Fakultät Maschinenwesen - Institut für Werkstoffwissenschaft - Professur für Werkstofftechnik

MSE Congress 2020

Additive manufacturing of complex pure copper parts via binder jetting

T.Ulrich, M.Greifzu, O. Fitzek, M. Dornick, L.Stepien, E.Lopez, F.Brückner, C.Leyens

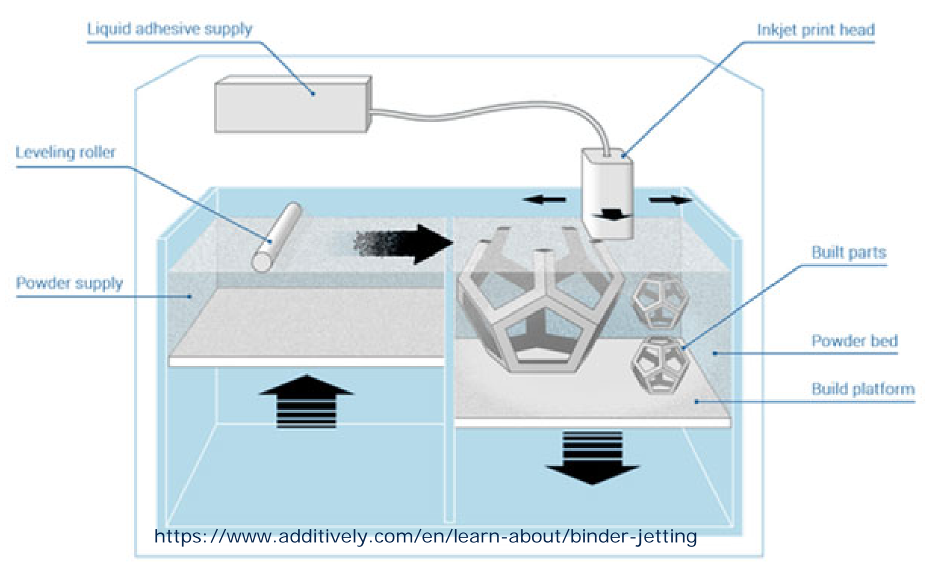
Dipl.-Ing. Tobias Ulrich

Technische Universität Dresden
Institute of Material Science – Chair of Material Technology
01062 Dresden

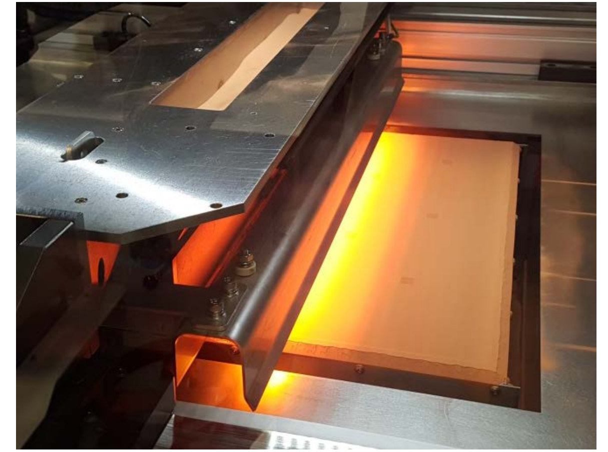
Kontakt: tobias.ulrich@iws.fraunhofer.de

Agenda

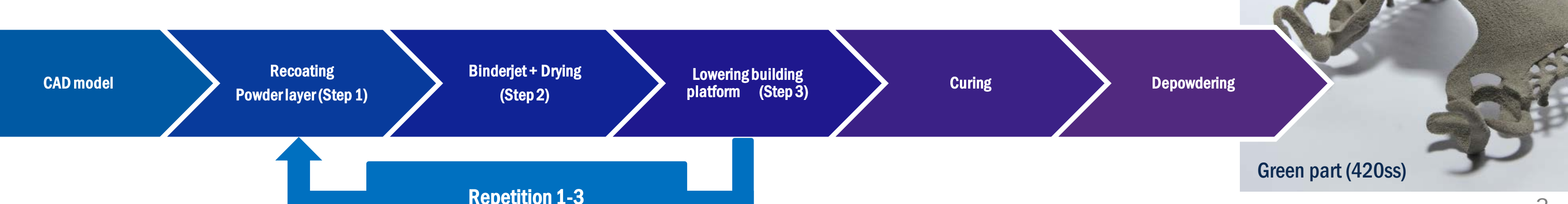
- Introduction to the Binder Jet process
  - **Motivation** and **Challenges** of processing Cu with AM
    - Metal Binder Jetting with copper
      - Powder properties
      - Thermal Treatment - **Sintering process**
    - Route towards complex, high dense copper parts



https://www.additively.com/en/learn-about/binder-jetting



Printing process– IR-drying of the binder (Step 2)
(Material: copper (purity 99,95%))



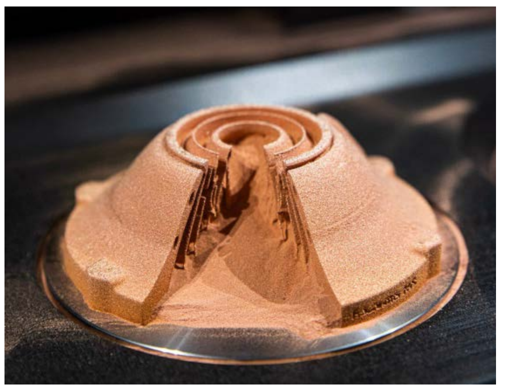
Green part (420ss)

Motivation

- Additive manufacturing - highly complex geometries
- Build up of pure copper bodies, highly thermally and electrically conductive
- Enables wide fields of applications:
  - E-Mobility: more efficient electric drives
  - High-performance components in power electronics
  - Heat transfer – thermal management in confined spaces, very compact and complex components

Additive manufactured copper components are suitable for compact devices with small installation space, high efficiency and high performance

E-Mobility – electric drives (https://www.schaeffler.de/)



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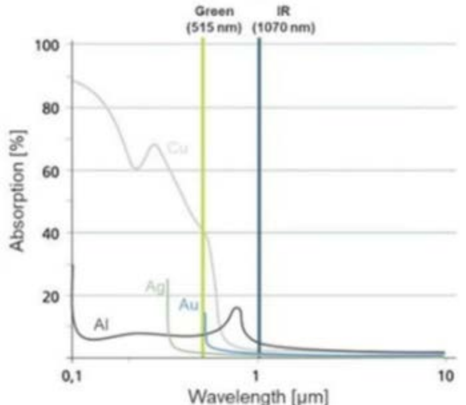
Challenges

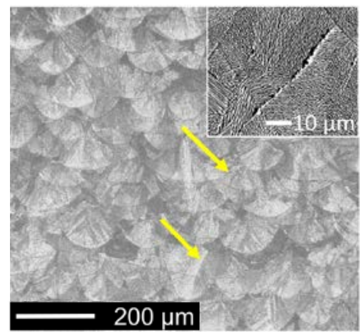
- High **conductivity** and **reflexion**
  - Low absorption of laser-based beam sources in the usual infrared wavelength range, high reflexion (LPBF)
  - Fast heat dissipation

Advantages of BJ:

- No high energy input, No thermal effects like "warping“ (FFF), cracking (LPBF)
- High production rates: 1.600 cm³/h up to **12.000** cm³/h
- Support structures not necessary
- Varity of materials

Current challenge of the BJAM: dimensionally stabile Cu-parts with good properties and high density





Cracking of Hastelloy-X with SLM (Montero et al., Materials and Design 165 (2019))

Densification

Sintering activity	Green part density	Sinter conditions

Powder

- Distribution
- Size & Shape

Process parameters

- Layer thickness
- Binder saturation

Time

Temperature

Atmosphere

T
Debinding
Sintering
1075 °C
2…12 h
10 K/min
> 450 °C
1 h
< 5 K/min
Time [min]

Used poweder: Cu (99,95%)

- Particle Size: 15 – 45 µm (D_{50}: 23 µm)
- Spherical – high flowbility

Sintering process: 1075°C (HR 5 K/min) under reduced atmosphere N_2 + 4% H_2

Binder saturation | Sintering time

70%

2h
SEI 20kV WD12mm SS50 x100 100µm 7451 19 Aug 2020
Fhg IWS Cu_3020720

6h
SEI 20kV WD11mm SS50 x100 100µm 7471 21 Aug 2020
Fhg IWS Cu_200810_2.2_6h

12h
SEI 20kV WD12mm SS50 x100 100µm 7436 17 Aug 2020
Fhg IWS Cu_200810_2.2

90%

2h
SEI 20kV WD10mm SS50 x100 100µm 7462 19 Aug 2020
Fhg IWS Cu_3140720

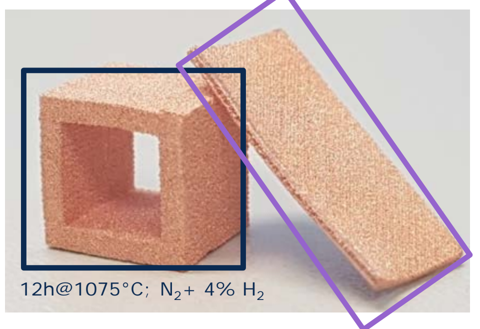
6h
SEI 20kV WD11mm SS50 x100 100µm 7481 21 Aug 2020
Fhg IWS Cu_200807_4_6h

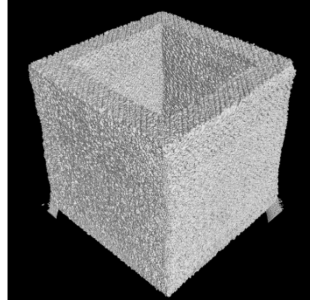
12h
SEI 20kV WD10mm SS50 x100 100µm 7444 17 Aug 2020
Fhg IWS Cu_200807_4

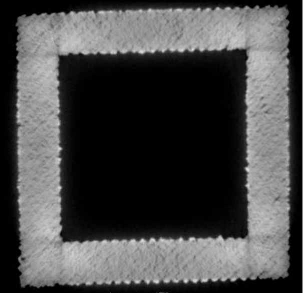
- low sintering activity
- long sintering time

Increasing particle contacts & sinter activation by filling up with with smaller particles

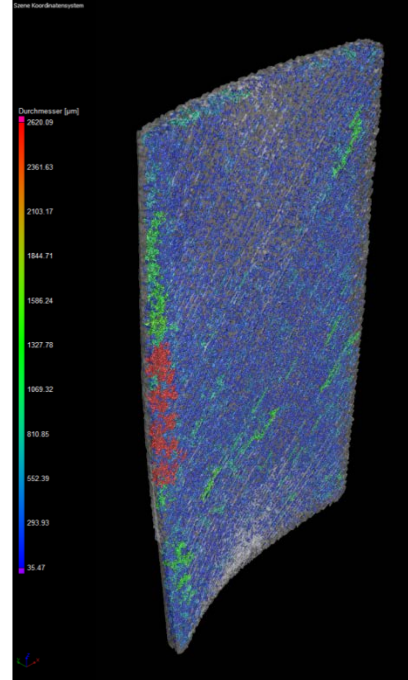
- **Density** (Powder D_{50}: 23 µm)
  - Computer tomography analysis







Form	Rel. density [%]
Cube	91,69
Plate	95,60



Defect volume copper sample
5,9x17,4x0,98mm

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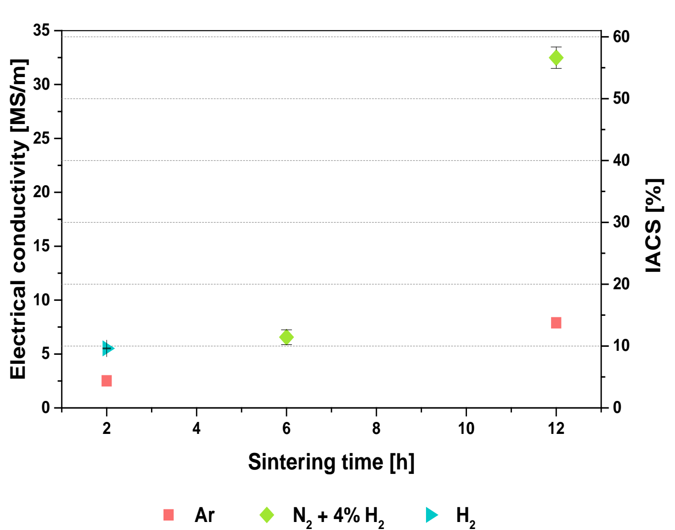
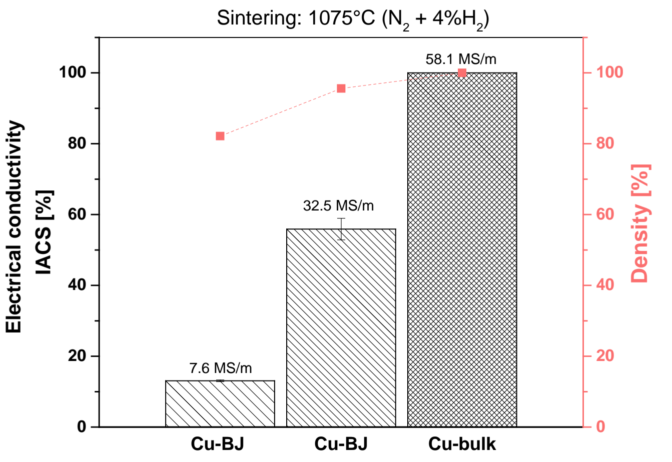
Electrical conductivity

- Measuring by 4-wire sensing, eddy curent testing (ECT)



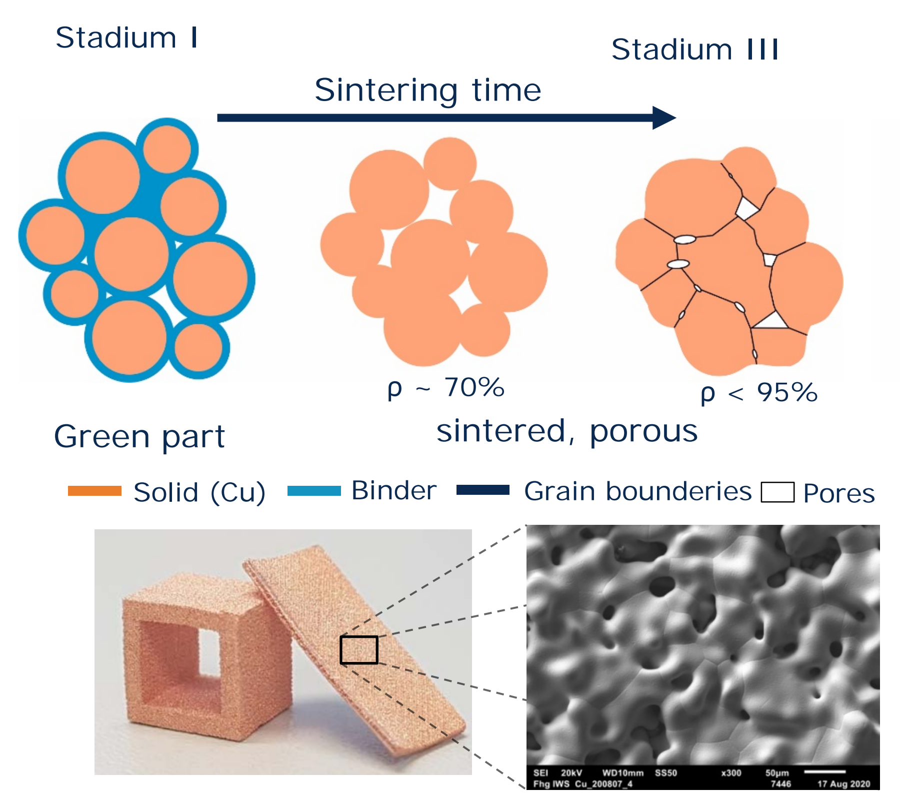
Influence of the sintering atmosphere and time on the electrical conductivity

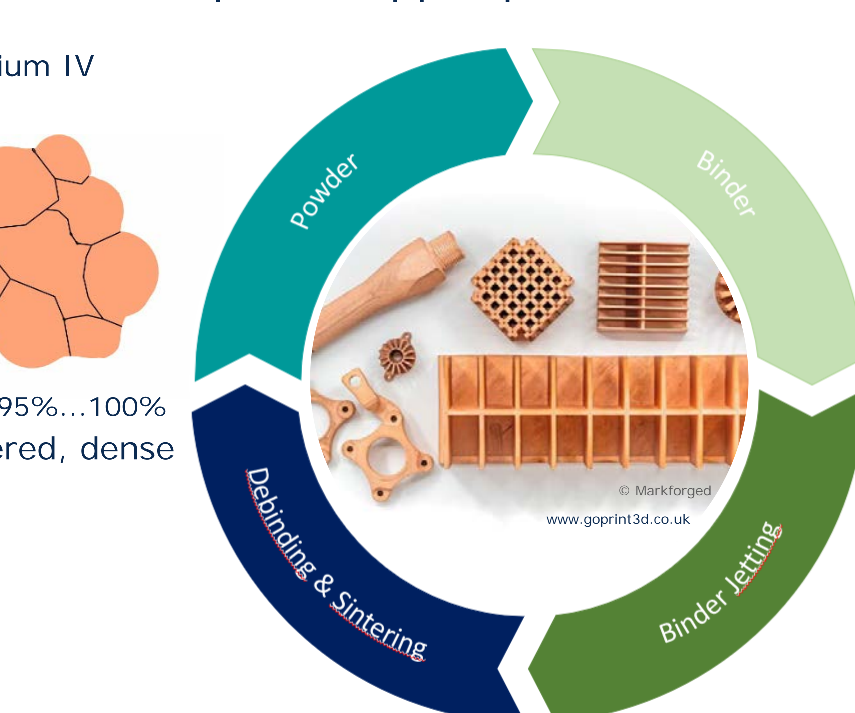


Electrical conductivity of additive manufactured Cu BJ parts compared to bulk-Cu in correlation of the relative density [%]

- Long sintering times necessary
- Reactive, reducing atmosphere necessary for increased conductivity
- Defects have a significant influence on the electrical conductivity

Route to fully dense, dimensionally stable and complexe copper parts





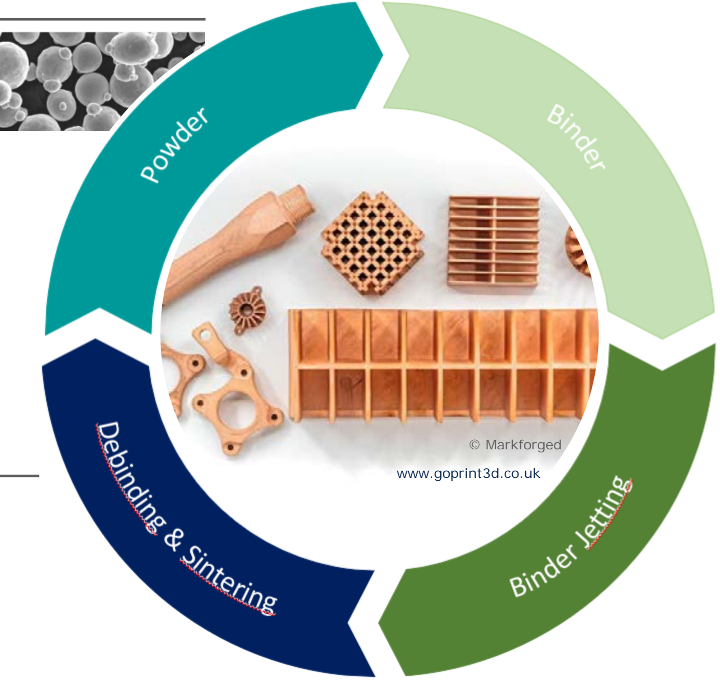
Route towards fully dense, dimensionally stable and complexe copper parts

Increasing the green part density

- Use of bimodal powders
- Modify binder mixture
  - Increase of particle contacts and sintering activity

    I Nanoparticles

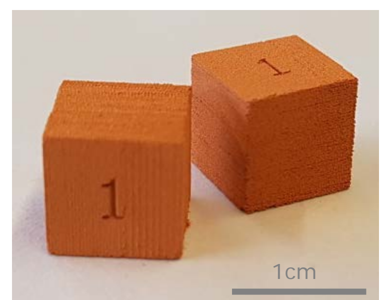
    II Metal salt (MOD)

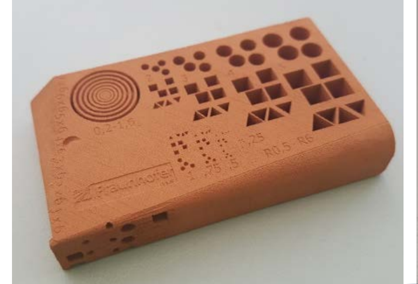


Investigation of the sintering & debinding behavior and influence of the printing parameters on the densification

- Residue-free binder decomposition

Increasing the complexity of additively manufactured components

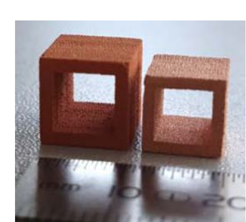




complexity

I Material properties

- Evaluation of the printing parameters
- Part properties:
  - Density
  - Conducivity
- **Shrinkage**



II Process limits → Design guidelines

- Shape tolerances
  - Wall thickness
  - Powder outlets
  - Radii
- Scaling

III Applications

- Heat exchangers
- Electrical mobility
- Power electronics

Summery

- **Binder Jetting** enables the processing of reflective, highly conductive Cu
  - No inert gas required during printing
  - A reduced atmosphere increases the component properties enormously
- Copper BJ-AM: density in the range up to **95%** (el. conductivity: 56% IACS)
- Improvement of the copper parts by:
  - Modification of powder and binder properties
  - Optimization of the **debinding** and sintering process

Thank you.

Dipl.-Ing. Tobias Ulrich

Technische Universität Dresden
Institut für Werkstoffwissenschaft – Professur für Werkstofftechnik

Tel.: +49 351 83391 - 3552
Kontakt: **tobias.ulrich@iws.fraunhofer.de**

Sitz am Fraunhofer IWS
Winterbergstraße 28, 01277 Dresden

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