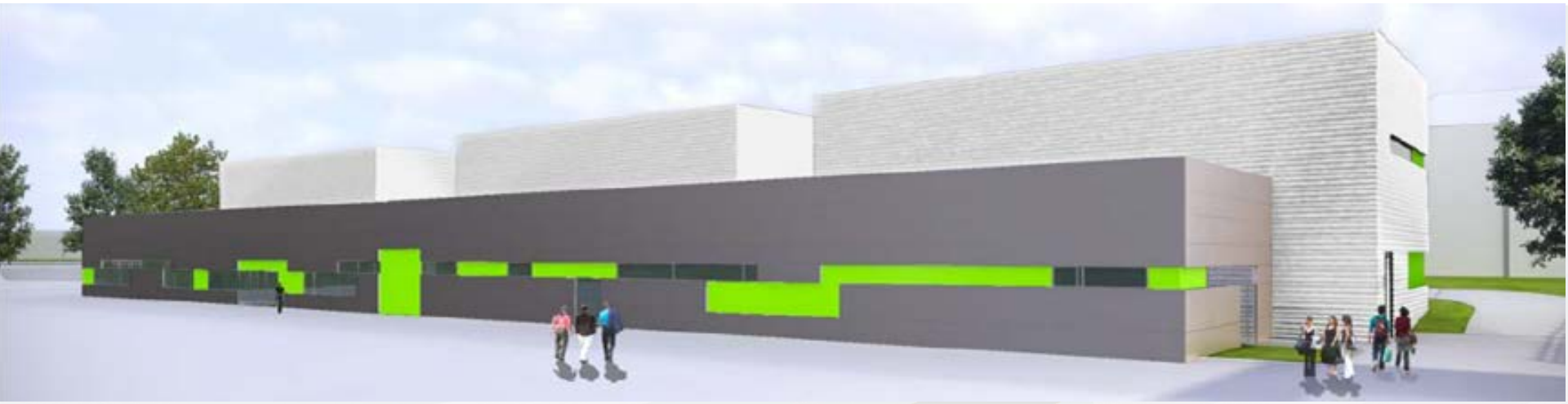
Fraunhofer Institute
for Material and Beam Technology IWS

amcd
Additive Manufacturing Center Dresden



Von Pulver zum fertigen Bauteil – unterstützt durch zerstörungsfreie Prüfung

13. September 2018 – **VDI TUM Expertenforum München**

Elena López, Christoph Wilsnack, Axel Marquardt, Mirko Riede,
André Seidel, Frank Brückner, Eckhard Beyer, Christoph Leyens

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Additive Manufacturing Center Dresden
AMCD @ Fraunhofer IWS

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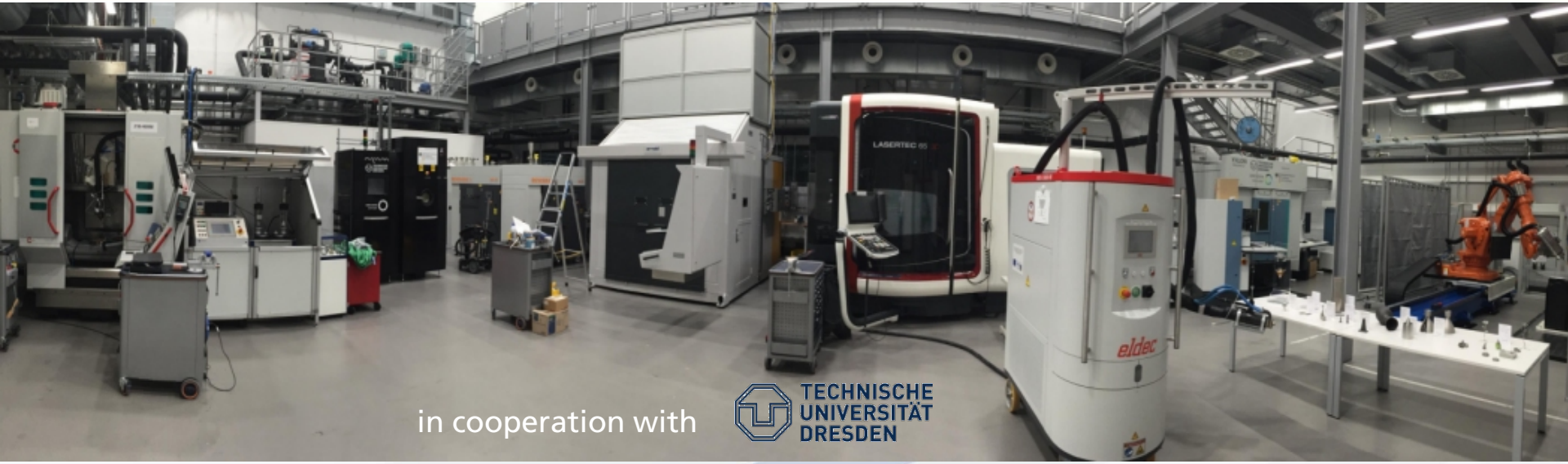

- Powder-based Direct Metal Deposition
- Wire-base Direct Metal Deposition
- Hybrid Processing (DMD + Milling)
- Selective Laser Melting (SLM)
- Electron Beam Melting (EBM)
- 3D printing, Stereolithography
- Test and Characterization

Center for Additive Manufacturing

Processing Chains

- Product Development
- Process Development
- Materials Development
- Quality Control
- Testing/Characterization

BRU: 2016

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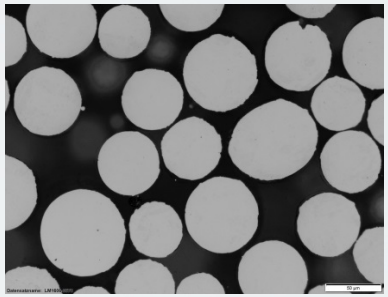
Quality Management in AM
Assurance along the process chain

Additive Manufacturing Center Dresden



Raw material/ powder

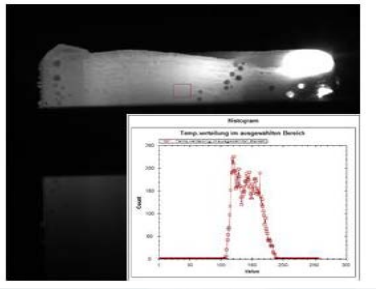
supplier/ testing

- Test report of the manufacturer
- Investigation of powder properties
- Particle shape
- Size distribution
- Chemical composition
- Residual oxygen

Manufacturing technology

System suitability test

- (Preventative) upkeep
- Machine properties
- Machine certification
- Production planning



Process

Process monitoring

- Working distance control
- Collision control
- Monitoring of the molten pool
- Temperature monitoring
- Oxygen content
- pressure

Component

Component testing/ NDT/Product protection

- Visual inspection
- CT/ radiography
- Red-white tests
- Destructive test
- Coordinate measuring machine

BRU: 2017

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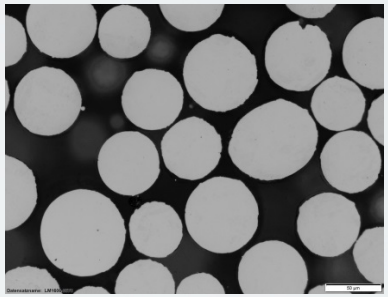

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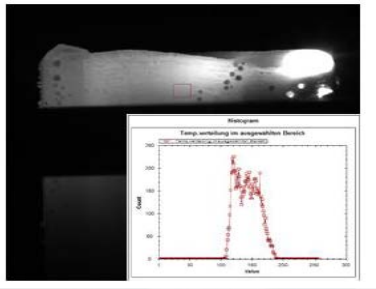

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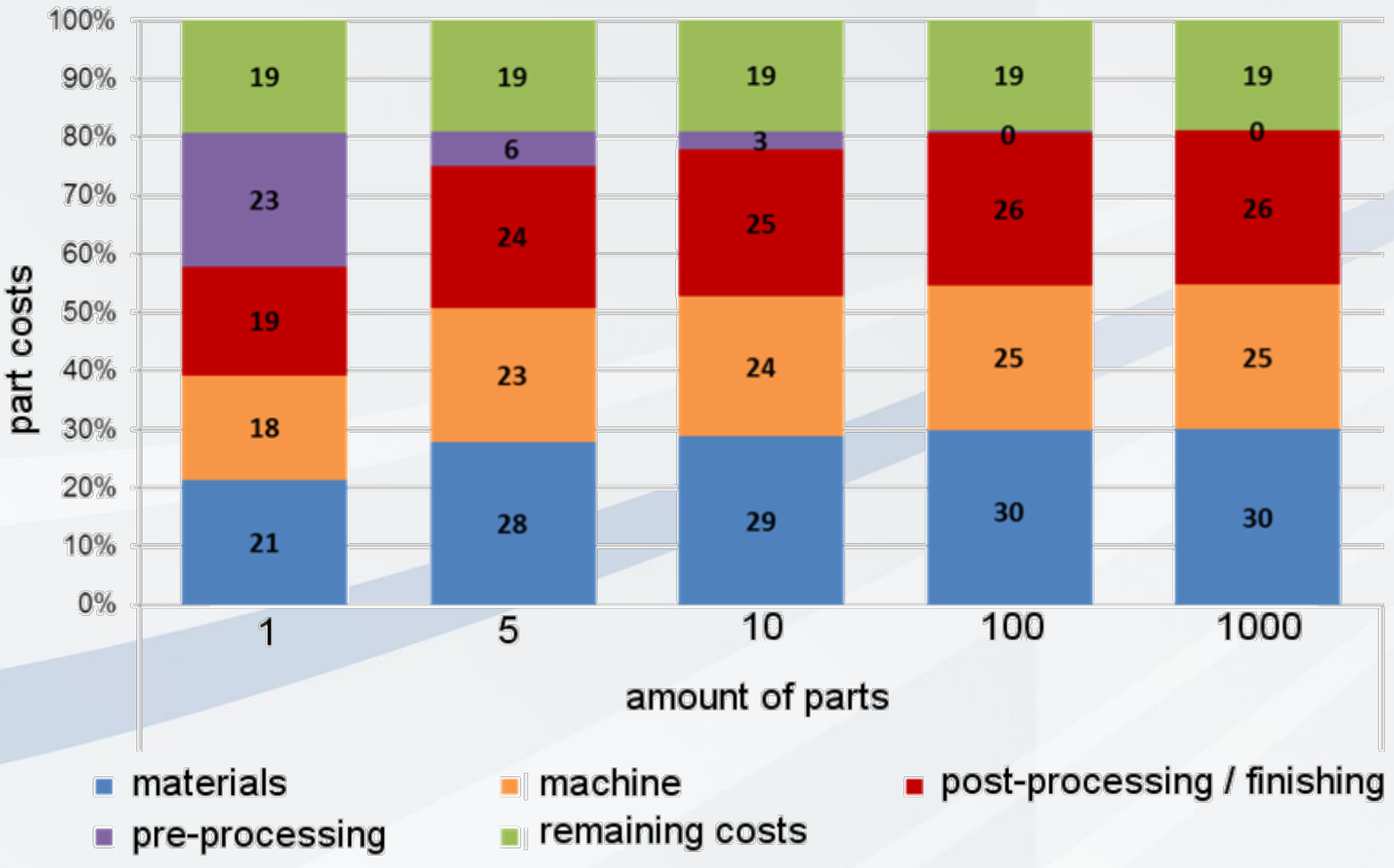
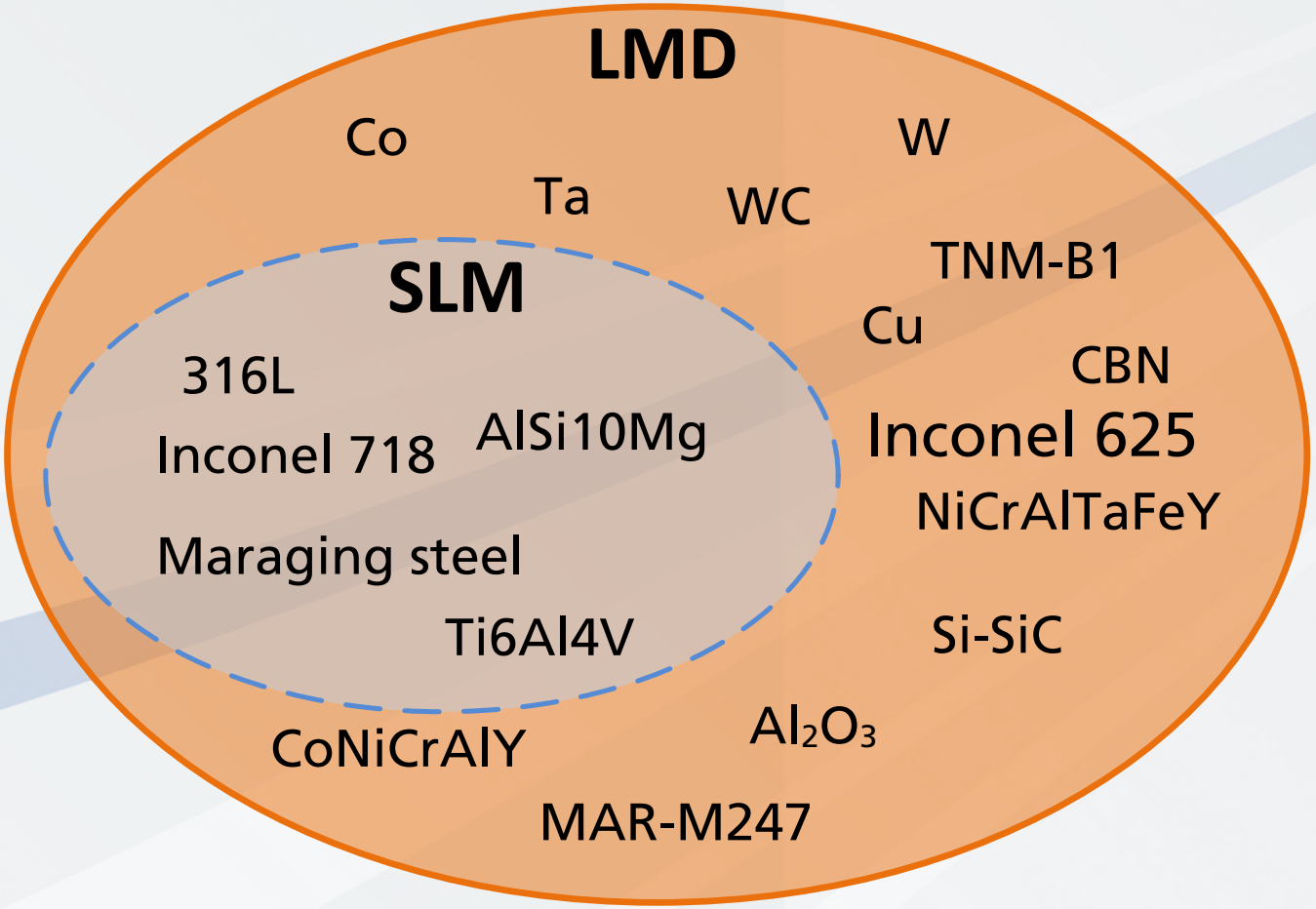
Additive Manufacturing (AM)
Challenges rel. to costs LMD



Additive Manufacturing
Materials for AM



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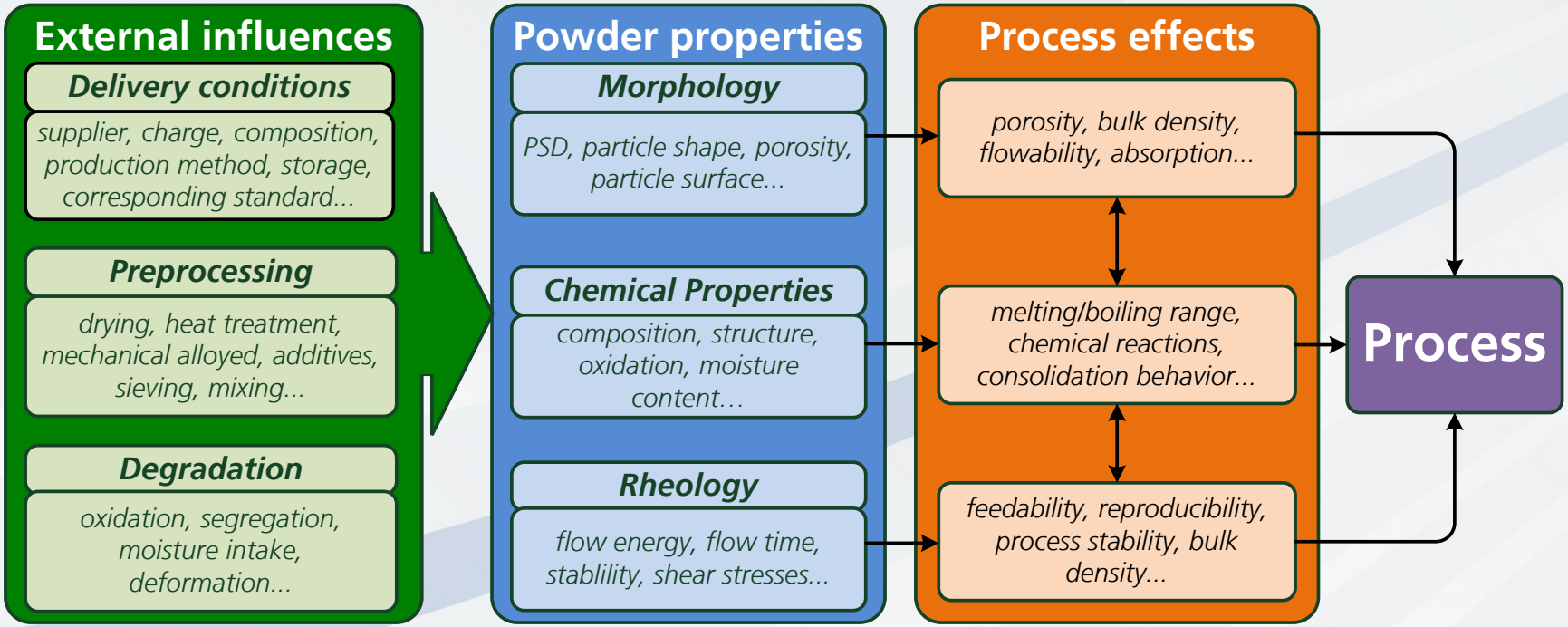
Powder Properties in AM route



- very much interactions between the powder characteristics

→ comprehensive powder characterization for Additive Manufacturing → „database“

→ **correlation with effects on process**

Quality assurance of raw material Challenges

- Quality assurance needs to be made along the entire process chain
  - Huge impact of the quality of the raw material
  - Verification of every component
- Higher reproducibility will improve public confidence in AM
  - High industrial demand for monitoring and regulation possibilities
- New materials/ new combinations of materials
- Recycling of powder → quality requirements?
- Storage or handling problems → contamination?
- Development from labor systems to industrial-suited machines
- Defined tolerable error states (e.g. max. pore size has to be analyzed)
- Multimaterial
- Material testing challenges → identification of new defect types (failure relevant defects)
- Definition of AM standards

Results Hybrid LMD
Powder Analysis Mar-M-247

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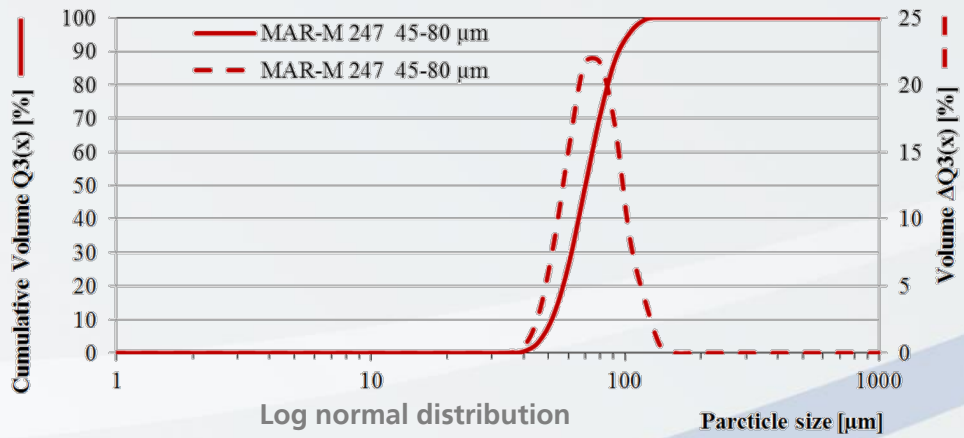
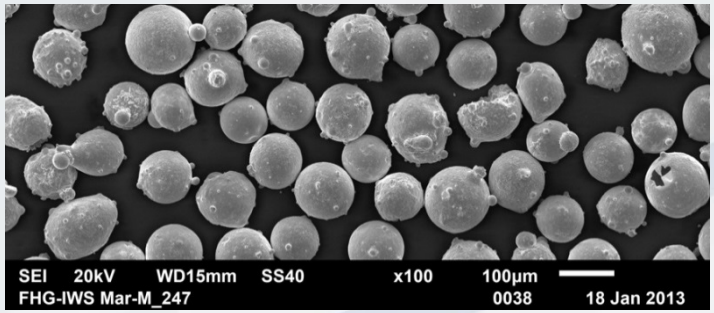
a.)

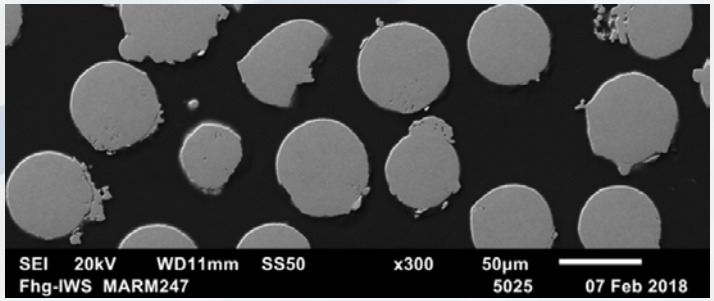
Span	D [4, 3] - Volume weighted mean	D [3, 2] - Surface weighted mean	d (0.1)	d (0.5)	d (0.9)
0.614	71.76	67.918	51.348	69.812	94.231



D [4, 3] … De Brouckere-mean, D [3, 2] … Sauter diameter



Gas atomized (argon) Mar-M-247 powder



	Ni	Co	W	Cr	Al	Ta	Hf	Ti	Mo	C	Zr	B
Mar-M-247*	59.59	9.86	10.20	8.10	5.69	3.00	1.57	1.03	0.69	0.06	0.03	0.18
Δ Wi**	—	– 0.14	+ 0.20	– 0.15	+ 0.19	+ 0.00	+ 0.07	+ 0.03	– 0.01	– 0.09	– 0.02	+ 0.17
CM 247 LC*	62.41	8.97	10.57	7.88	4.20	3.08	1.62	0.68	0.46	0.01	0.03	0.08
Δ Wi**	—	– 0.23	+ 1.07	– 0.22	– 1.40	– 0.12	+0.22	– 0.02	– 0.04	– 0.06	+ 0.01	+ 0.07

*Ni, Co, W, Cr, Al, Ta, Hf, Ti, Mo, Zr, B measured *via* ICP-OES/ICP-AES; C measured *via* Py-IR.
**Delta of measured value of the mass fraction and the nominal mass fraction.

→ Impact on rheological properties

TECHNISCHE UNIVERSITÄT DRESDEN
DRESDEN concept
Fraunhofer IWS Dresden

Application: Analysis of Powder with CT

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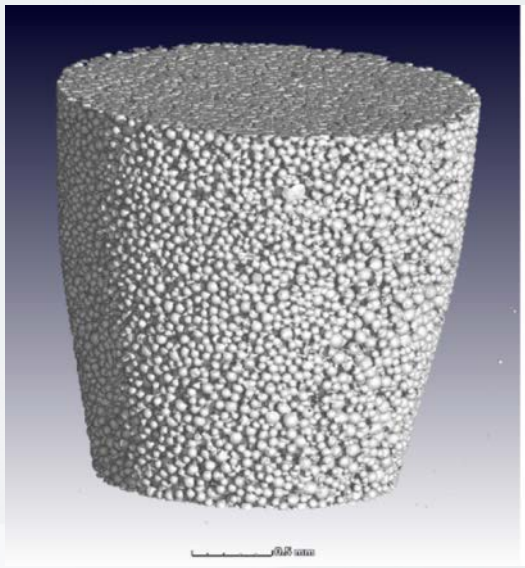

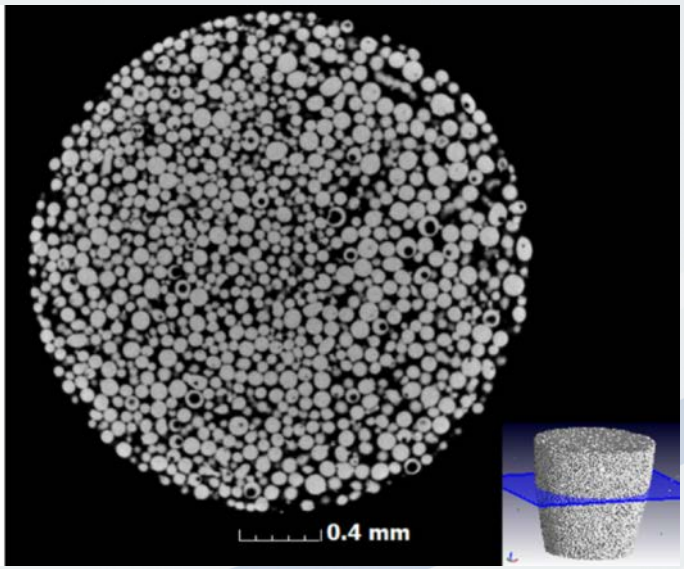

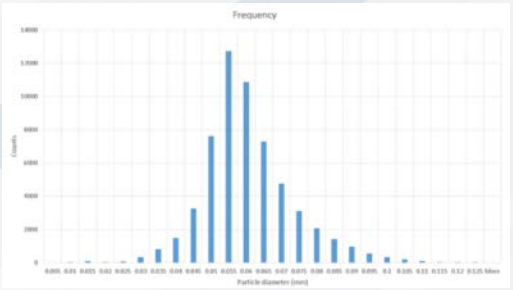

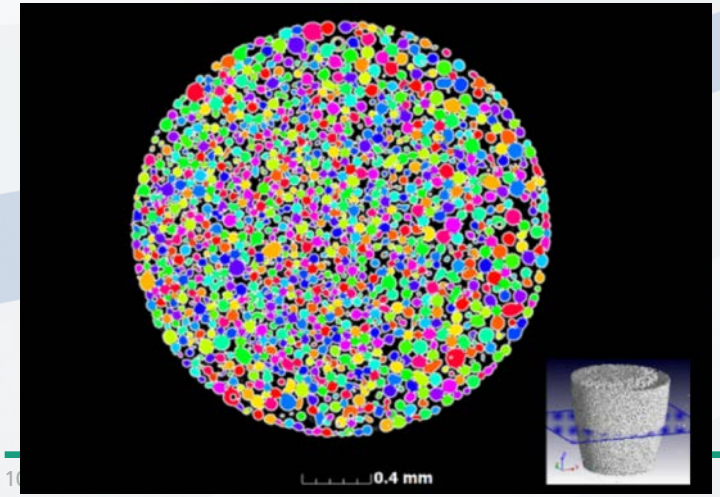

- Ti6Al4V-powder
- Volume with 50.000 particles in 2mm x 2mm x 2mm
- inhomogeneous structure
- metal powder with „porosities“

YXLON

CAF Central Analytical Facilities
STELLENBOSCH UNIVERSITY

Dr. Anton du Plessis

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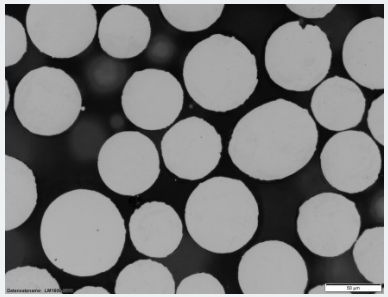
Quality Management in AM
Assurance along the process chain

Additive Manufacturing Center Dresden



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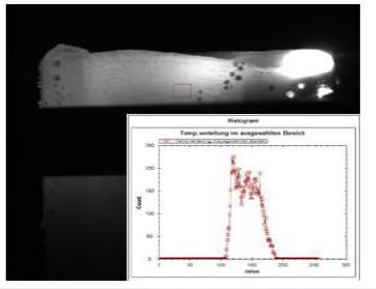

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Quality Management in AM
Digital manufacturing systems LMD

Goals / Functionalities in Additive Manufacturing

- nozzle and optic monitoring
- temperature and heat control
- media and leakage monitoring
- counting hours of operation (wear and tear)
- preventive maintenance
- collision monitoring
- machine interaction ➔ emergency stop
- data logging for process analysis & optimization

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Quality Management in AM
System monitoring by supervised learning

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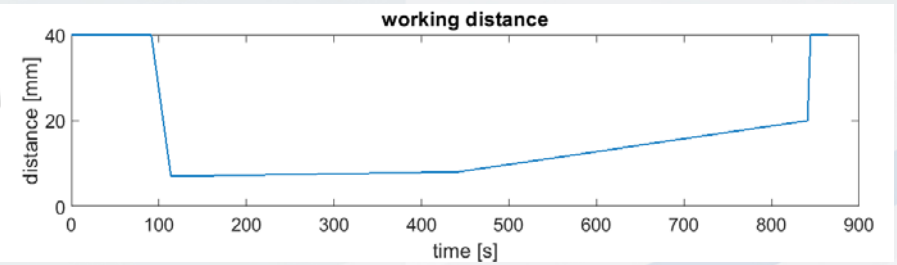
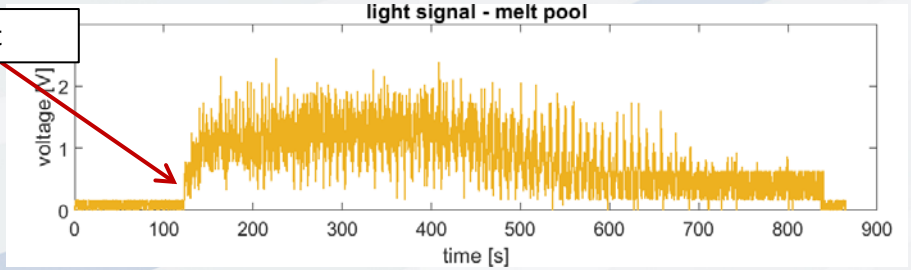
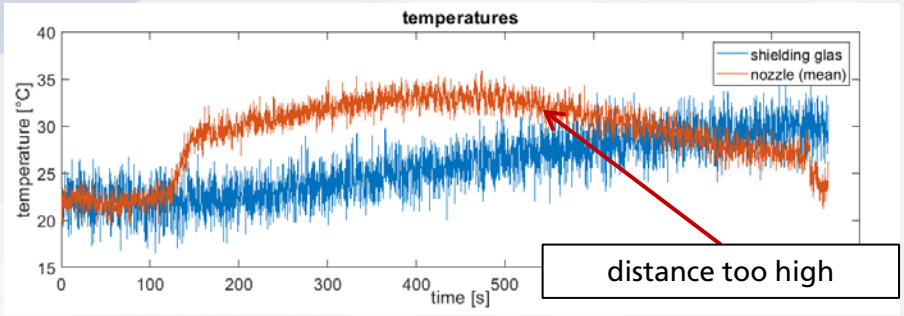


start





distance too high

- results of test scenarios
  - layer thickness too high → increased distance
    nozzle temperature ↓
  - distance ↑ → backscattered light↓
    build rate ↓
  - processtime ↑ → shielding glas load ↑
    nozzle temperature ↑

huge potential due to multiparametric data acquisition + machine learning

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Quality Management in AM
Assurance along the process chain

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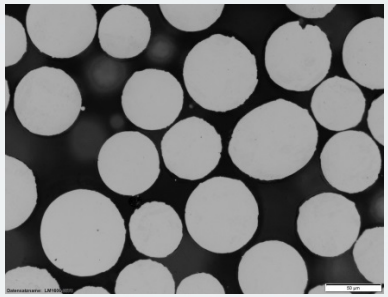

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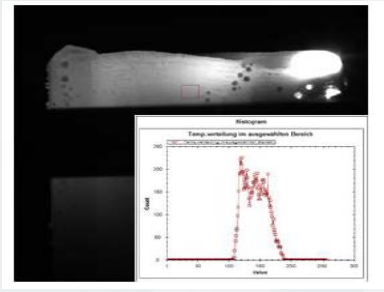

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Quality Management in AM
Automated preheating / distance control

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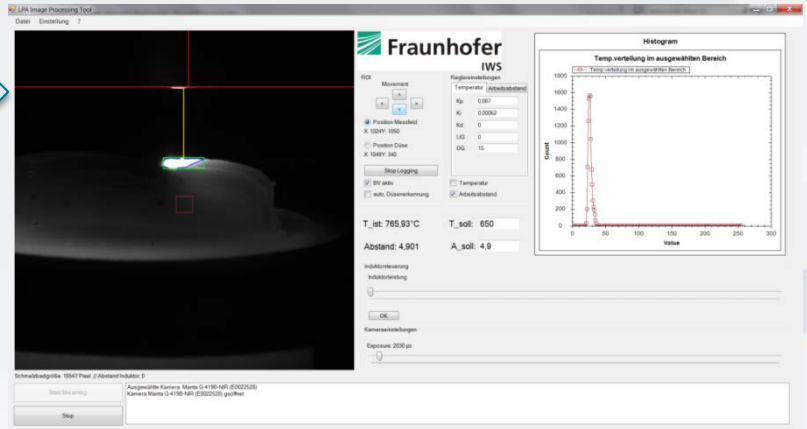
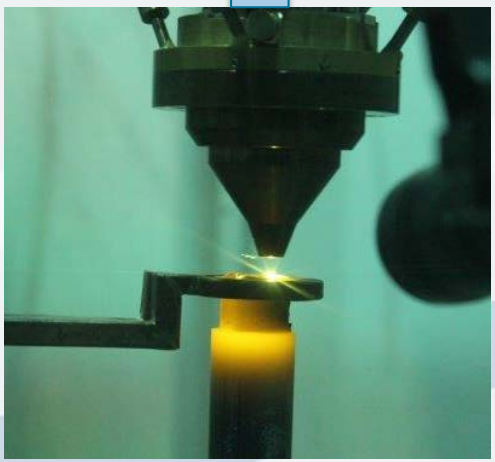
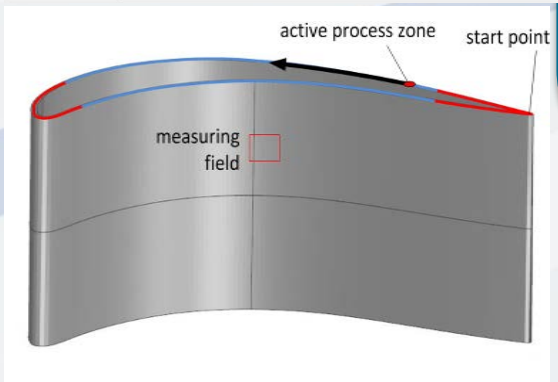
process monitoring and control





induction preheating



without control

with control

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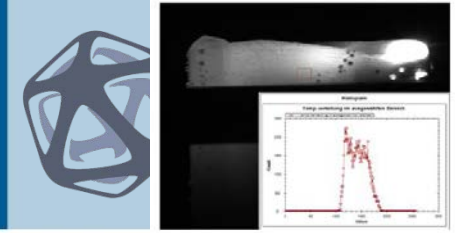
Quality Management in AM
Process Monitoring

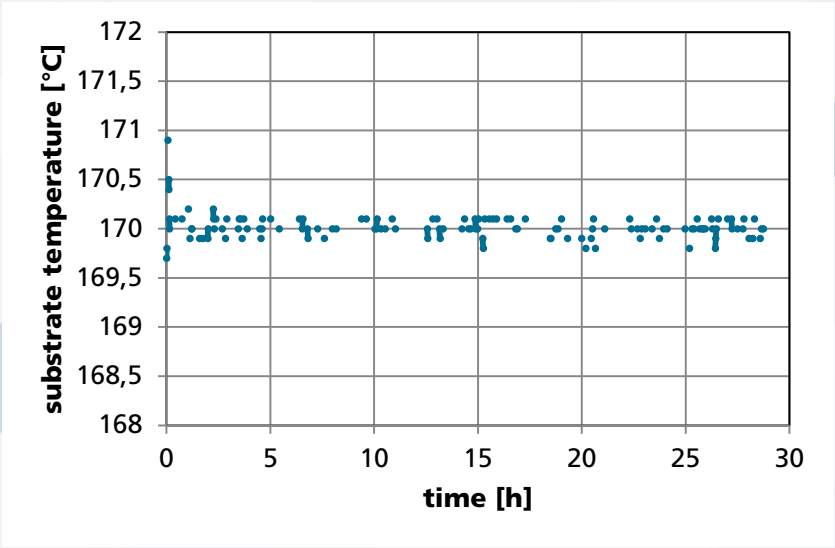


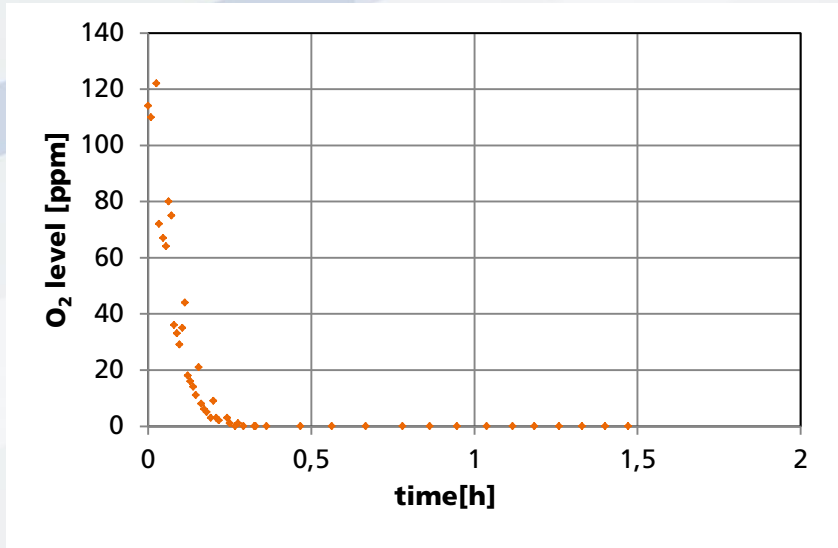
Monitoring of the substrate temperature

- **monitoring** and **control** of the substrate Temperature
- improvement of the processabilty of hot cracking materials

Monitoring of the O_2 level

- **monitoring** and **control** of the oxygen Level
- improvement of the processability of materials susceptible of oxidation





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Quality Management in AM
Assurance along the process chain

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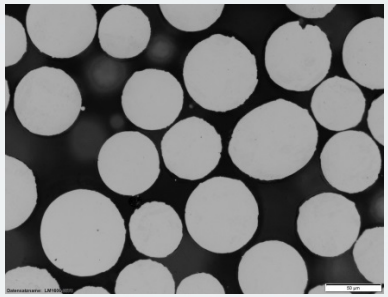

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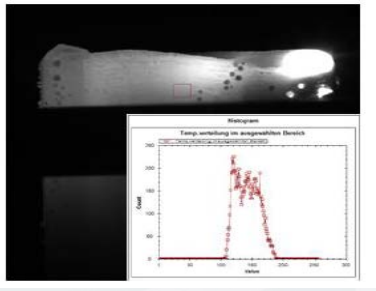

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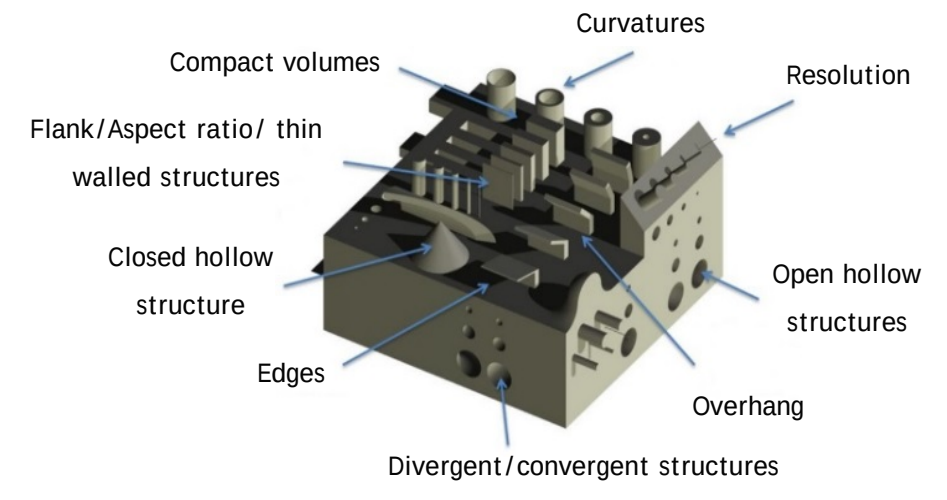
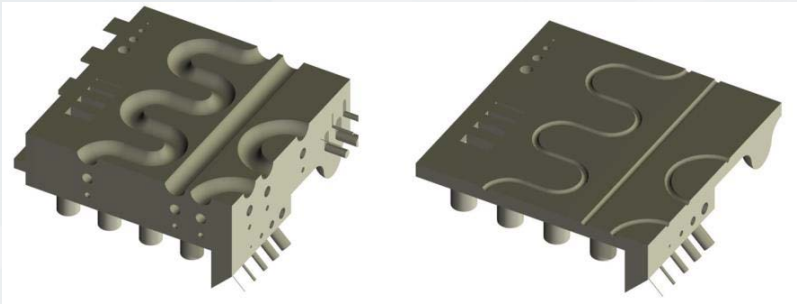
Additive manufacturing demonstrators
Fraunhofer IWS demonstrator





Feature	Purpose
Flat base	Flatness and straightness.
Cube	Squareness, parallelism, linear accuracy and repeatability.
Cylindrical hole	Roundness, cylindricity, accuracy and repeatability of radius (internal).
Sphere	Sphereness, relative accuracy and repeatability of continuously changing surface.
Solid cylinder	Roundness, cylindricity, accuracy and repeatability of radius (external).
Hollow cylinder	Roundness, cylindricity and coaxially of cylinders.
Cone	Concity, sloping and profile and taper.
Angled surfaces	Angularity, accuracy and repeatability of angled surfaces.

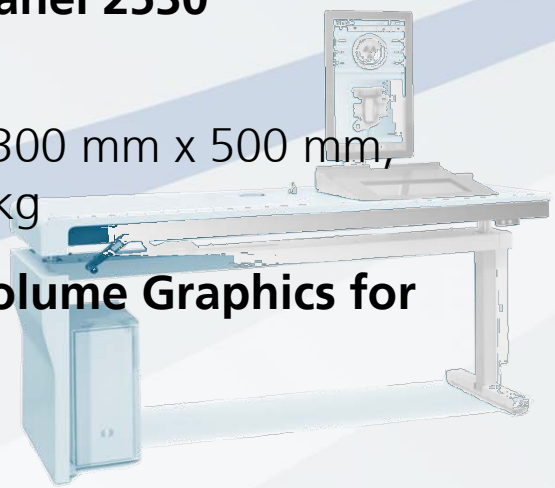
Computertomograph FF35CT

amcd
Additive Manufacturing Center Dresden

- **Principle:** all-side radiography→ direct creation of a volume model
- **CT-Modi:** QuickScan, QualityScan, Offset-Scan, HeliExtend, FlexCenter

Technical description

- **Reflexion X-ray tube**
  Voltage < 225 kV, Power < 500 W,
  Resolution ≥ 3 µm
- **Detector YXLON Panel 2530**
- **Test Part**
  Dimensions (Ø x H) 300 mm x 500 mm,
  maximal weight 30 kg
- **Use of software Volume Graphics for image processing**



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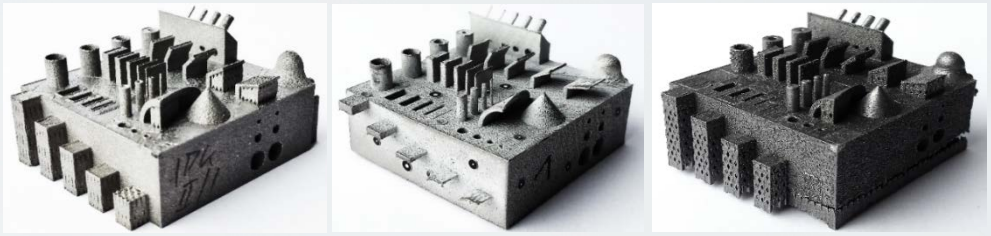
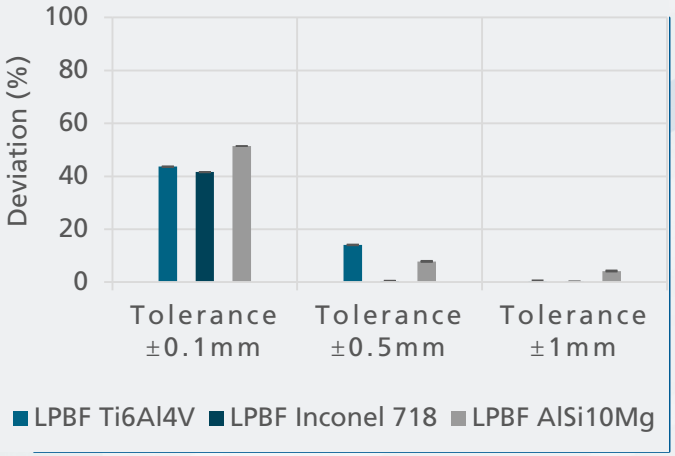
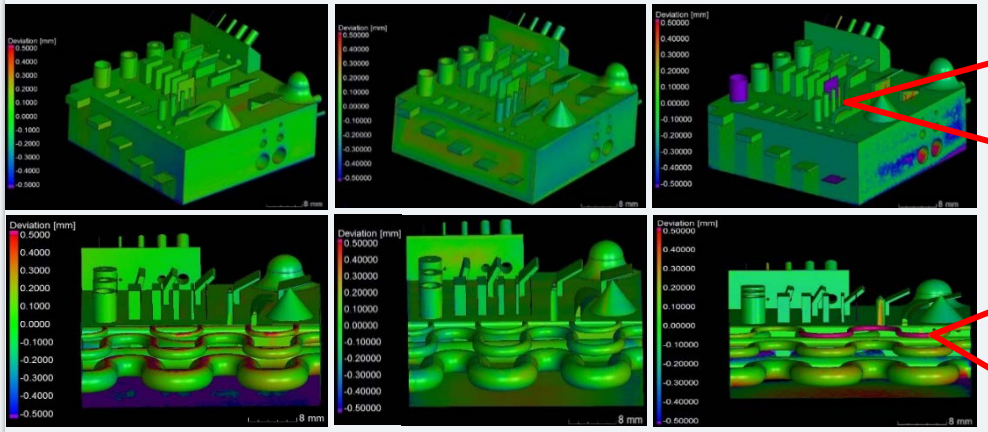
Geometrical analysis CT
SLM demonstrators

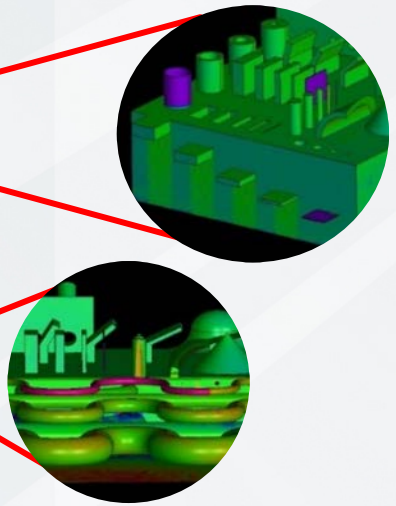


Demonst.	Fraunhofer 1	Fraunhofer 2	Fraunhofer 3
Equipment	SLM Solutions SLM250HL	Renishaw AM 250	Concept laser M2 cusing
Material	Ti6Al4V	Inconel 718	AlSi10Mg



Tolerance ±0.5 mm





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Geometrical analysis CT
EBM demonstrators

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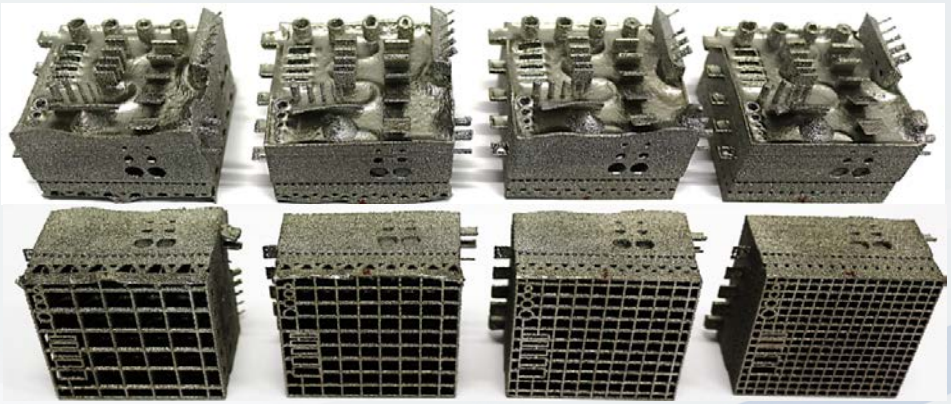
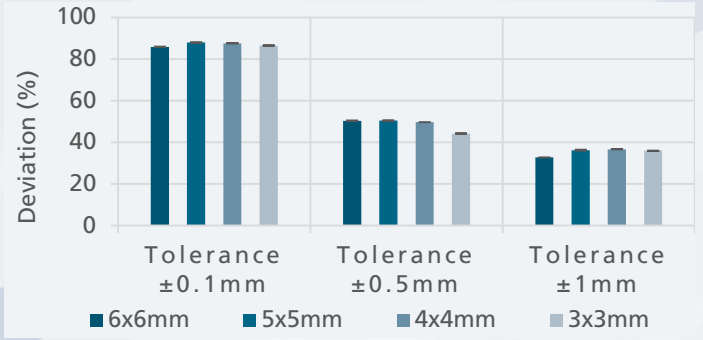
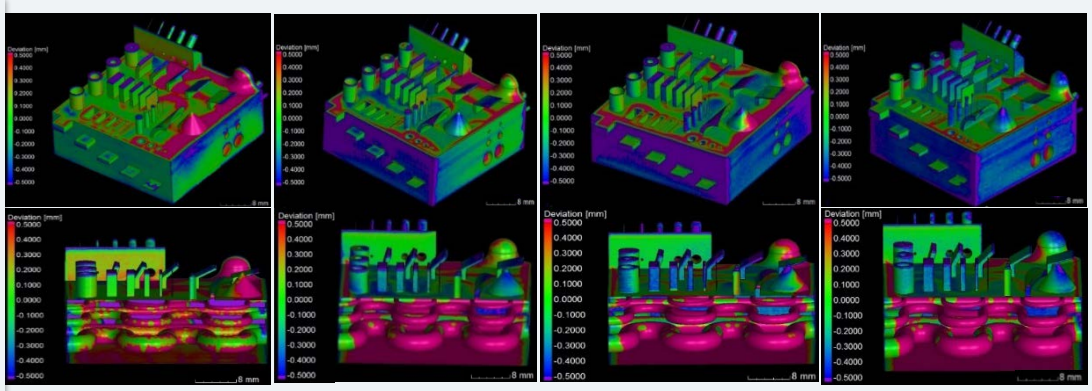
Institute	Equipment	Material
Fraunhofer IWS	Arcam A2X	Ti6Al4V



6x6 mm | 5x5 mm | 4x4 mm | 3x3 mm



Tolerance ±0.5 mm



Smaller support size slighty beneficial

High temperature sintered powder in the channels

Best fit registration might decrease deviation

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AGENT3D
ADDITIV GENERATIVE FERTIGUNG

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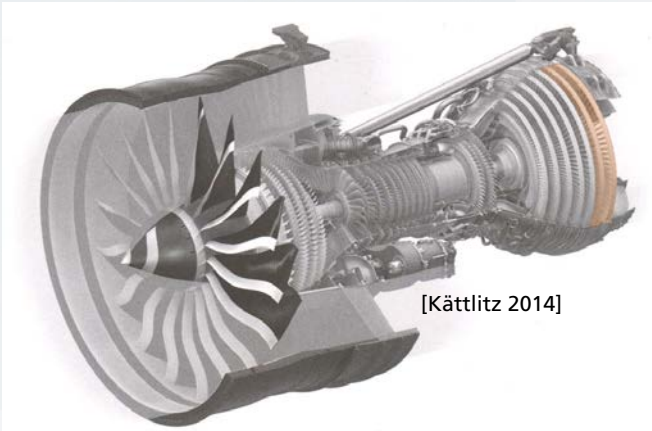
TiAl - TNM-B1

[GfE 2017]

- Turbocharger wheels
- Better response times possible due to TiAl



[Kättlitz 2014]

- Low-pressure turbine blades
- Reduced fuel consumption as a result of weight savings

- High temperature properties ensure operating temperatures between 600 - 800 °C
- Low density (2,9 - 4,3 g/cm^3)
- High tensile strength (up to 1000 MPa)

  → high specific strength
- Excellent oxidation and corrosion resistance
- High modulus of elasticity

Results

mechanical properties and porosity of TNM-B1 SEBM printed parts

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Parameter set		Mechanical properties			Porosity			
	EL [J/m]	YS [MPa]	TS [MPa]	El. [%]	ImageJ Φ	Archimedes Φ	CT 1 Φ	CT0,5 Φ
1	187,5	343,1±16,4	518,8 ± 88,4	0,05	0,36	0,71	0,03	0,07
2	150	-	333,2 ± 48,2	0,15	0,78	0	0,03	0,08
2a	150	too porous			5,2	2,88	0,51	1,13
2b	150	too porous			15,92	5,77	0,59	2,4
3	225	589,9 ± 85,1	762,4 ± 54,9	0,09	0,67	0,24	0,01	0,07
4	500	-	405,7 ± 19,8	0,02	2,93	0,24	0,1	0,21
7	187,5	360,4 ± 21,6	531,6 ± 8,7	0,09	0,74	0,95	0,03	0,08

- **variation of SEBM process parameters to achieve different line energies E_L for dense material (187.5 - 500.0 J/m)**
- **scan speed = 1500 - 4000 mm/s, current = 10 - 15 mA**
- **variation of line offset for parameter set No. 2 (0.1 - 0.3 mm)**
- **porosity is strongly influenced by the line energy**

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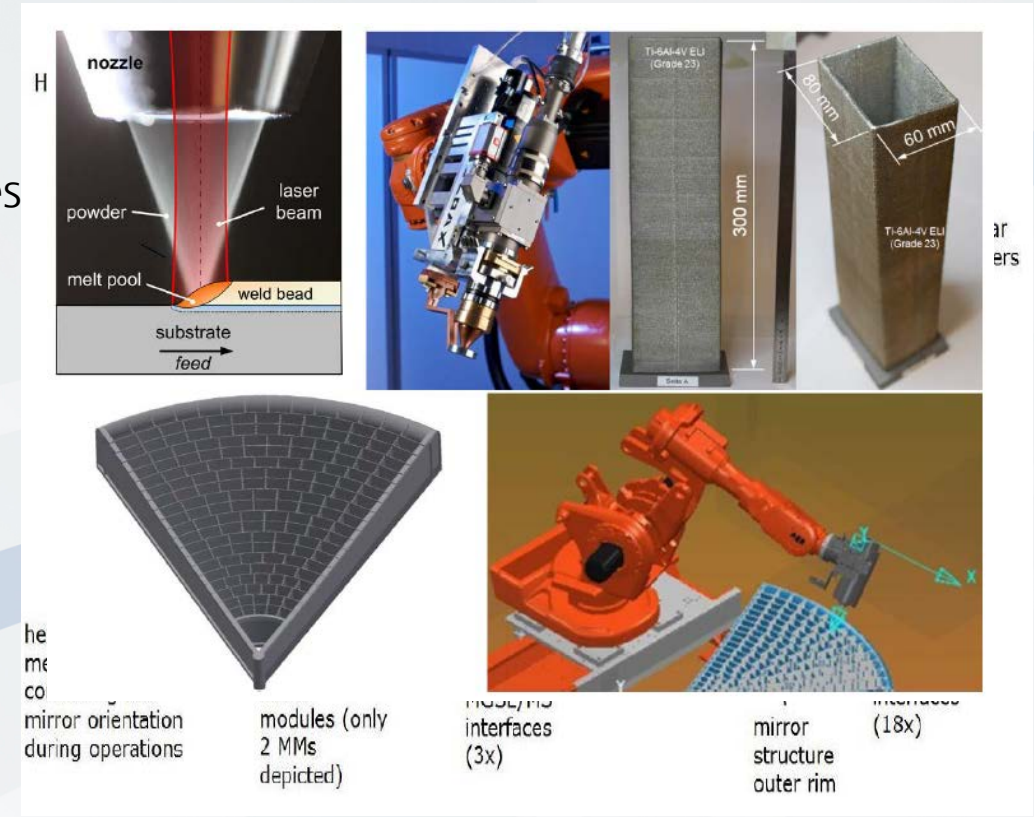
ATHENA Project

Additive manufacturing of optical bank

- Advanced Telescope for High-Energy Astrophysics
- Goal of mapping hot gas structures and search for supermassive black holes
- Large Support Structure for X-Ray optics to be made of Ti-6Al-4V for stability during launch and space operations
- Due to the complexity of the structure and tight tolerances, AM was chosen as the fabrication method



Athena, Spie Proceedings (2017)

European Space Agency

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Residual stress by neutron diffraction
SALSA Beamline @ ILL, Grenoble

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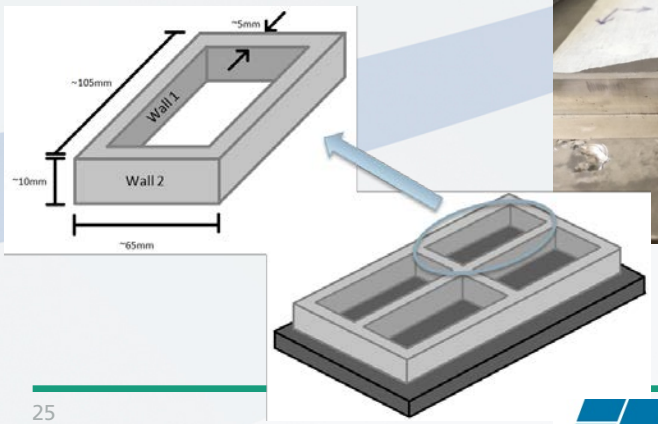
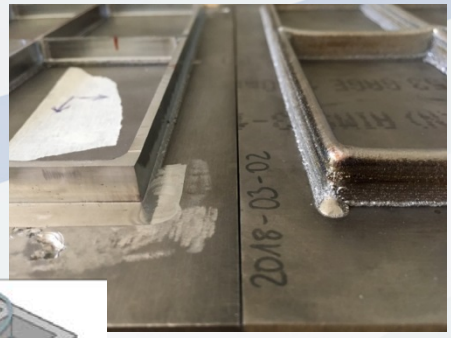
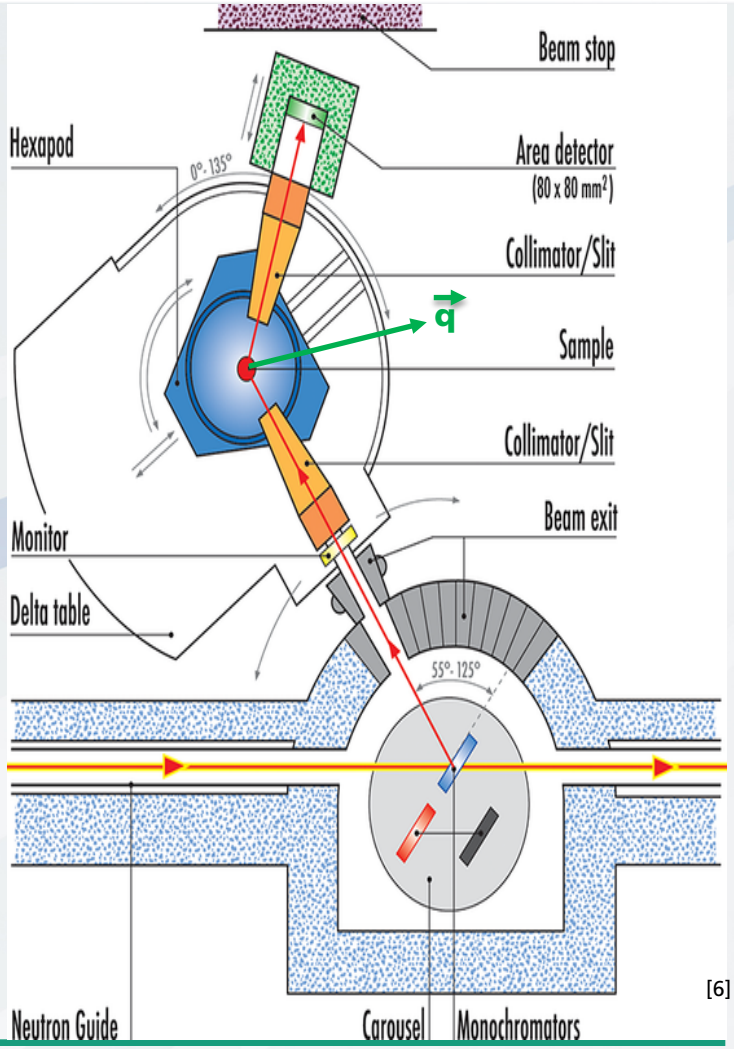
- ILL's strain imager → Non Destructive
- Strain component to be measured is aligned with scattering vector q
- Hexapod table + Cradle allow for accurate orientation adjustments
- Interchangeable collimators for different gauge volumes





Institut Laue-Langevin



[6]

NEUTRONS FOR SOCIETY

esa European Space Agency

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Why product protection?
Potential Additive Manufacturing

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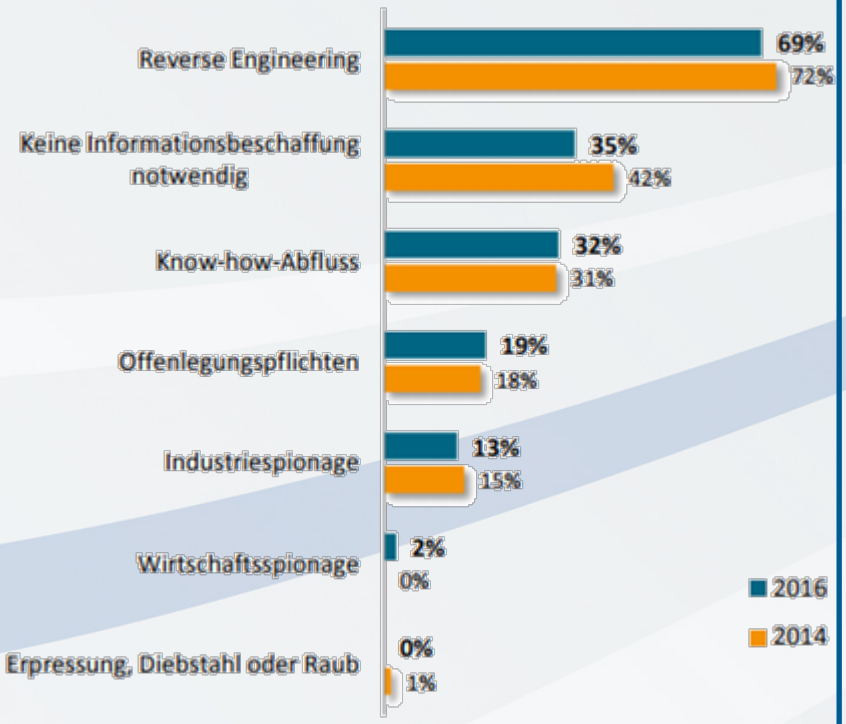
How did plagiarist get to knowledge?



Potential Additive Manufacturing

Increasing difficulty of Reverse Engineering

„Complexity for free“
➔ Function integration
➔ Less single parts
➔ Topology optimization

Reference: VDMA Studie Produktpiraterie 2016

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Testing of non-visible features
NDT

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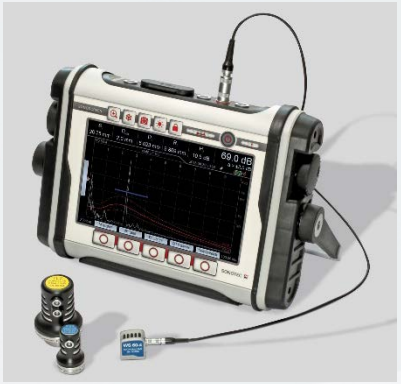
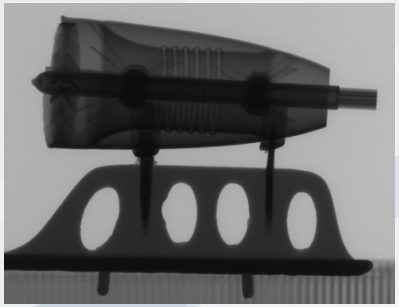
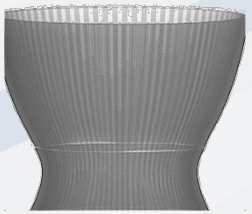
Ultrasonic Testig

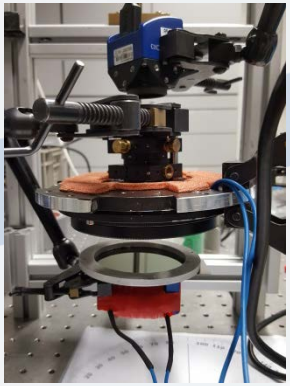


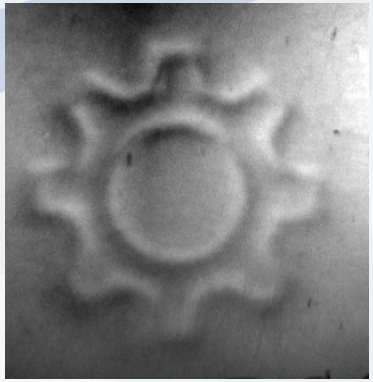
2D Radiography





Magnetical Testing





Computer Tomography (CT)

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Summary

amcd
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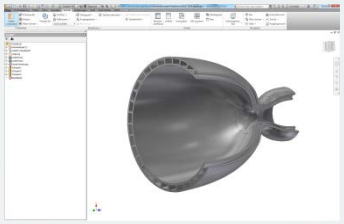
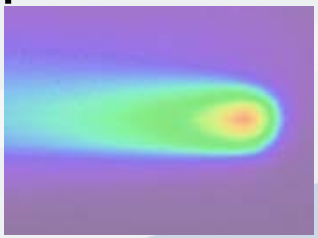
Education AM construction and design

Construction



Reliable and **efficient** process **simulation**

Simulation



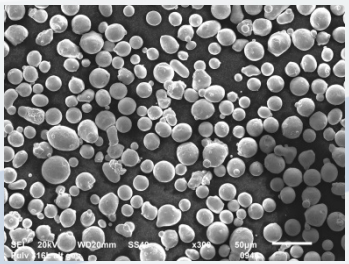
Development of new **system technology**

System technology

Final Part

Automatization, decreasing rate of manual work

Powder materials



Development of representative **models** and efficient **computing algorithms**

base material

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