano system from KLA with a NanoBlitz module, which allows >1 indent per second: ~50,000 indents in one night!

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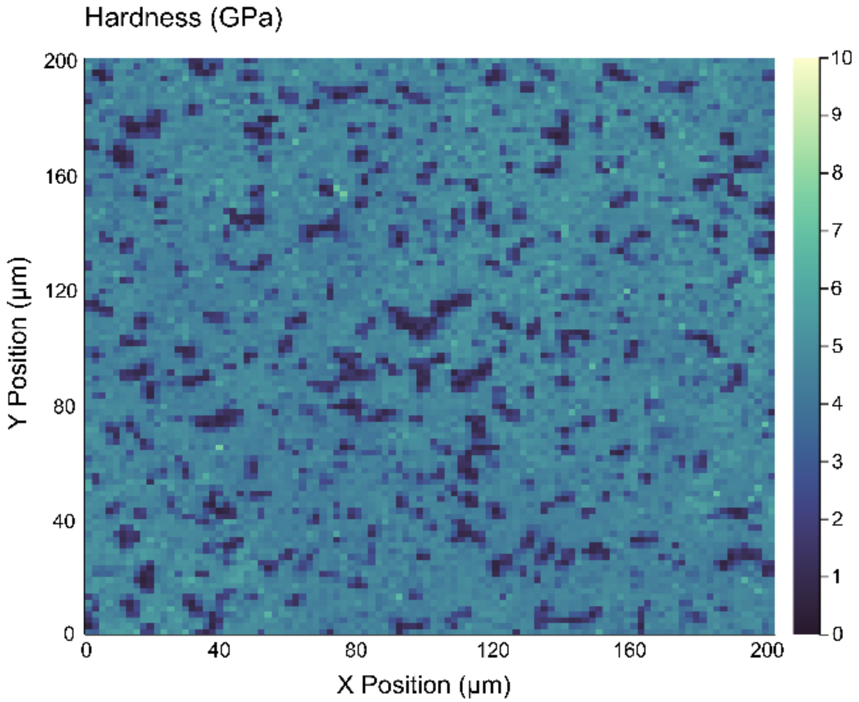
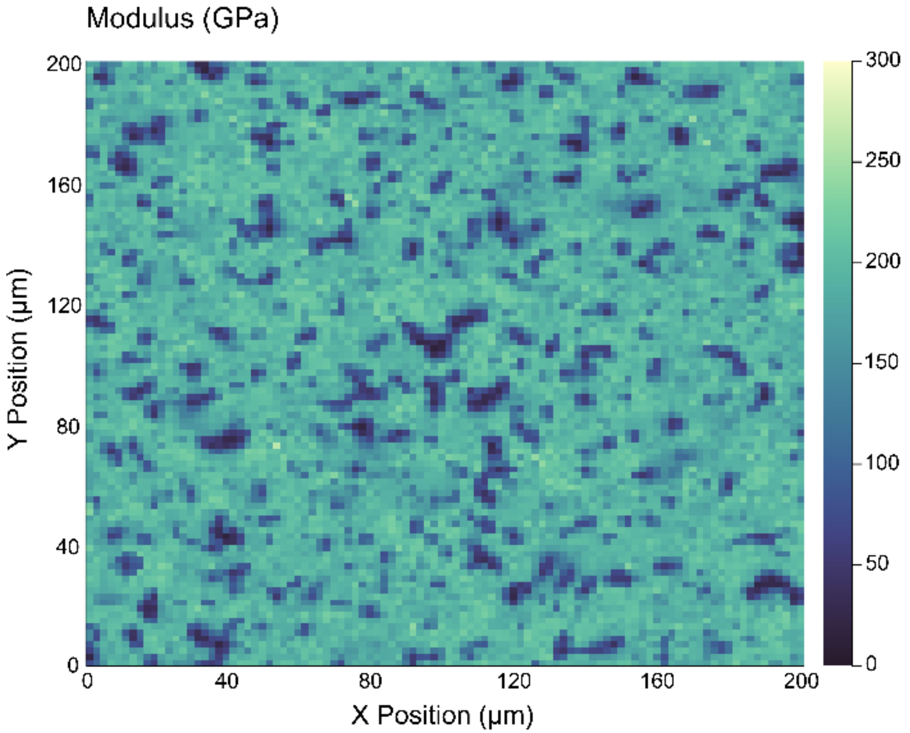
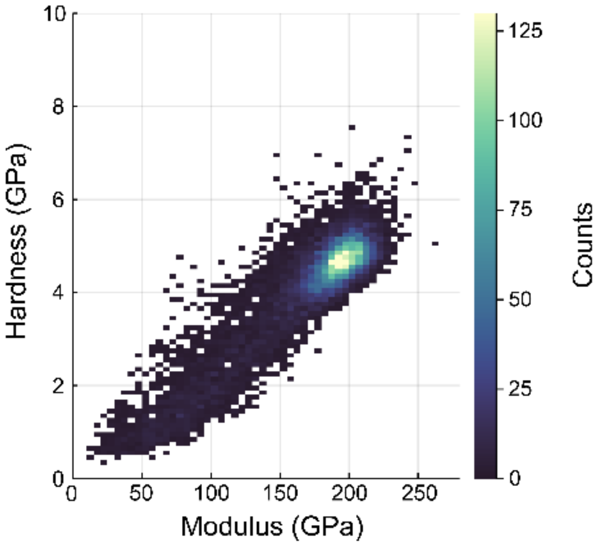
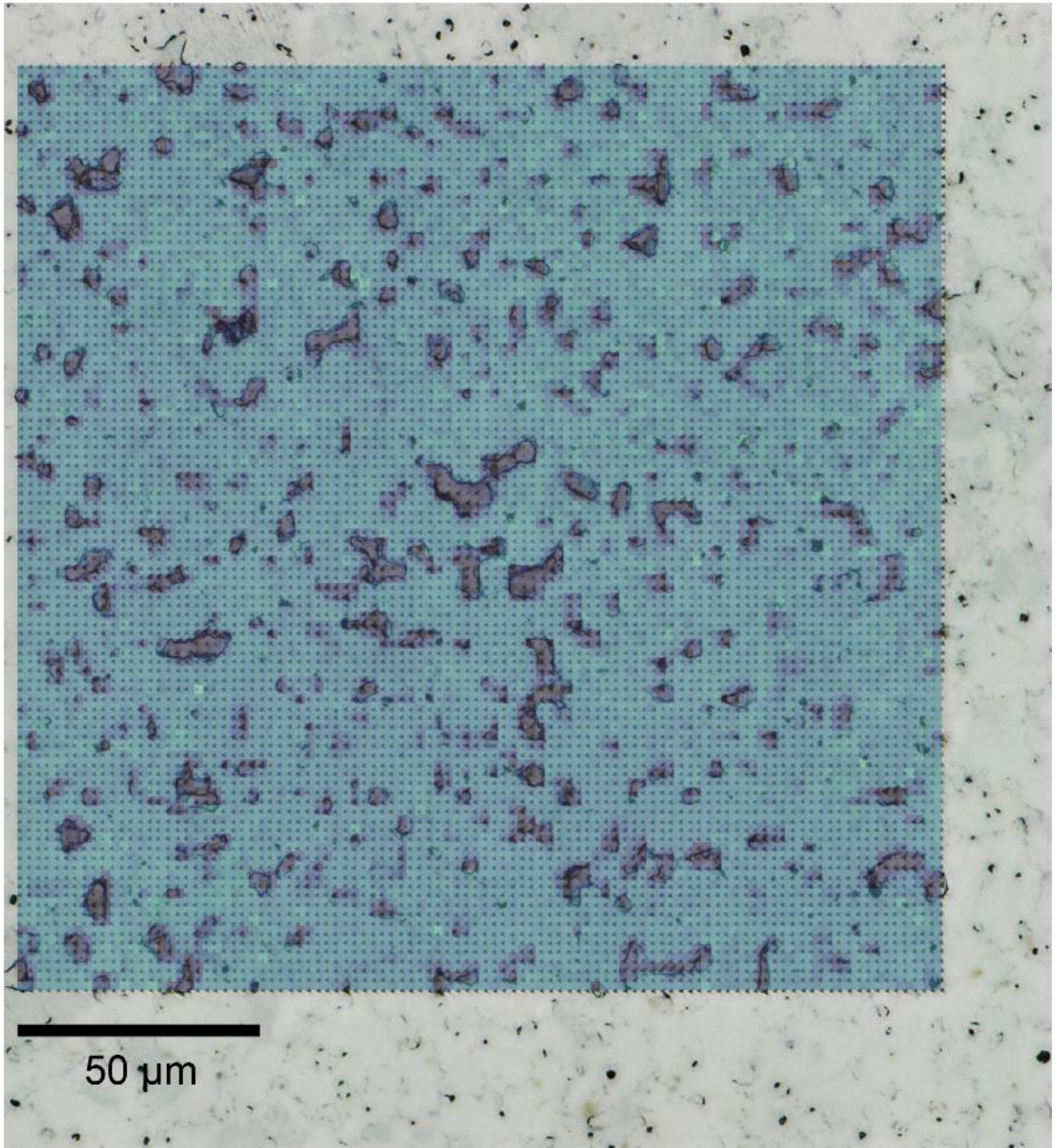
Indentation Mapping of Sintered 316L







Indentation Mapping of Sintered 316L

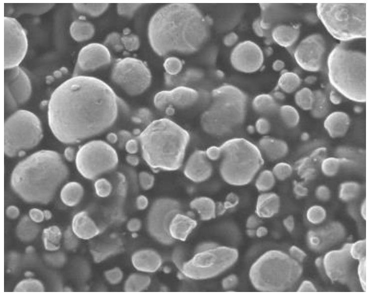


Nanoindentation porosity:
15%

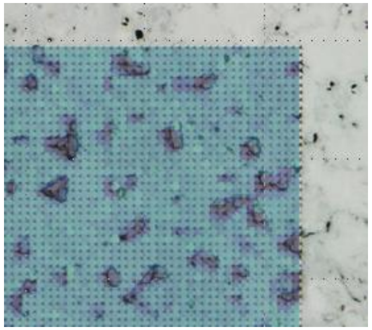
Optical porosity:
14%

Conclusion

- The binder system developed allows printing on low-cost FDM printers
- Optimization of the stiffness and viscosity enables a significant improvement of the printing resolution



- In-situ ESEM provides insights in the thermal debinding process
- Nanoindentation mapping can be used for characterization of hardness, modulus, and porosity



Future work:
- New materials (shape-memory alloys)
- Multi-material

ETH zürich | laboratory for nanometallurgy | Empa | ScopeM

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Thank You

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Advanced Manufacturing

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