Fraunhofer Additive Manufacturing Alliance

WORKSHOP

A Series of Workshops and presentations provided by the Fraunhofer Additive Manufacturing Alliance

A SERIES OF WORKSHOPS AND PRESENTATIONS PROVIDED BY THE FRAUNHOFER ADDITIVE MANUFACTURING ALLIANCE

FRAUNHOFER ADDITIVE MANUFACTURING ALLIANCE

9:00	**Opening and Welcome** (Mueller)
9:10	**Introduction to Fraunhofer and AM Alliance** (Mueller)
10:20	**Design for Additive Manufacturing – Guidelines and Case Studies for Metal Applications** (Mueller, Kloeden)
10:50	**Powder for PBF AM – how to assess it & recent developments in analysis** (Aumund-Kopp, Kloeden)
11:20	**Additive Manufacturing for Space Applications – Challenges and Chances for Surface Technology** (Dietz)
11:50	**Q&A Session** (all speakers with auditorium)
12:15	**End of Workshop**
12:30	Bus transfer to EOS

Fraunhofer GENERATIV

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YOUR SPEAKERS

FRAUNHOFER ADDITIVE MANUFACTURING ALLIANCE

- **Dr. Bernhard Mueller**
  Fraunhofer Institute for Machine Tools and Forming Technology IWU, Dresden
  Head of Department »Additive Manufacturing«
  Spokesman Fraunhofer Additive Manufacturing Alliance
- **Claus Aumund-Kopp**
  Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM, Bremen
  Group Manager Additive Manufacturing, Department Powder Technology
- **Dr. Andreas Dietz**
  Fraunhofer Institute for Surface Engineering and Thin Films IST, Braunschweig
  Head of Business Unit Aerospace
- **Dr. Burghardt Kloeden**
  Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM, Dresden
  Group Manager Additive Manufacturing – Electron Beam Melting
- **Klaus Hoschke**
  Fraunhofer Institute for High-Speed Dynamics, Ernst-Mach-Institut, EMI, Freiburg
  Group Manager Additive Design & Manufacturing
- **Marius Bierdel**
  Fraunhofer Institute for High-Speed Dynamics, Ernst-Mach-Institut, EMI, Freiburg
  Group Additive Design & Manufacturing

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Additive Manufacturing at Fraunhofer

Dr. Bernhard Mueller
Fraunhofer Additive Manufacturing Alliance (Spokesman)

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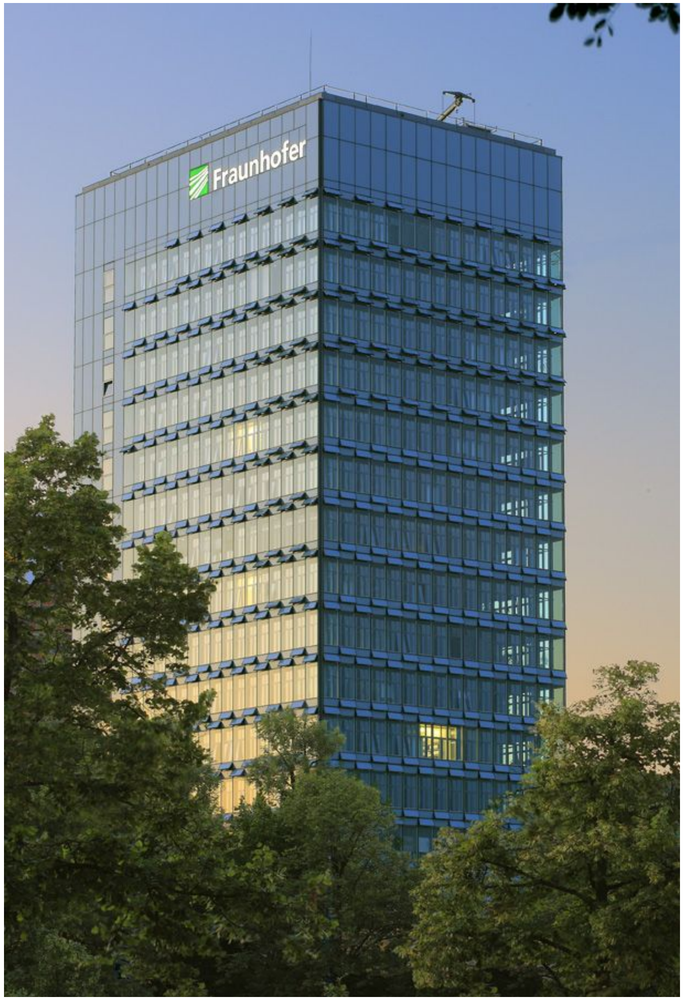
The Fraunhofer-Gesellschaft



The Fraunhofer-Gesellschaft undertakes applied research of direct utility to private and public enterprise and of wide benefit to society.

Our Customers:

- Industry
- Service sector
- Public administration

Joseph von Fraunhofer
(1787-1826)

The Fraunhofer-Gesellschaft
(founded 1949)

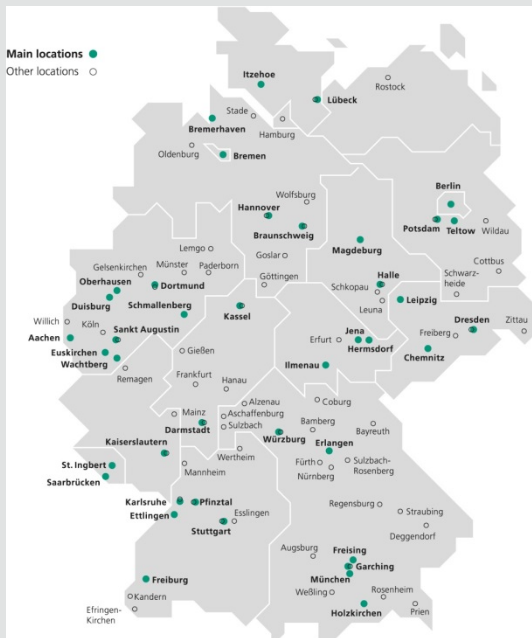
Joseph von Fraunhofer		The Fraunhofer-Gesellschaft
Discovery of the "Fraunhofer lines" in the solar spectrum	**Researcher**	Research and development on behalf of industry and state
New methods for processing lenses	**Inventor**	mp3 music format, white LED, high-resolution thermal camera
Director and partner in a glassworks	**Entrepreneur**	Research volume: approx. €2.3 billion annually

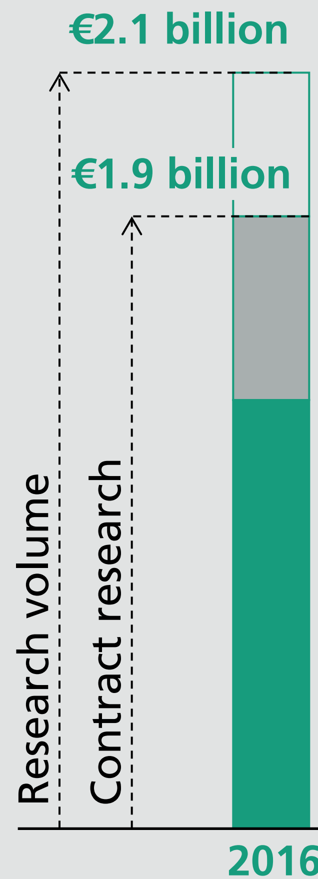
The Fraunhofer-Gesellschaft at a Glance

Applied research for immediate utility of economy and benefit of society

More than
24,500 staff

69 Institutes and
research units





roughly **30%** are contributed by the German federal and *Länder* governments

roughly **70%** are generated through contract research on behalf of industry and publicly funded research projects

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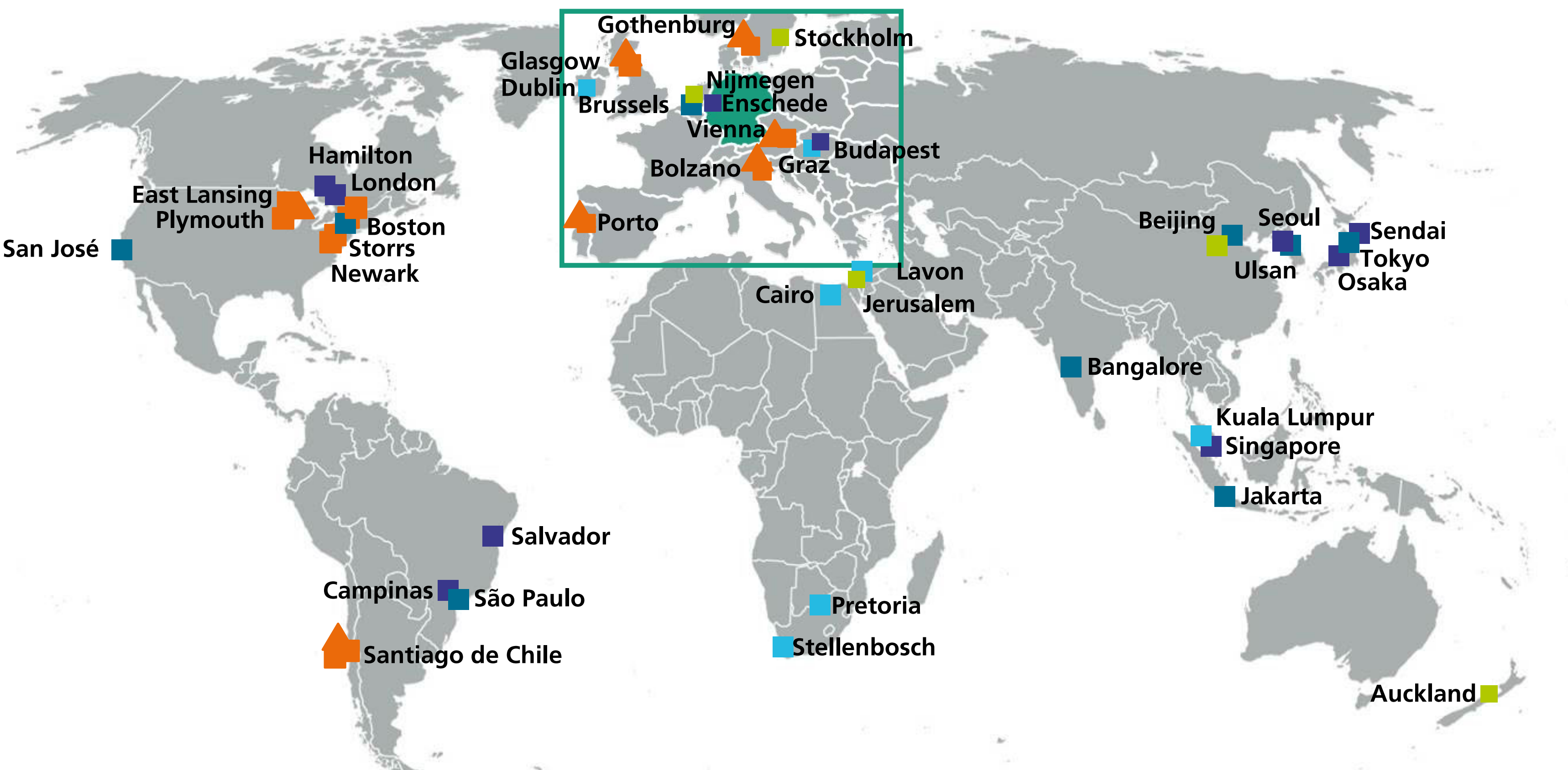
Fraunhofer Worldwide



- Subsidiary
- Center
- Project Center
- ICON / Strategic cooperation
- Representative / Marketing Office
- Senior Advisor

Fraunhofer fields of research

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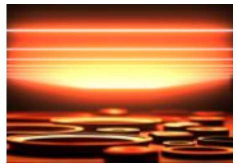
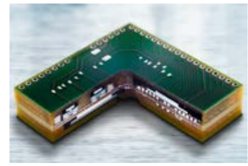
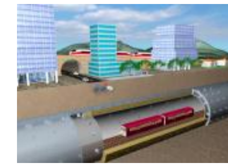
Pooling expertise
Fraunhofer Groups



Institutes working in related subject areas cooperate in Fraunhofer Groups and foster a joint presence on the R&D market. They help to define the Fraunhofer-Gesellschaft's business policy and act to implement the organizational and funding principles of the Fraunhofer model.

- ICT
- Life Sciences
- Light & Surfaces
- Microelectronics
- Production
- Materials and Components – MATERIALS
- Defense and Security VVS

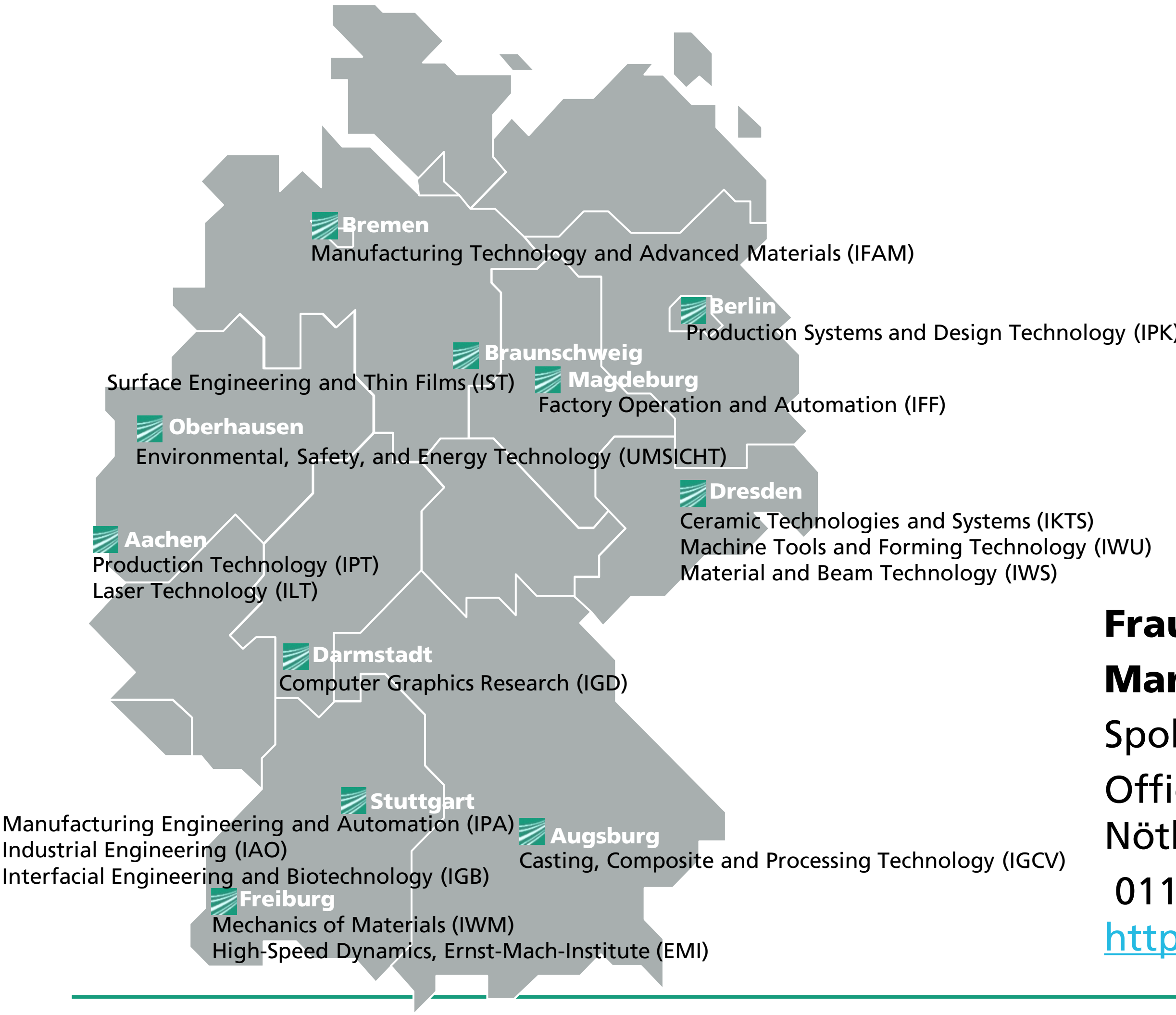
Pooling expertise
Fraunhofer Alliances

The Fraunhofer Alliances facilitate customer access to the services and research results of the Fraunhofer-Gesellschaft. Common points of contact for groups of institutes active in related fields provide expert advice on complex issues and coordinate the development of appropriate solutions.

- Adaptronics
- **Additive Manufacturing**
- AdvanCer
- Ambient Assisted Living
- AutoMOBILE Production
- Battery
- Big Data
- Building Innovation
- Cleaning Technology
- Cloud Computing
- Digital Media
- Embedded Systems
- Energy
- Food Chain Management
- Lightweight Structures
- Nanotechnology
- Photocatalysis
- Polymer Surfaces
- Simulation
- Space
- Technical Textiles
- Traffic and Transportation
- Vision
- Water Systems (SysWasser)

Additive Manufacturing at Fraunhofer

One topic – seventeen institutes – one alliance



Fraunhofer Additive Manufacturing Alliance

Spokesman: Dr.-Ing. Bernhard Mueller

Office: c/o Fraunhofer IWU,
Nöthnitzer Straße 44,
01187 Dresden (Germany)
http://www.generativ.fraunhofer.de

Fraunhofer Additive Manufacturing Alliance
Research areas

- **Engineering**
  to invent and design new products and develop suitable process chains

- **Materials**
  to adapt new materials

- **Technologies**
  to achieve (cost-)efficient processes

- **Quality**
  to control and ensure manufacturing reproducibility and product quality

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Engineering

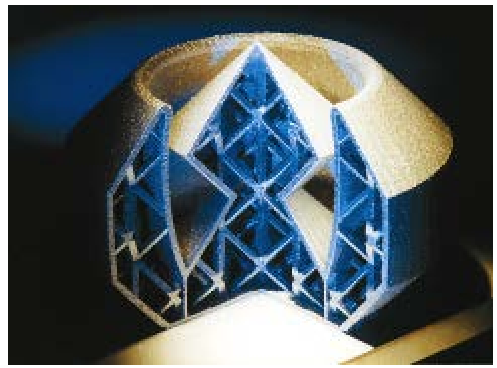
Main focus:

- Design & design rules for additive technologies (plastic and metal)
- Simulation and system integration
- New product and applications, e.g. micro technologies

Lightweighting: Internal hollow & grid structures

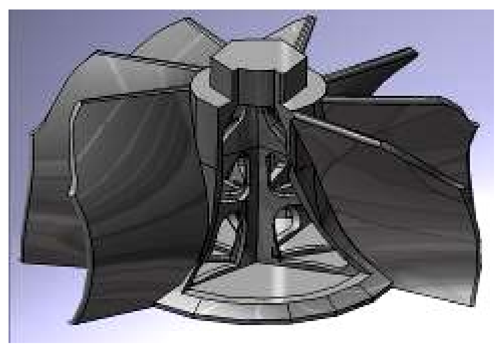
Ultra-light weight metal structures

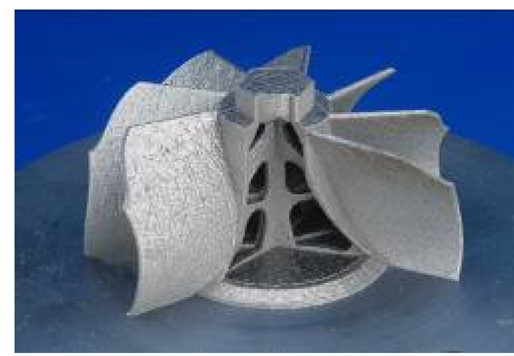
- ✓ internal hollow structures provide maximum stiffness at lowest possible weight
- ✓ almost unlimited freedom in designing these structures
- ✓ best in combination with light weight materials like aluminum or titanium
- ✓ made by Laser Beam Melting



TiAl6V4

AlSi10Mg





Inconel 718

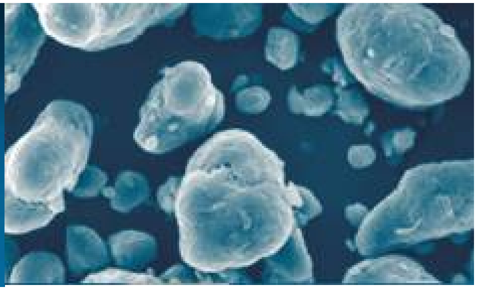
Source: Fraunhofer ILT

Research & Services of the Alliance
Materials

Main focus:

- Polymers
- Metals
- Ceramics
- Graded materials



New Polymers

Material sample #1: PP powder

Material sample #2: PBT powder

Material sample #3:
Impregnated DuraForm PA12

Source: Fraunhofer UMSICHT

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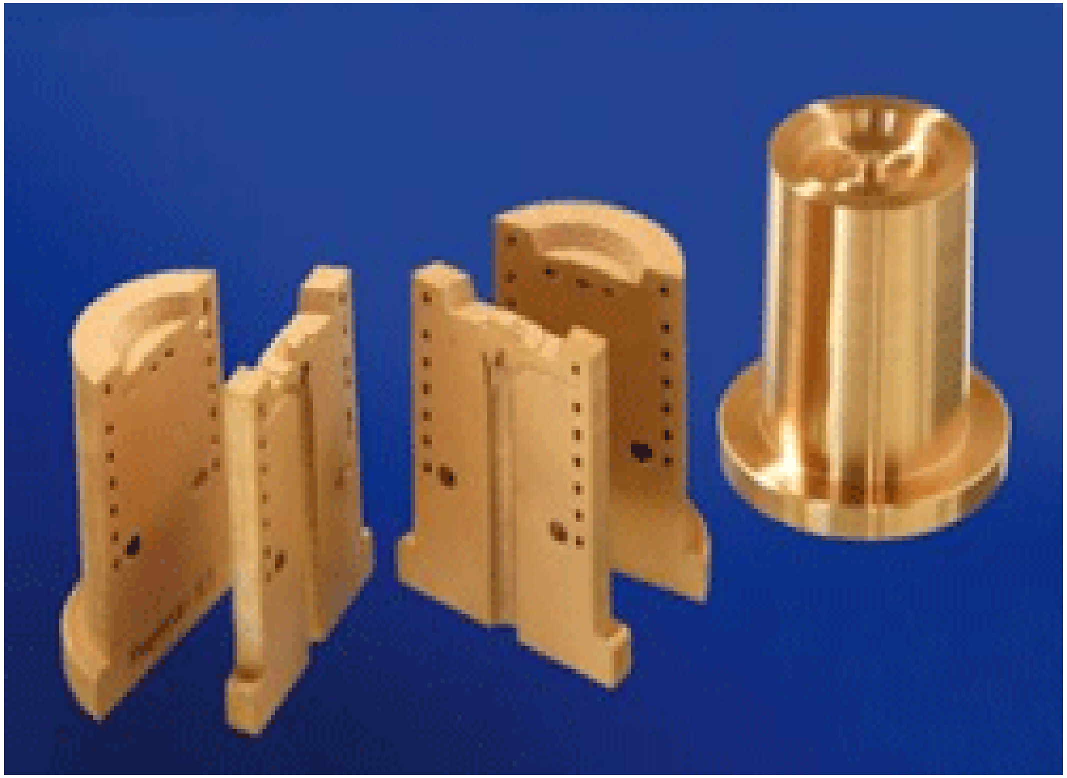
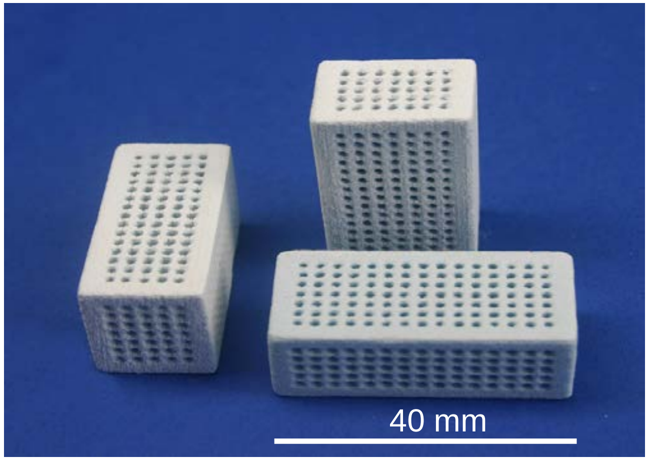
Metals – Copper

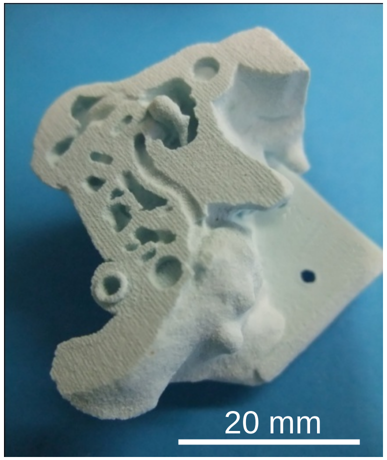
- Copper alloy:
  Hovadur K220
- manufactured via LBM
  with 1000 Watt laser
- e.g. for tooling
  with conformal cooling

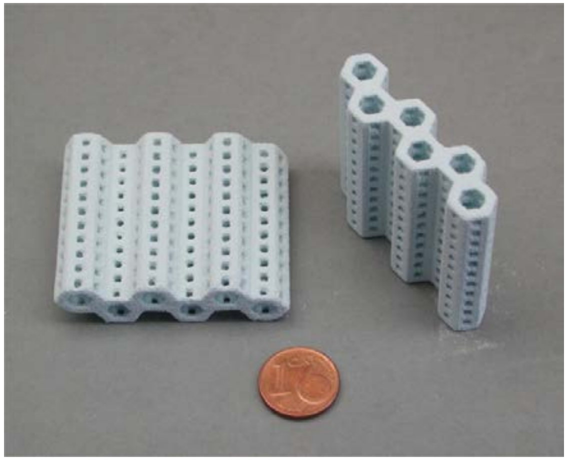


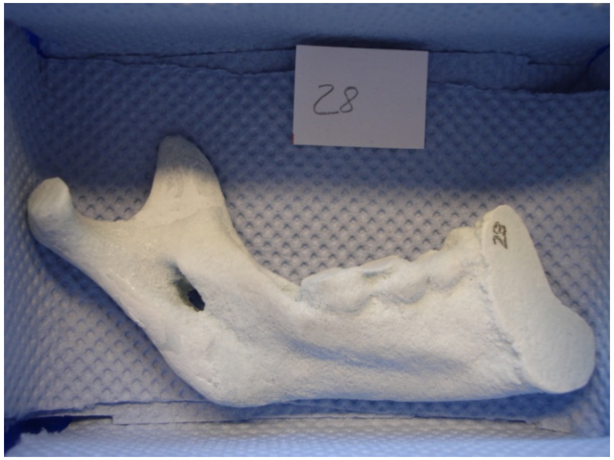
Source: Fraunhofer ILT

Materials
Ceramics – bioactive hydroxyapatite structures









- 3D powder bed printing

Source: Fraunhofer IKTS

Technology

Main focus:

- Metal AM
- 3D Printing technologies
- Automated process chains and peripheries





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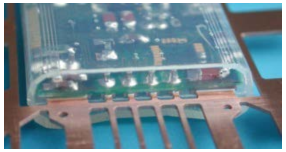
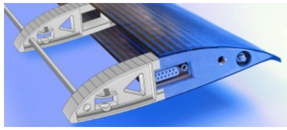
Quality

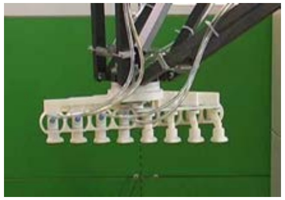
Main focus:

- Process simulation
- Process development
- Parts quality
- Standards & Quality Management

Industrial application
Solutions for different industrial sectors

- Bio-medical engineering
- Micro-system engineering
- Automotive
- **Aerospace & Space**
- Tool making
- Handling & Assembly
- …



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Industrial application

Solutions for the Aerospace & Space Industry

Selected case studies from

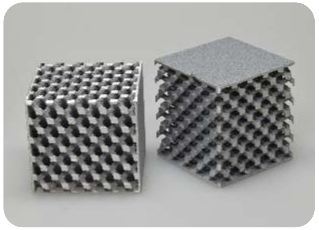
- Fraunhofer EMI
- Fraunhofer IWS
- Fraunhofer IFAM
- Fraunhofer IPT/ILT

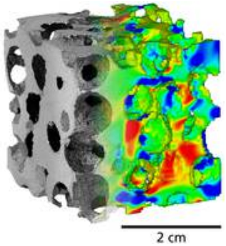
[1] Picture: Airbus A300-600 Beluga 2 F-GSTB "Supertransporter" von Olivier Cabaret, Licence: CC BY-NC-ND 2.0, https://www.flickr.com/photos/oliviercabaret/8032637719, abgerufen am 15.11.2017
[2] Picture: Turbinenschaufel von tigeltuf, Licence: CC BY-SA 2.0, https://www.flickr.com/photos/11596438@N00/23281649182/in/photolist-eSddE9-eS1Mik-dhXQD3-Btjxbw-BzjoNh, abgerufen am 15.11.2017
[3] Picture: Airbus A380 von Greg Hounslow, Licence: CC BY-NC-ND 2.0, https://www.flickr.com/photos/gregorio/11420265/, abgerufen am 15.11.2017

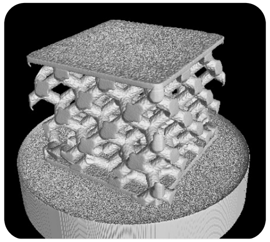
AM research focus: Additive Design and Designed Materials

- **Multidisciplinary Additive Design and Design Optimization**
  - Topology Optimization, Design for AM (DfAM)
  - Parametric design of Mesostructures
  - Multiphysics and rough operation conditions (Fail-safe design, extreme events (e.g. bird strike, space debris)

- **Designed Materials, simulation and characterization**
  - Structuring of materials on multiple scales and interaction of process parameters
  - Microstructuring, Mesostructures (lattices)
  - Material mechanics, modeling and characterization in experiment and simulation



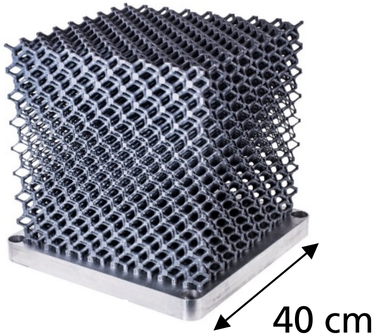




Fraunhofer EMI

AM research focus: Additive Design and Designed Materials

- **AM Equipment**
  - Metal AM systems: EOS M400, M100
  - Materials: Al, Ti64, Scalmalloy®
  - Building volume: 400 x 400 x 400 mm³
  - Composite AM system: Mark X



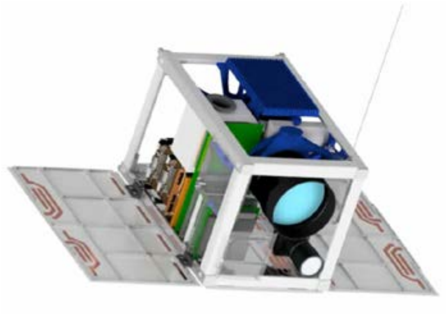
- **Project Examples**

Fitting for cargo door

- Topology optimized, Fail-safe design
- Partner: SAAB

Optical bank for 12U nanosatellite ERNST

- Multidisciplinary design (Thermal, Mechanical)



Fraunhofer IWS

Additive Manufacturing – Laser Metal Deposition *...in Aerospace*

Processes

Laser Metal Deposition with Powder

AM + conventional Manufacturing

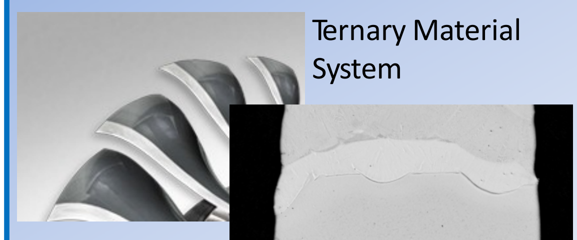
Laser Metal Deposition with Wire

Engine Components – Nickel Superalloys

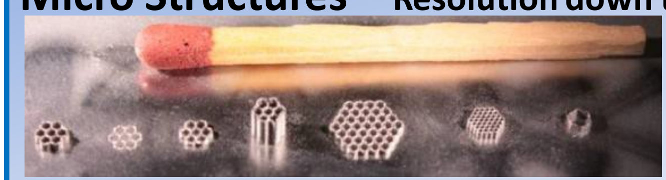
Thruster

Multi-Material Components

Ternary Material System



Micro Structures – Resolution down to 30 µm



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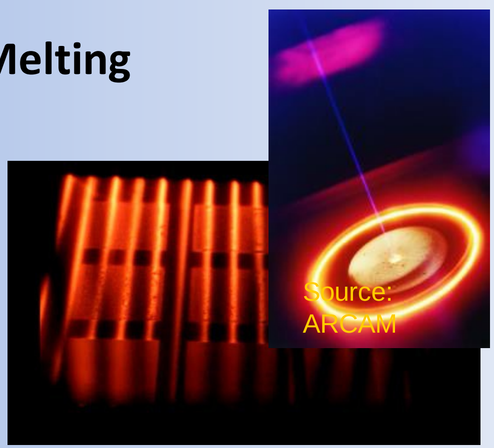
Additive Manufacturing – Powder Bed Processes
...in Aerospace

Processes

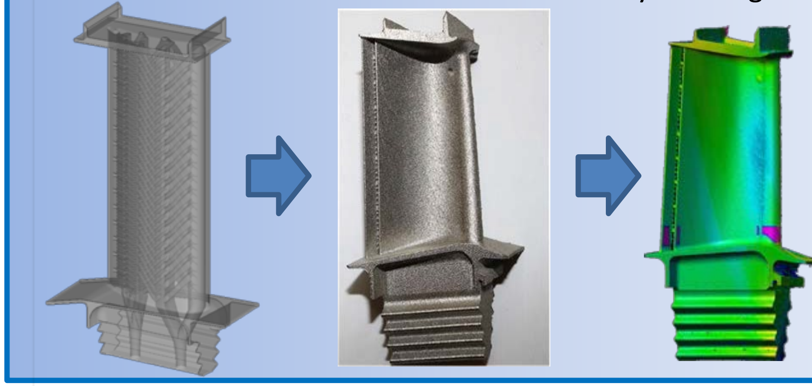
Selective Laser Melting

Electron Beam Melting

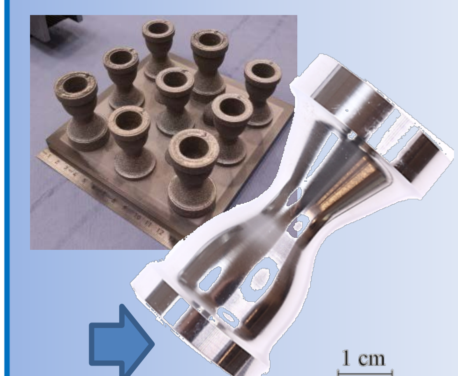


Turbine Blades with Cooling Channels

CAD Data | SLM - AM | Quality - Management

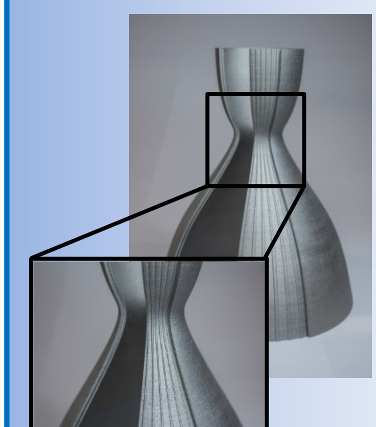


Thruster TNM-B1



High precision finish

Conformal Cooling



Electron Beam Melting

Project

GenFLY

- BMWi (LuFo), 01/14-03/17
- Partners: Airbus, Liebherr, LZN, ...
- Increase of TRL of PBF processes for use in aerospace industry
- Consideration of whole process chain

Work packages IFAM

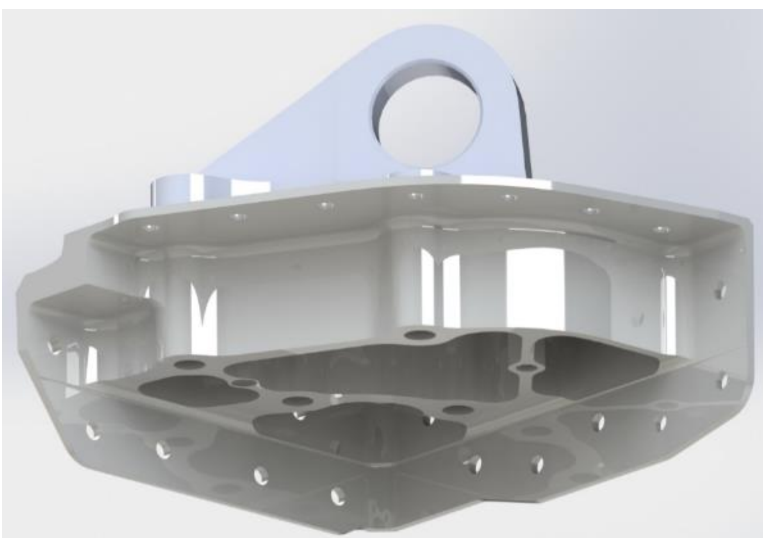
- design
- powder, manufacturing (EBM)

Electron Beam Melting

Topology optimization of aerospace part

optimization result

- Improvement of mass distribution → OK (weight reduction: -50%)
- Part integration → one final part, one material → OK
- Load and stress criteria need to be fulfilled → OK
- CAD of optimized part, which can be built → OK after post-processing



Fraunhofer IFAM Dresden

Electron Beam Melting

Topology optimization of aerospace part

optimization result (II)

- step 1: scale 1:2, material: Ti-6Al-4V (1st design)
- step 2: full scale part (recalculated design after changes in loads, rivet holes, …)
  - dimensions in build chamber (x/y/z): 171 / 179 / 158 mm
  - build time: 29h
- for testing, part has been completely surface-treated (CNC + electro-polish)

1st design

2nd design, as-built

2nd design, finished

Fraunhofer IFAM Dresden

Electron Beam Melting

Topology optimization of aerospace part (II)

demonstrator part production (bell crank Liebherr)

- Topology optimization was done at Laserzentrum Nord (LZN)
- Manufacturing by LBM (@LZN) and EBM (@IFAM)

demonstrators manufactured by EBM

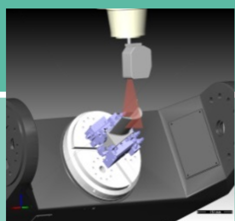
Fraunhofer IPT / Fraunhofer ILT

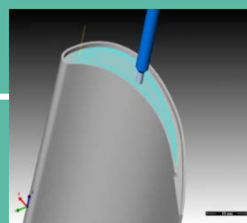
Automated Tip Repair of Turbine Blades for Gas Engine

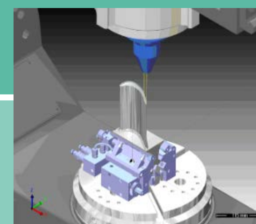
TurPro

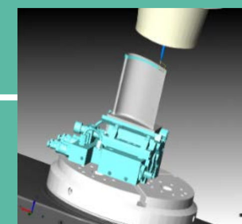
Tip Repair of Turbine Blades

»CAx-Framework«

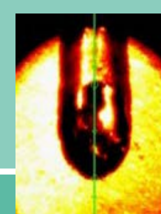


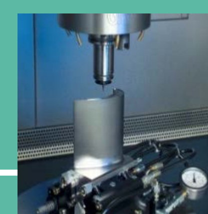






Optical Metrology → Machining and Preparation → Laser Deposition Welding and Process Monitoring → Reshaping Adaptive Milling

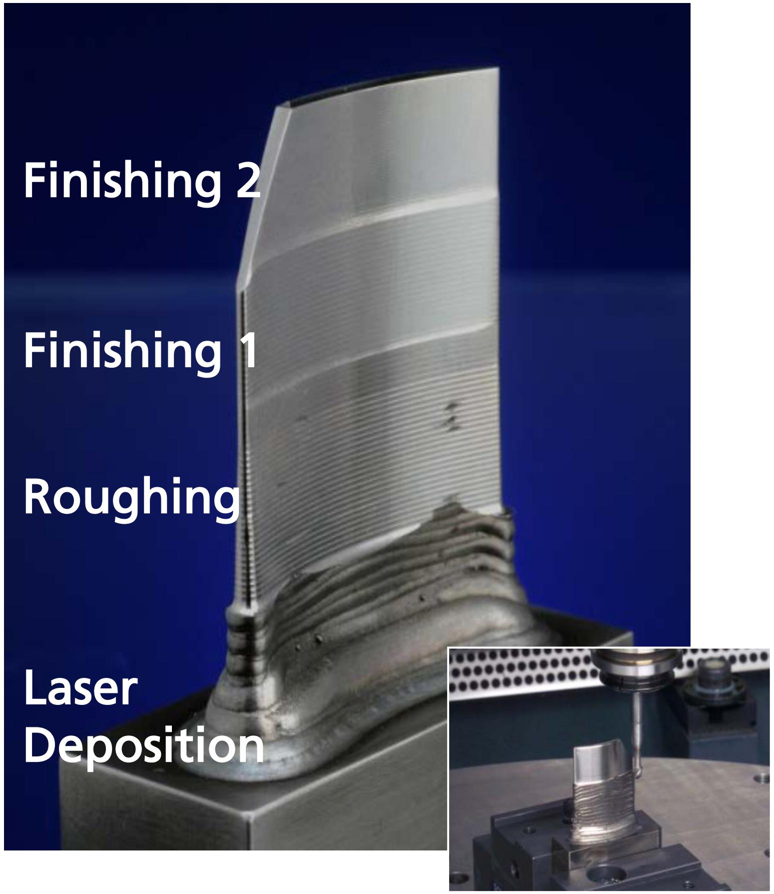




Universal Clamping Solution

Fraunhofer GENERATIV

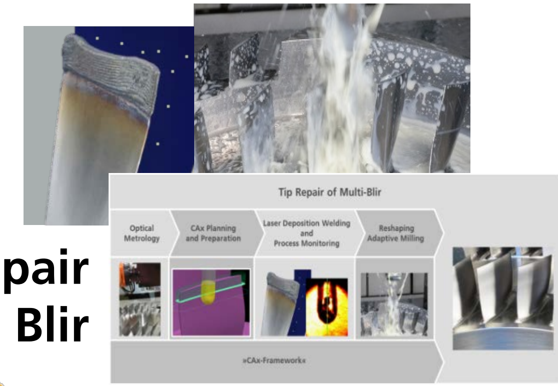
Near-net-shape Additive Manufacturing of HPC Blades



Fraunhofer IPT / Fraunhofer ILT

Examples of Pre-Competitive R&D Projects within the two Fraunhofer Innovation Clusters AdaM and TurPro

HPC Blade Mock-up

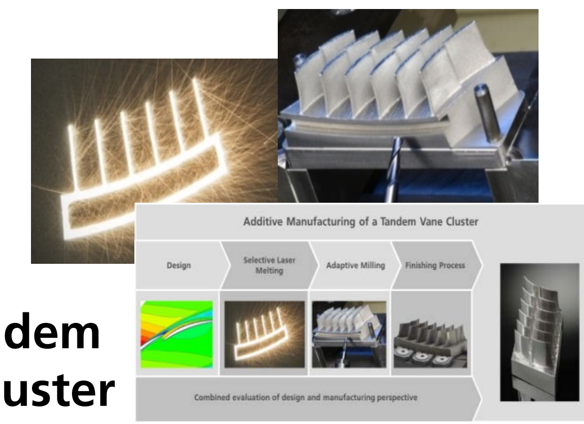


Tip Repair Multi Blir

AdaM

TurPro

Tip Repair Turbine Blade



Tandem Vane Cluster

Fraunhofer Direct Digital Manufacturing Conference DDMC 2018

Berlin, March 14 - 15, 2018

DDMC2018
Fraunhofer Direct Digital
Manufacturing Conference

Range of topics:

- Product Development
- Technologies
- Materials
- Quality

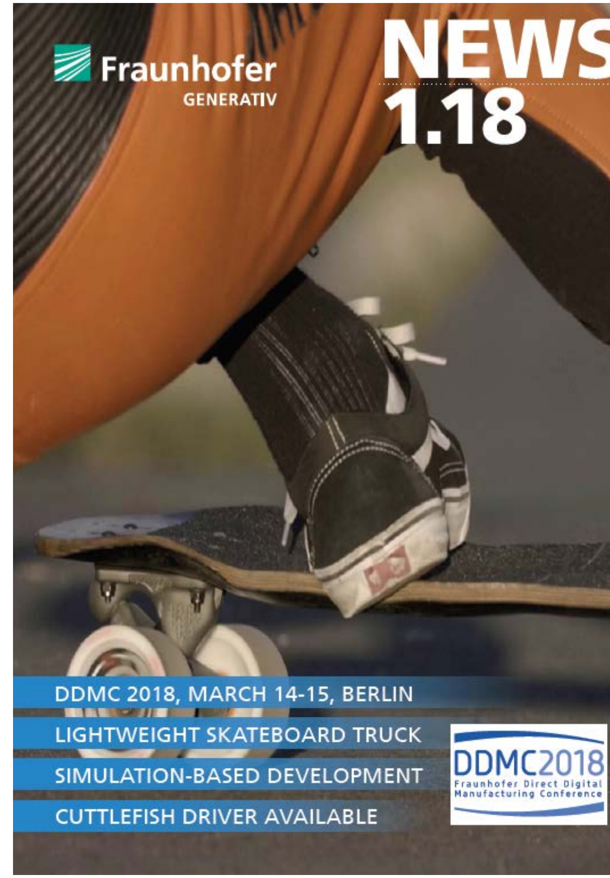
Join us in Berlin next month!

MARCH 14-15, 2018

Full program online now:
www.ddmc-fraunhofer.de

Fraunhofer Additive Manufacturing Alliance

Alliance NEWS



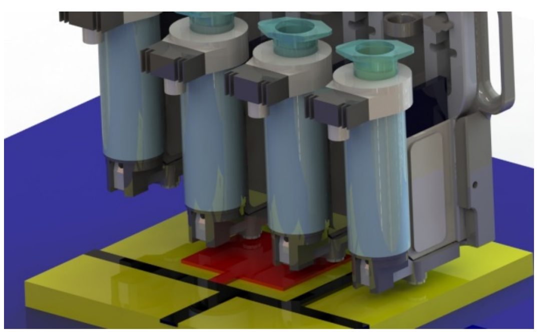
Highlights:

- DDMC 2018, March 14-15, Berlin
- Lightweight Skateboard Truck
- Simulation-based Development
- Cuttlefish Driver available

Online at:

www.generativ.fraunhofer.de/en

Leave your business card with us to receive a **paper copy via mail**!



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Call for Proposals

Can Fraunhofer Solve Your Problem?

Submit your problem or question related to additive manufacturing and 3D printing!
Topics may cover:

- materials and technologies
- assessing/improving quality of 3DP parts
- optimizing parts for weight, stiffness, etc.
- digital workflow: slicers, adaptive control etc.

Generic questions welcome, e.g. feasibility studies

One problem will be selected and the Alliance will provide a workshop with Fraunhofer experts to solve it.

Submission deadline:
March 31, 2018

Online at:
www.generativ.fraunhofer.de/en/solutions.html

Contact

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http://www.generativ.fraunhofer.de

WORKSHOP @ AM 4 AEROSPACE & SPACE

FRAUNHOFER ADDITIVE MANUFACTURING ALLIANCE

9:00	**Opening and Welcome** (Mueller)
9:10	**Introduction to Fraunhofer and AM Alliance** (Mueller)
10:20	**Design for Additive Manufacturing – Guidelines and Case Studies for Metal Applications** (Mueller, Kloeden)
10:50	**Powder for PBF AM – how to assess it & recent developments in analysis** (Aumund-Kopp, Kloeden)
11:20	**Additive Manufacturing for Space Applications – Challenges and Chances for Surface Technology** (Dietz)
11:50	**Q&A Session** (all speakers with auditorium)
12:15	**End of Workshop**
12:30	Bus transfer to EOS

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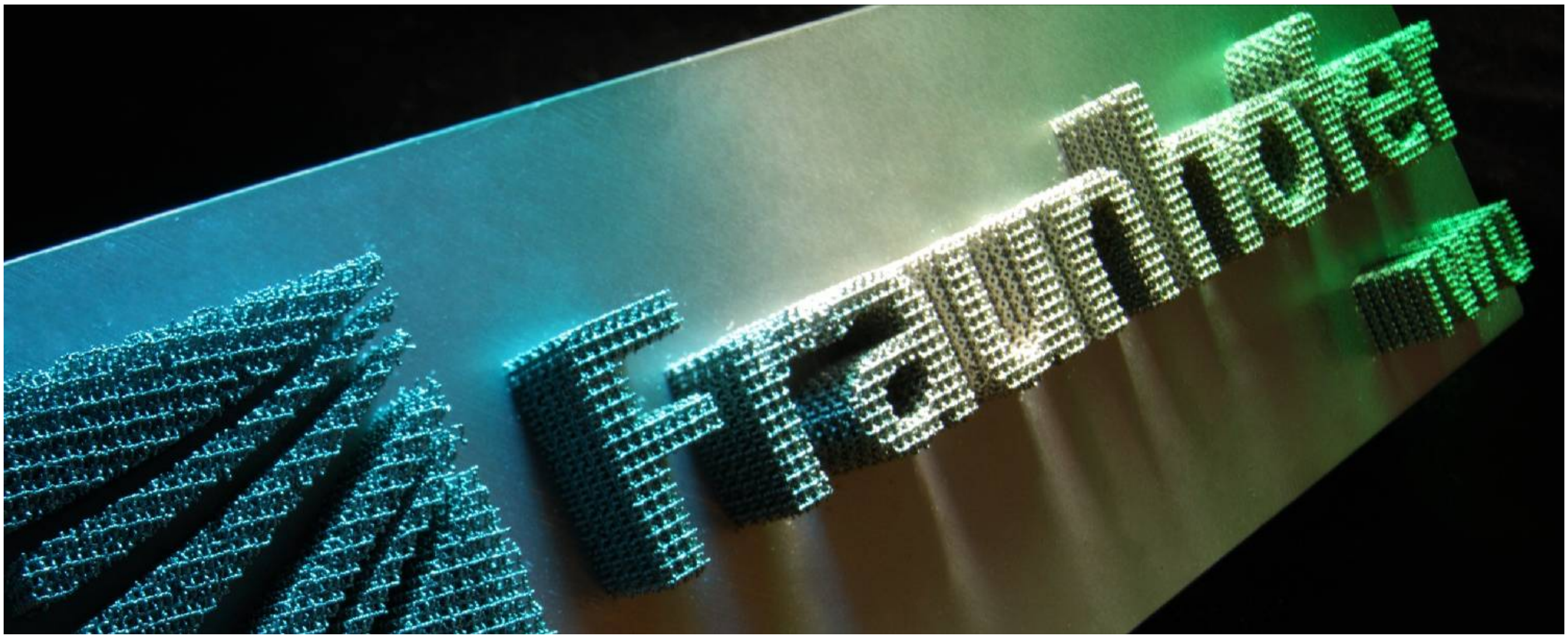
DESIGN FOR ADDITIVE MANUFACTURING

GUIDELINES AND CASE STUDIES FOR METAL APPLICATIONS

Dr. Bernhard Mueller, T. Schnabel, M. Oettel, T. Toeppel, M. Gebauer (Fraunhofer IWU)
Dr. Burghardt Kloeden, C. Aumund Kopp (Fraunhofer IFAM)
K. Hoschke, A. Pfaff (Fraunhofer EMI)



Additive Manufacturing for Aerospace and Space 2018, Munich, February 20, 2018

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DESIGN FOR ADDITIVE MANUFACTURING

GUIDELINES AND CASE STUDIES FOR METAL APPLICATIONS

- Scope
- AM-specific Design Opportunities
- AM Processes and related Design Principles
- AM-relevant Standards and Guidelines
- Analysis of seven Case Studies
  - Bionic Wheel Carrier of Electric Vehicle
  - Main Gearbox Bracket
  - Calibration Tool for Extrusion Process
  - Heat Exchanger
  - Miniature Heat Exchanger / Cooler
  - Functionally Integrated Implant – MUGETO®
  - Functionally Integrated Tooling Segments
- Summary

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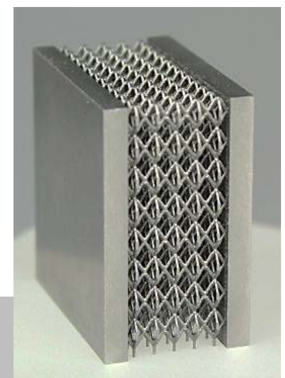
Design for Additive Manufacturing
Scope

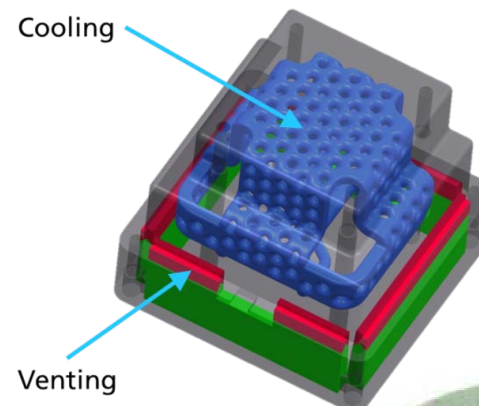
- **Main challenges of AM:**
  - AM technologies require a **rethinking in 3D design**
    → still a barrier particularly for SMEs!
  - **Knowledge** about advantages, opportunities and restrictions is essential in order to make AM a competitive manufacturing method
- **The report:**
  - Identification of leading edge **industrial applications and trends** associated with the design for AM
  - Translating AM-specific design rules and principles in a simplified format **accesible to industry**
  - Highlighting **general design principles** for LBM and EBM
  - Evaluation of seven individual components, reviewed and assessed in **detailed case studies**

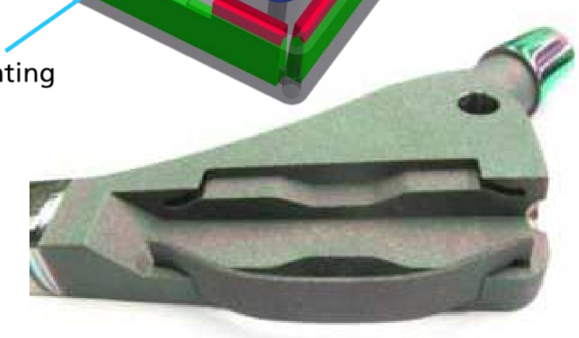
Design for Additive Manufacturing
AM-specific Design Opportunities

- Design and manufacturing of very **complex** component geometry
- Required information taken directly from CAD data, no need for forming tools etc. → fully **flexible** production

Topology Optimization **Lattice Structures** **Integrated Functions**

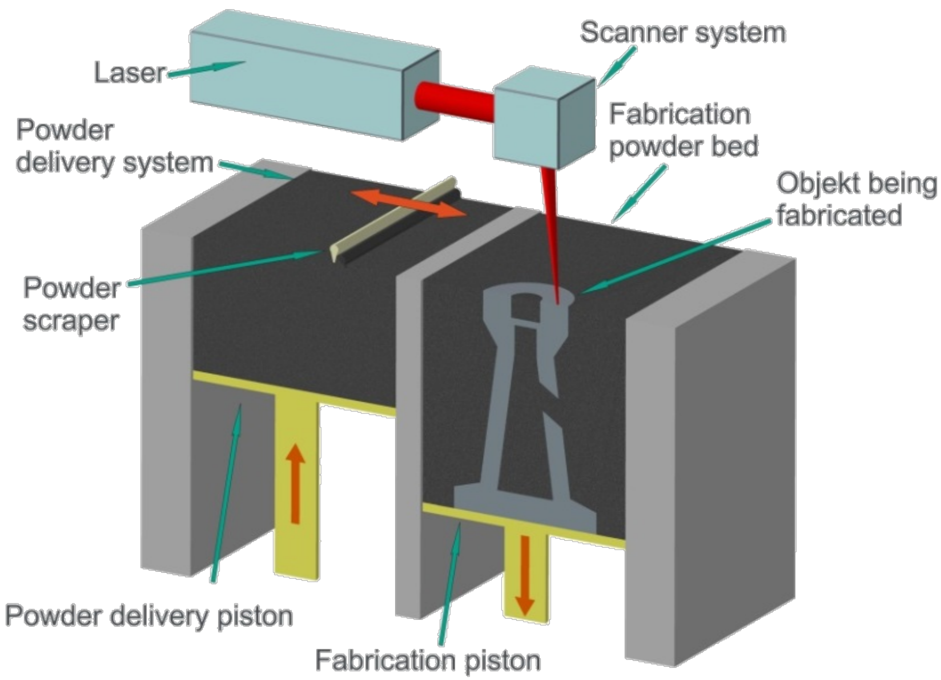


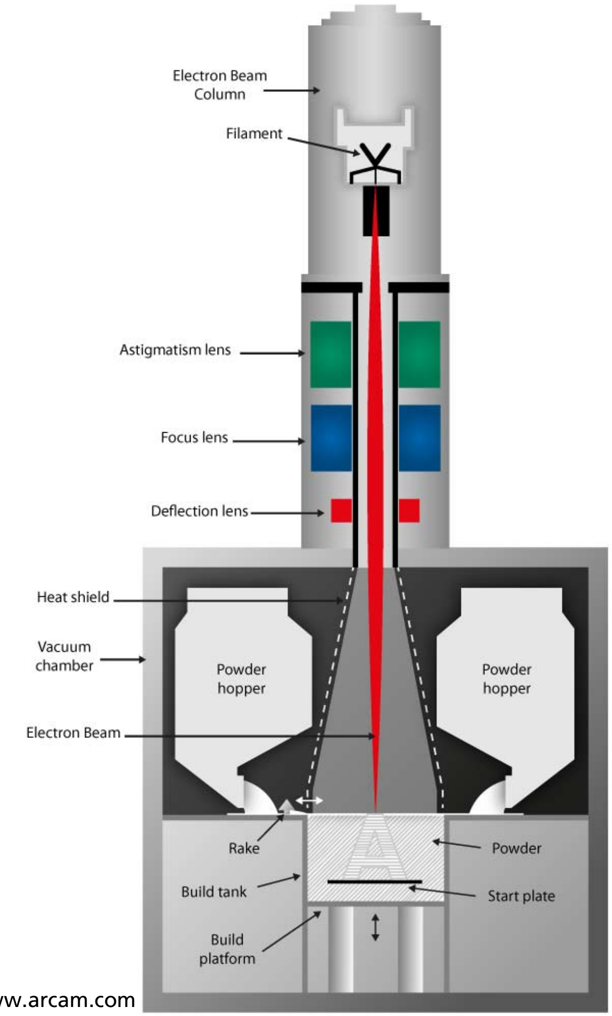




AM Processes and related Design Principles

Powder bed based AM processes LBM and EBM





Source: www.arcam.com

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AM Processes and related Design Principles
Powder bed based AM processes LBM and EBM

	Laser Beam Melting (LBM)	**Electron Beam Melting (EBM)**
Energy Source	Laser (up to 1 kW, up to 4 lasers)	Electron Beam (up to 3.5 kW)
Range of Materials	Tool steels, Stainless steels, Aluminium alloys, Titanium and Ti-alloys, Nickel-based alloys, Cobalt-chrome alloys	Titanium and Ti-alloys, Nickel-based alloys, Cobalt-chrome alloys
Controlled Atmosphere	Nitrogen, Argon	Vacuum
Process Temperatures	room temperature, build plate optionally heated up to 250 °C or even higher	Pre-heating of each layer up to 1,000 °C (e.g. for TiAl)
Susceptibility to Residual Stresses	High	Low
Stress-relief heat treatment required	Yes (in most cases)	No (in most cases)
Complexity of parts	High	Medium
Size of Powder Particles (typical range)	10-45 µm	45-105 µm
Part surface roughness (as-built)	R_z = 30-140 µm	Poorer than LBM
Dimensional accuracy	0.1 mm	Poorer than LBM (~ 0.5 mm)
Typical Layer Thickness	30-50 µm	50-100 µm
Process Speed	Poorer than EBM (single laser machines)	High (very high scan rates)

References: [5], [7], [8], [9]

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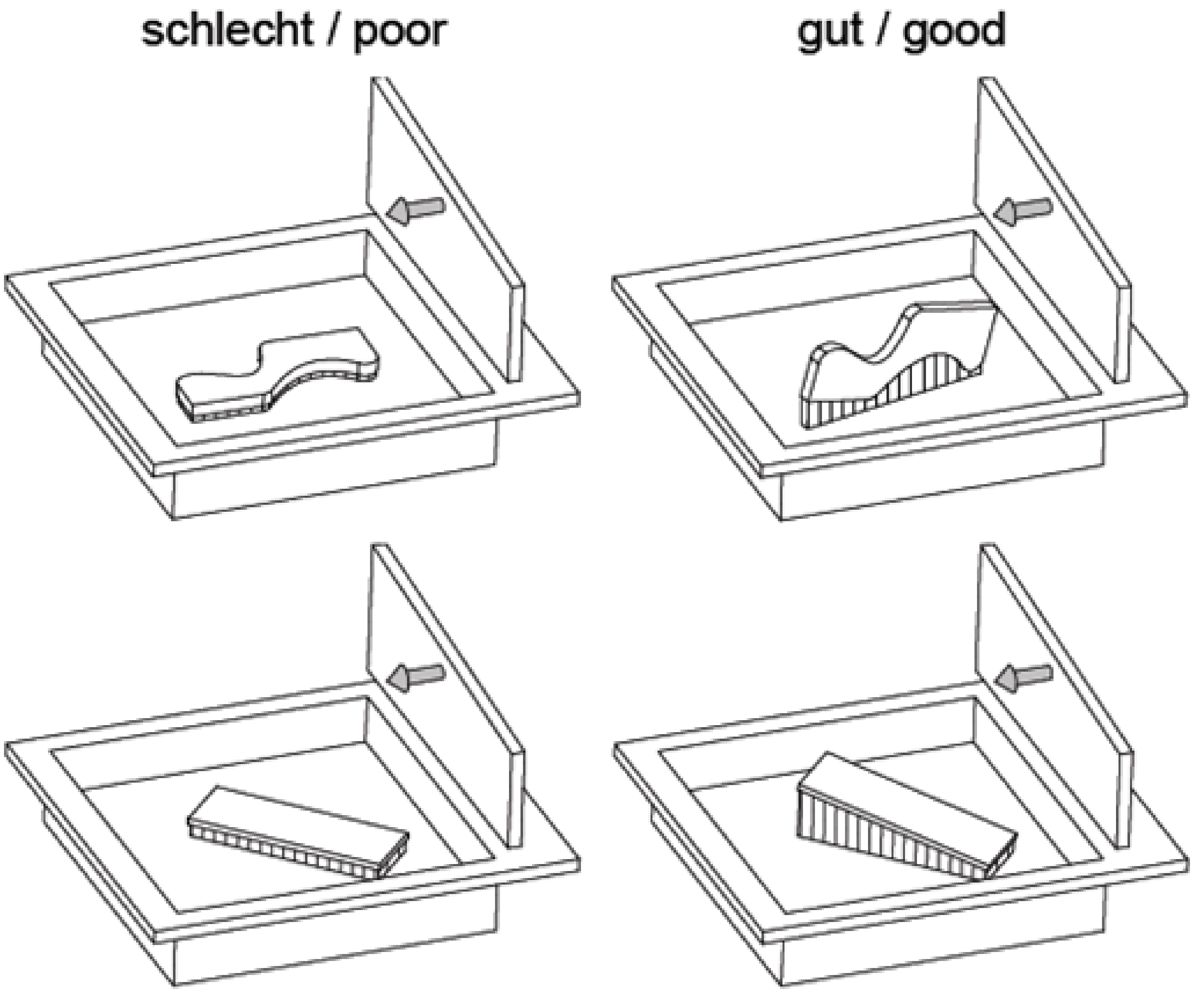
AM Processes and related Design Principles

Part orientation during build

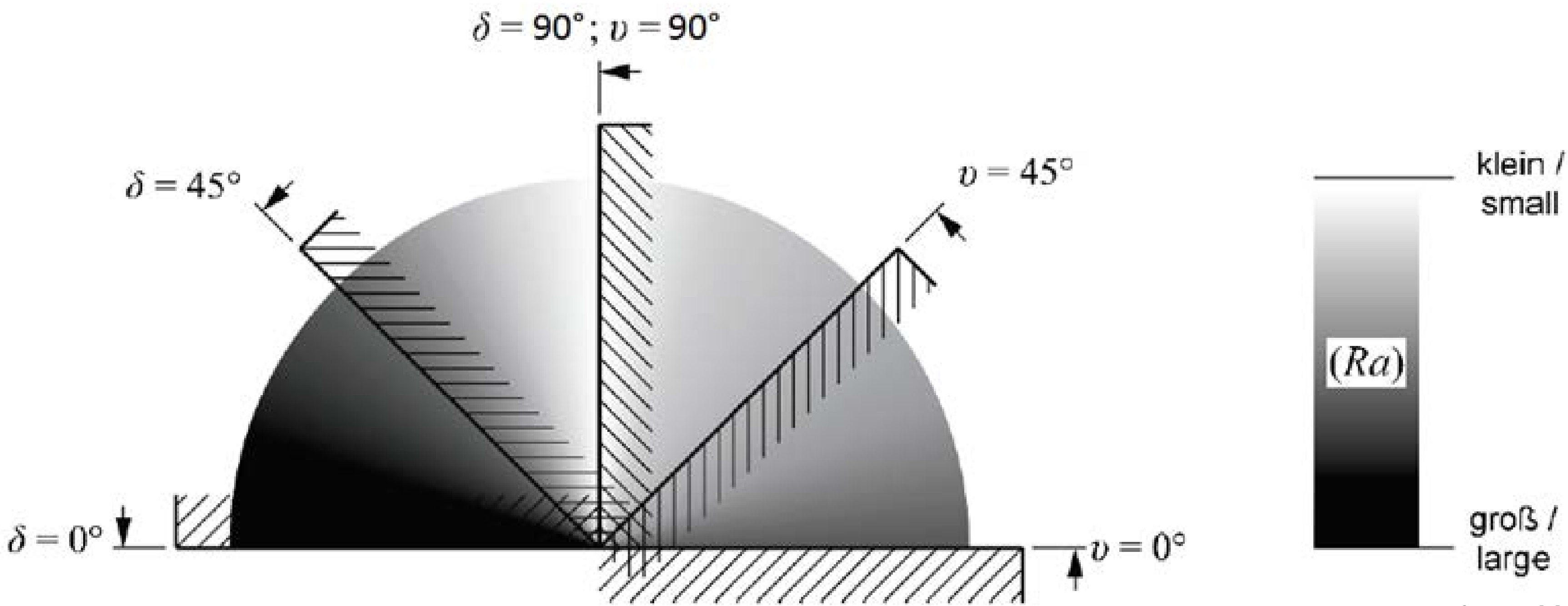
- Orientation, position and arrangement of parts can have a significant influence on the process speed, process stability and various component properties
- Due to insufficient heat dissipation the so-called curl-effect may occur in both processes, LBM and EBM



Reference: [5]

AM Processes and related Design Principles
Surface roughness dependent on build angle

- Depending on the angle between part surface and build platform, surface roughness differs noticeably
- Both, for LBM and EBM, this effect is significant:
  LBM: R_z = 30 - 140 µm [5]
  EBM: R_z = 150 - 300 µm

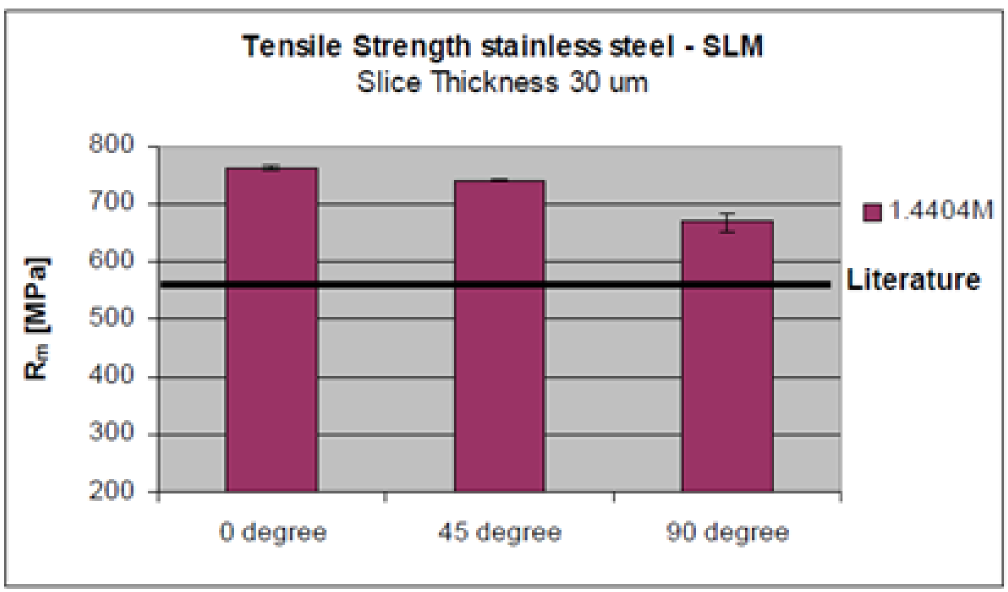


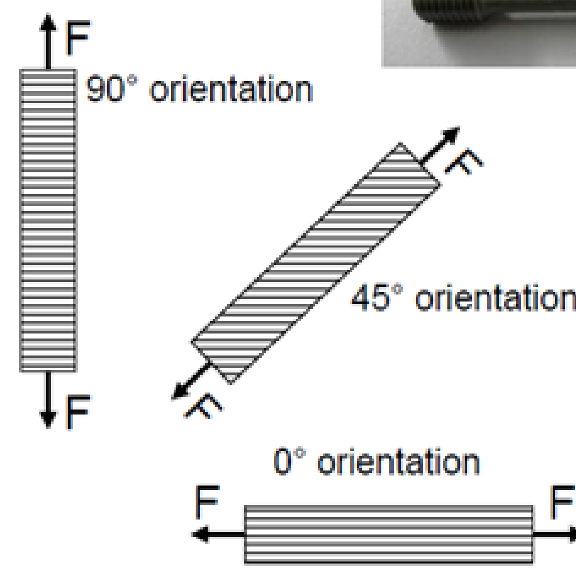
Reference: [5]

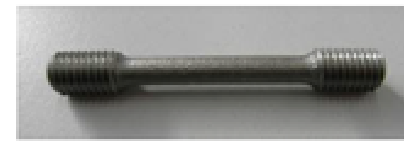
AM Processes and related Design Principles

Anisotropic material properties (as built)

- For LBM in a typical range of about 5 to 15% [10], similar for EBM (e.g. processing 316L)
- Compared to solid objects, this effect is increased for delicate geometries like lattice structures [11]







Reference: [10]

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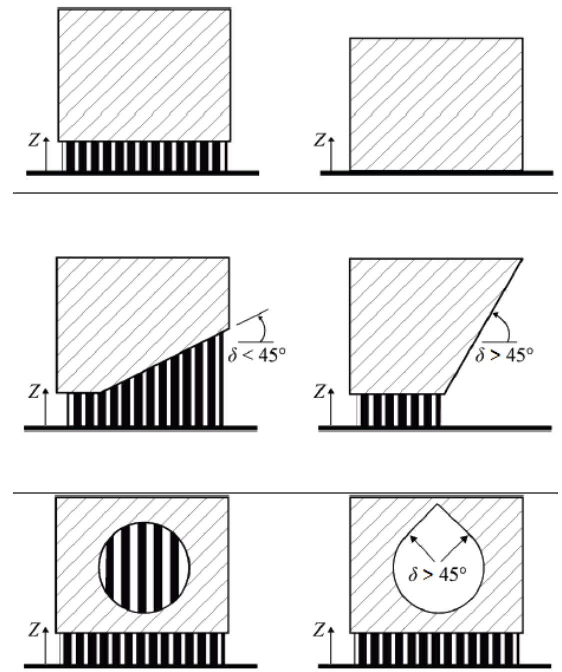
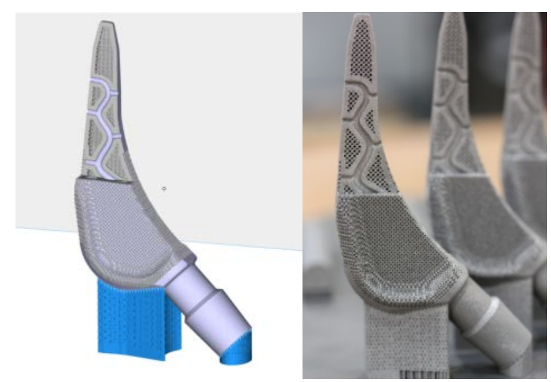
AM Processes and related Design Principles

Support structures

- Purpose of support structures:
  - Fixation of the part on the build platform
  - Support of overhanging structures
  - Heat dissipation, avoidance of residual stresses
  - Compensation of residual stress-induced warping
- Support structures need to be removed after the AM process
- Affected surfaces require adequate mechanical post-processing



Reference: [5]



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AM Processes and related Design Principles

Tolerances / Machining allowance

- Accuracy of LBM: ~ +/- 0.1 mm
- Accuracy of EBM: ~ +/- 0,5 mm

    - Functional surfaces and fits need to be finished by suitable machining processes
    - appropriate machining allowance to be considered during design, at least for those locations on the component which have to fulfil high tolerance requirements

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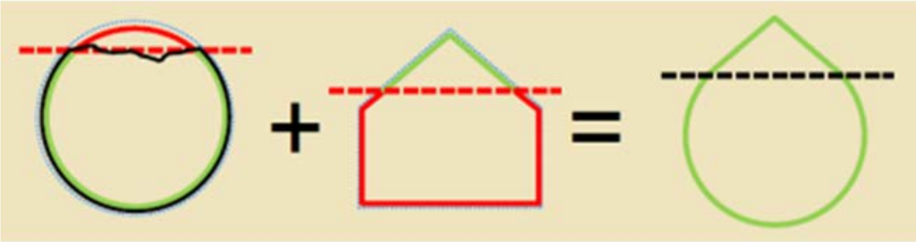
AM Processes and related Design Principles

Min/Max part/feature size

- **Positive volumes:**
  - **Maximum** size only limited by the AM machine (process chamber)
  - **Minimum** size basically limited by beam focus diameter and feature requirements (e.g. pressure tightness of wall structure)
    → 0.3 mm (LBM) / 0.6 mm (EBM)
- **Negative volumes** (hollow structures, e.g. channels, cavities, bores)
  - Avoid support structures for inaccessible cavities:
    - **Maximum** diameter w/o any need of support: d = 8 mm
    - Align hollow structure (e.g. channel) vertical to build platform
    - Adapt cross-section of structure (round → oval/droplet shape)
    - **Minimum** channel size:
      LBM: 0.4 (straight)
      0.6 (curved)
      EBM: 0.8 (straight)



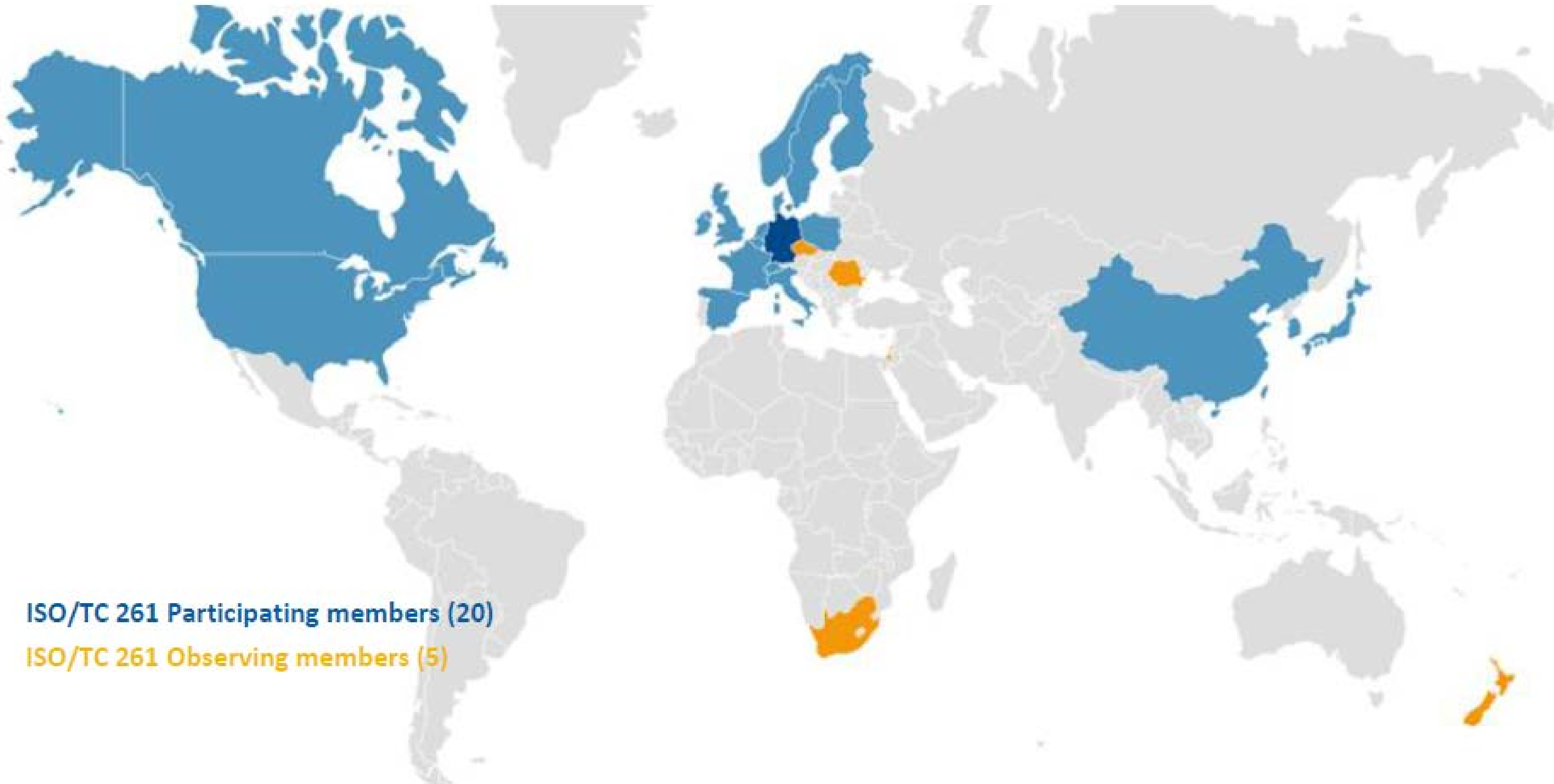
Reference: [12]

Design for Additive Manufacturing

AM-relevant Standards and Guidelines

- **Standards for conventional manufacturing methods**
  - Developed over decades
  - Based on comprehensive theoretical knowledge and broad practical experience
  - Serving either as a guidance or as hard specification in order to define a common language in related industry
- **Standards for Additive Manufacturing**
  - AM technology like LBM and EBM is from particular interest for industry only for a number of years now
    → delevopment of standards for AM is still in an early stage
  - Significant lack with regard to materials and processes

AM-relevant Standards and Guidelines
Countries active in AM standardization



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AM-relevant Standards and Guidelines

Overview of AM-specific standards

	Standard / Guideline	Title
1	ISO 17296-2:2015	Additive manufacturing -- General principles -- Part 2: Overview of process categories and feedstock
2	ISO 17296-3:2014	Additive manufacturing -- General principles -- Part 3: Main characteristics and corresponding test methods
3	ISO 17296-4:2014	Additive manufacturing -- General principles -- Part 4: Overview of data processing
4	ISO / ASTM 52900:2015	Additive manufacturing -- General principles -- Terminology
5	ISO / ASTM 52901-16	Standard Guide for Additive Manufacturing – General Principles – Requirements for Purchased AM Parts
6	ISO / ASTM 52910-17 (supersedes ISO DIS 20195)	Standard Guidelines for Design for Additive Manufacturing
7	ISO / ASTM 52921:2013	Standard terminology for additive manufacturing -- Coordinate systems and test methodologies
8	ISO / ASTM 52915:2016	Standard Specification for Additive Manufacturing File Format (AMF) Version 1.2
9	ASTM F2924-14	Standard Specification for Additive Manufacturing Titanium-6 Aluminum-4 Vanadium with Powder Bed Fusion
10	ASTM F2971-13	Standard Practice for Reporting Data for Test Specimens Prepared by Additive Manufacturing
11	ASTM F3001-14	Standard Specification for Additive Manufacturing Titanium-6 Aluminium-4 Vanadium ELI (Extra Low Interstitial) with Powder Bed Fusion
12	ASTM F3049-14	Standard Guide for Characterizing Properties of Metal Powders Used for Additive Manufacturing Processes
13	ASTM F3055-14a	Standard Specification for Additive Manufacturing Nickel Alloy (UNS N07718) with Powder Bed Fusion
14	ASTM F3056-14e1	Standard Specification for Additive Manufacturing Nickel Alloy (UNS N06625) with Powder Bed Fusion
15	ASTM F3122-14	Standard Guide for Evaluating Mechanical Properties of Metal Materials Made via Additive Manufacturing Processes
16	ASTM F3184-16	Standard Specification for Additive Manufacturing Stainless Steel Alloy (UNS S31603) with Powder Bed Fusion
17	VDI 3405 (supersedes 3404)	Additive manufacturing processes, rapid prototyping - Basics, definitions, processes
18	VDI 3405 Part 2	Additive manufacturing processes, rapid prototyping - Laser beam melting of metallic parts - Qualification, quality assurance and post processing
19	VDI 3405 Part 2.2 (DRAFT)	Additive manufacturing processes, Laser beam melting of metallic parts, Material data sheet nickel alloy material number 2.4668
20	VDI 3405 Part 2.1:2015-07 and related correction dated 2017-01	Additive manufacturing processes, rapid prototyping - Laser beam melting of metallic parts - Material data sheet aluminium alloy AlSi10Mg
21	VDI 3405 Part 3	Additive manufacturing processes, rapid manufacturing – Design rules for part production using laser sintering and laser beam melting
22	VDI 3405 Part 3.5 (DRAFT)	Additive Manufacturing processes, rapid manufacturing – Design rules for part production using electron beam melting

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Design for Additive Manufacturing
Analysis of seven Case Studies

Component	Target Industry
1. Bionic Wheel Carrier of Electric Vehicle	Automotive / Motorsports
2. Main Gearbox Bracket	Aerospace
3. Calibration Tool for Extrusion Process	Energy
4. Heat Exchanger	Energy
5. Miniature Heat Exchanger / Cooler	not limited to specific industry
6. Functionally integrated Implant	Medical
7. Functionally integrated Tooling Segment	Tooling

Comp. No.	AM technology	Replaced Manuf. Technology	Material	Equipment used
1	LBM	Machining	AlSi10Mg	EOS M 400
2	EBM	Milling	Ti6Al4V	Arcam A2X
3	LBM	Milling and/or investment casting	Stainless Steel 1.4542 = 17-4PH	EOS M 270 Dual Mode
4	LBM	Milling and/or investment casting	Nickel based alloy (~Inconel 718)	EOS M 270 Dual Mode
5	LBM	Stamping, Soldering	AlSi10Mg	Concept Laser M2 Cusing
6	LBM	Casting, Die Forging, Cutting	Ti-6Al-4V	Concept Laser M2 Cusing
7	LBM	Milling, Drilling	1.2709 (AMS6514)	Concept Laser M2 Cusing

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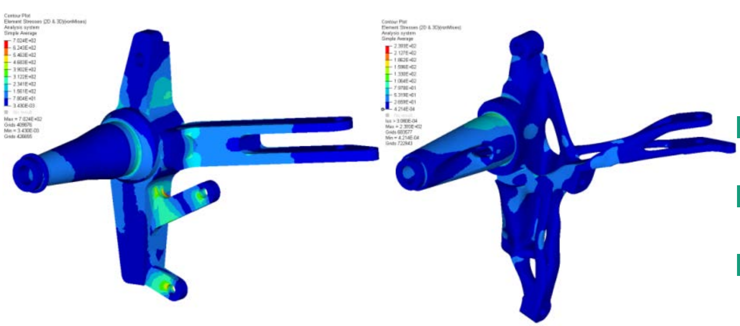
Analysis of seven Case Studies

#1: Bionic Wheel Carrier of Electric Vehicle



Fraunhofer EMI

Case Study Input from:	Fraunhofer EMI	Equipment used:	EOS M 400
AM Technology:	Laser Beam Melting	Equipment Configuration:	OEM Delivery Condition
Replaced Manufacturing Technology:	Machining	Parameter used:	OEM Standard + Customized
Material:	AlSi10Mg	Inert Gas used:	Argon

- Design Objectives:
  - Weight reduction
  - Reduction of parts
- Related Design Features and Benefits
  - Organic shape / topology optimization
  - Achieved weight reduction: ~13%
- Post-processing of functional surfaces: Milling, Drilling
- Requirements for non-functional surfaces: fatigue relevant
- Post-processing of non-functional surfaces: Blasting (peanut shells)
- Post-process heat treatment: N/A

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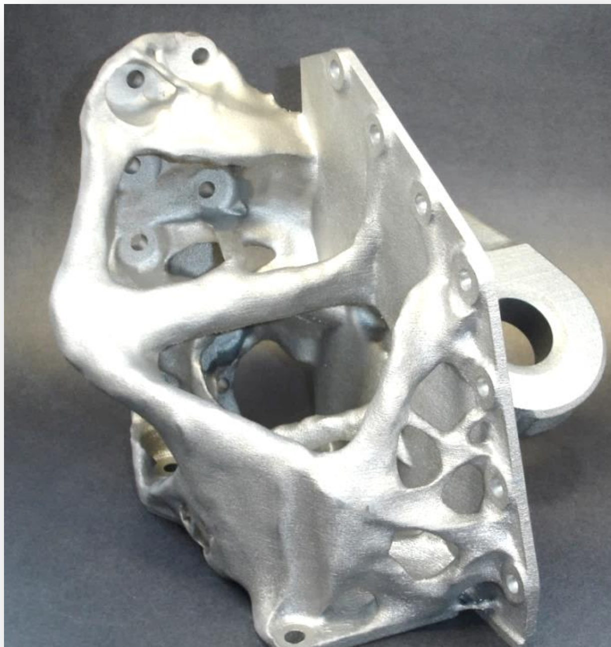
Analysis of seven Case Studies
#2: Main Gearbox Bracket



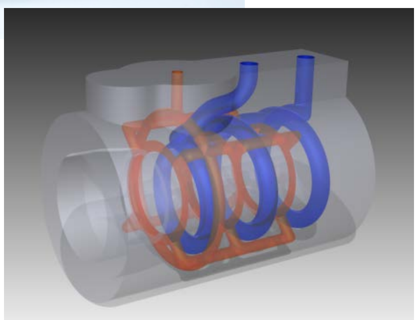
Case Study Input from:	Fraunhofer IFAM DD	Equipment used:	Arcam A2X
AM Technology:	Electron Beam Melting	Equipment Configuration:	OEM Delivery Condition
Replaced Manufacturing Technology:	Milling	Parameter used:	OEM Standard
Material:	Ti-6Al-4V	Inert Gas used:	- (in vacuo)

- Design Objectives:
  - Weight reduction
  - Reduction of parts
- Related Design Features and Benefits
  - Organic shape / topology optimization
  - Achieved weight reduction: ~60%
- Post-processing of functional surfaces: Milling, Drilling
- Requirements for non-functional surfaces: fatigue relevant
- Post-processing of non-functional surfaces: Electro-chemical polishing
- Post-process heat treatment: HIP

Fraunhofer IFAM

Analysis of seven Case Studies

#3: Calibration Tool for Extrusion Process



Case Study Input from:	Fraunhofer IFAM HB	Equipment used:	EOS M 270 Dual Mode
AM Technology:	Laser Beam Melting	Equipment Configuration:	OEM Delivery Condition
Replaced Manufacturing Technology:	Milling, Investment Casting	Parameter used:	OEM Standard
Material:	Stainless Steel 1.4542 = 17-4PH	Inert Gas used:	Nitrogen

- Design Objectives:
  - Integration of functions
  - Size reduction
  - Reduction of parts
- Related Design Features and Benefits
  - Internal channels / cavities
  - Achieved weight reduction: ~50%
- Post-processing of functional surfaces: Milling, Thread cutting
- Requirements for non-functional surfaces: N/A
- Post-processing of non-functional surfaces: Blasting (glass beads)
- Post-process heat treatment: N/A

Fraunhofer IFAM

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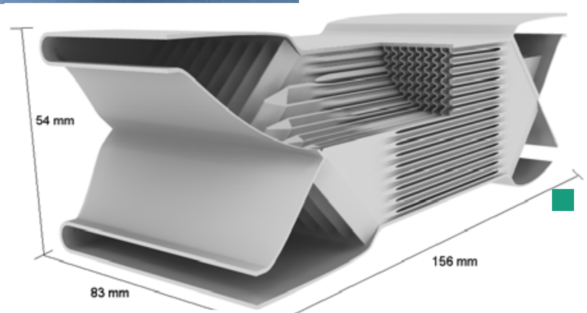
Analysis of seven Case Studies

#4: Heat Exchanger



Fraunhofer IFAM

Case Study Input from:	Fraunhofer IFAM HB	Equipment used:	EOS M 270 Dual Mode
AM Technology:	Laser Beam Melting	Equipment Configuration:	OEM Delivery Condition
Replaced Manufacturing Technology:	Milling, Investment Casting	Parameter used:	Customized
Material:	Nickel based alloy (similar to Inconel 718)	Inert Gas used:	Nitrogen

- Design Objectives:
  - Weight reduction
  - Size reduction
  - Reduction of parts
- Related Design Features and Benefits
  - Internal channels / cavities
  - Achieved weight reduction: ~30%
- Post-processing of functional surfaces: N/A
- Requirements for non-functional surfaces: N/A
- Post-processing of non-functional surfaces: Blasting (glass beads)
- Post-process heat treatment: Stress-relief annealing

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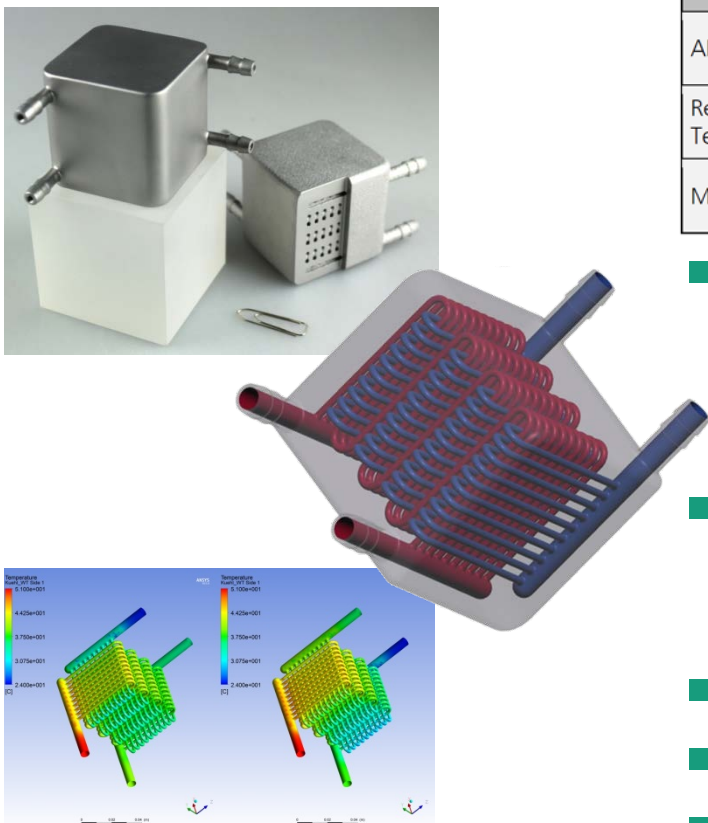
Analysis of seven Case Studies
#5: Miniature Heat Exchanger / Cooler



Case Study Input from:	Fraunhofer IWU	Equipment used:	Concept Laser M2 Cusing
AM Technology:	Laser Beam Melting	Equipment Configuration:	OEM Delivery Condition
Replaced Manufacturing Technology:	Stamping, Soldering	Parameter used:	Customized
Material:	AlSi10Mg	Inert Gas used:	Nitrogen

- Design Objectives:
  - Weight reduction
  - Size reduction
  - Reduction of parts
- Related Design Features and Benefits
  - Internal channels / cavities
  - Achieved weight reduction: >50%
- Post-processing of functional surfaces: Grinding, Polishing
- Requirements for non-functional surfaces: Optical, Aesthetical
- Post-processing of non-functional surfaces: Grinding, Blasting
- Post-process heat treatment: N/A

Fraunhofer IWU

Fraunhofer GENERATIV

Analysis of seven Case Studies

#6: Functionally Integrated Implant – MUGETO®

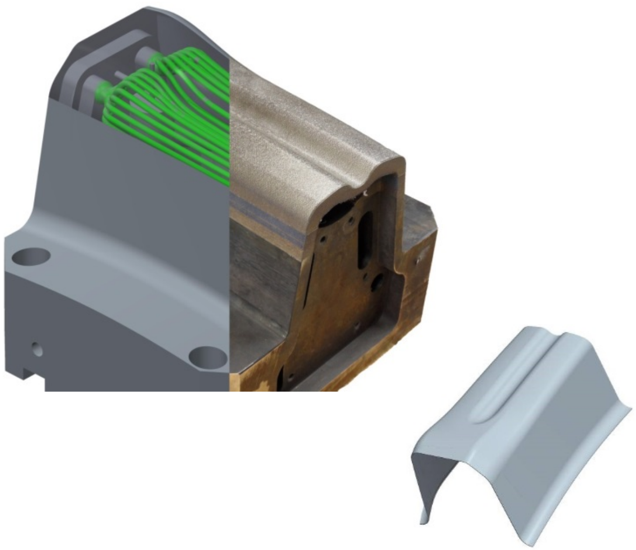
Case Study Input from:	Fraunhofer IWU	Equipment used:	Concept Laser M2 Cusing
AM Technology:	Laser Beam Melting	Equipment Configuration:	OEM Delivery Cond.
Replaced Manufacturing Technology:	Casting, Die Forging, Cutting	Parameter used:	OEM Standard
Material:	Ti-6Al-4V	Inert Gas used:	Argon

- Design Objectives:
  - Integration of functions
- Related Design Features and Benefits
  - Lattice Structures
  - Internal channels / cavities
- Post-processing of functional surfaces: Turning, Milling, Grinding, Polishing
- Requirements for non-functional surfaces: N/A
- Post-processing of non-functional surfaces: Blasting (corundum)
- Post-process heat treatment: Stress-relief annealing

Fraunhofer IWU

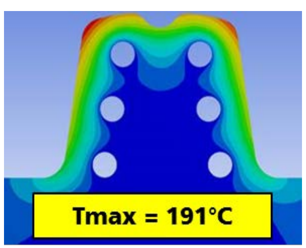
Analysis of seven Case Studies

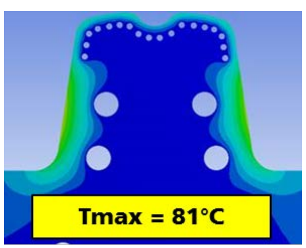
#7: Functionally Integrated Tooling Segments



Case Study Input from:	Fraunhofer IWU	Equipment used:	Concept Laser M2 Cusing
AM Technology:	Laser Beam Melting	Equipment Configuration:	OEM Delivery Cond.
Replaced Manufacturing Technology:	Milling, Drilling	Parameter used:	OEM Standard
Material:	1.2709 (X3NiCoMoTi18-9-5)	Inert Gas used:	Nitrogen

- Design Objectives:
  - Integration of functions
- Related Design Features and Benefits
  - Internal channels / cavities
- Post-processing of functional surfaces: Machining
- Requirements for non-functional surfaces: N/A
- Post-processing of non-functional surfaces: Blasting (corundum)
- Post-process heat treatment: Stress-relief annealing + hardening





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Analysis of seven Case Studies
Summary

	Bionic Wheel Carrier	Main Gearbox Bracket	Calibration Tool	Heat Exchanger	Miniature Heat Exchanger	Functionally Integrated Implant	Functionally Integrated Tooling Segment
Design Objectives							
Integration of functions	-	-	x	-	-	x	x
Weight reduction	x	x	-	x	x	-	-
Size reduction	-	-	x	x	x	-	-
Reduction of parts	x	x	x	x	x	-	-
Related Design Features and Benefits							
Organic shape / topology optimization	x	x	-	-	-	-	-
Lattice structures	-	-	-	-	-	x	-
Internal channels / cavities	-	-	x	x	x	x	x
Achieved weight reduction	~13%	~60%	~50%	~30%	>50%	-	-
Component- and AM-specific Requirements							
Minimum allowable size of geometrical features / driven by …	2 mm / process and mat.	3 mm / strength requirem.	3 mm / powder removal	0.5 mm / process and mat.	1.5 mm / performance	0.3 mm / process and mat.	2 mm / process and mat.
Maximum allowable size of geometrical features / driven by …	-	-	8 mm / no need for support	3 mm / applic.	8 mm / no need for support	-	8 mm / no need for support
Post-processing of functional surfaces	Milling, Drilling	Milling, Drilling	Milling, Thread cutting	-	Grinding, Polishing	Turning, Milling, Grinding, Polishing	Machining
Requirements (finish) for non-functional surfaces	fatigue relevant	fatigue relevant	-	-	optical / aesthetic	-	-
Post-Processing of non-functional surf.	Blasting (peanut shells)	Electro-chemical polishing	Blasting (glass beads)	Blasting (glass beads)	Grinding, Blasting (corundum)	Blasting (corundum)	Blasting (corundum)
Need for drawings	-	Post-Process	AM and Post-Process	AM and Post-Process	-	Post-Process	-
Post-process heat treatment	-	HIP	-	stress-relief annealing	-	stress-relief annealing	stress-relief annealing + hardening

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Design for Additive Manufacturing
References (1/2)

[1] Adam, Guido A. O.: *Systematische Erarbeitung von Konstruktionsregeln für die additiven Fertigungsverfahren Lasersintern, Laserschmelzen und Fused Deposition Modeling*. Aachen : Shaker, 2015 (Forschungsberichte des Direct Manufacturing Research Centers 1)

[2] Gebauer, Mathias ; Müller, Bernhard ; Spierings, Adriaan ; al, et: High performance sheet metal forming tooling by additive manufacturing. In: Drstvenšek, Igor; Drummer, Dietmar; Schmidt, Michael (Hrsg.): *6th International Conference on Additive Technologies - iCAT 2016* : *Proceedings : Nürnberg, Germany, 29.-30. November 2016 : DAAAM Specialized Conference*. Ljubljana : Interesansa - zavod, 2016, S. 354–361

[3] Schwarze, Dieter: *Auswirkungen der Bauraumvorheizung auf die thermomechanischen Bauteileigenschaften*. Augsburg, 09.07.2010 (Abschlussveranstaltung SimuSint)

[4] Over, Christoph: *Generative Fertigung von Bauteilen aus Werkzeugstahl X38CrMoV5-1 und Titan TiAl6V4 mit "Selective Laser Melting"*. Aachen : Shaker, 2003

[5] VDI-Guideline 3405 Part 3. December 2015. *Additive Manufacturing Processes, Rapid Manufacturing - Design Rules for Part Production using Laser Sintering and Laser Beam Melting*

[6] Kahnert, Markus: *Scanstrategien zur verbesserten Prozessführung beim Elektronenstrahlschmelzen (EBM)*. München, Technische Universität München. Dissertation. 2014

[7] Klöden, Burghardt ; Kirchner Alexander ; Vock, Silvia ; Weißgärber, Thomas ; Kieback, Bernd: *Additive Manufacturing by Electron Beam Melting (EBM)* (Expertenkreis Additive Manufacturing, 2. Treffen). Dresden, 08.12.2015

[8] Ruffo, Massimiliano: Metal Rapid Manufacturing: Laser vs Electron Beam technology : TCT2008 conference, Bd. 2008. In: *TCT2008 conference*.

[9] Fraunhofer-Institut für Fertigungstechnik und Angewandte Materialforschung IFAM: *Pulvermetallurgische Verfahren für die generative Fertigung*. Dresden

[10] Spierings, Adriaan: *Stand der Technik und Eigenschaften typischer SLM-Materialien*. St. Gallen, Schweiz, 15.04.2010 ([MEET THE EXPERT] Rapid Prototyping & Rapid Manufacturing in der Medizintechnik)

[11] Niendorf, Thomas ; Brenne, Florian ; Schaper, Mirko: *Lattice Structures Manufactured by SLM: On the Effect of Geometrical Dimensions on Microstructure Evolution During Processing*. In: *Metallurgical and Materials Transactions B* 45 (2014), Nr. 4, S. 1181–1185

[12] Reinarz, Bernd ; Sehrt, Jan T. ; Witt, Gerd ; Deiss, Olga ; van Kampen, Jaap ; Münzer, Jan ; Ott, Michael: *Optimization of media feed channels in laser beam melting*. In: *Proceedings ASPE 2014 Spring Topical Meeting* 57 (2014), S. 13–18.
URL http://aspe.net/publications/Spring_2014/2014%20ASPE%20SPRING%20proceedings-PRINT%20FINAL.pdf – last checked; 2017-03-29

[13] Süß, M. ; Schöne, Chr. ; Stelzer, R. ; Klöden, B. ; Kirchner, A. ; Weißgärber, Th. ; Kieback, B.: Aerospace Case Study on Topology Optimization for Additive Manufacturing. In: Fraunhofer Generativ (Hrsg.): *DDMC - Direct Digital Manufacturing Conference 2016*, 2016

Design for Additive Manufacturing
References (2/2)

[14] Antonysamy, A. A.: *Microstructure, Texture and Mechanical Property Evolution during Additive Manufacturing of Ti6Al4V Alloy for Aerospace Applications*. Manchester, University of Manchester, Faculty of Engineering and Physical Sciences. Dissertation. 2012

[15] Mahale, T. ; Cormier, D. ; Harryson, O. ; Ervin, K.: Advances in Electron Beam Melting of Aluminium Alloys. In: *18th Solid Freeform Fabrication Symposium, SFF 2007, 2007*, S. 312–323

[16] Ohldin, Patrik: *Implant Manufacturers use Additive Manufacturing to Reduce Production Costs and Differentiate Products* (Rapid.Tech 2011). Erfurt, 24.05.2011

[17] Kovács, George L. (Hrsg.); Kochan, Detlef (Hrsg.): *Digital Product and Process Development Systems* : *IFIP TC 5 International Conference, NEW PROLAMAT 2013, Dresden, Germany, October 10-11, 2013. Proceedings*. Berlin Heidelberg : Springer Berlin Heidelberg, 2013 (IFIP Advances in Information and Communication Technology 411)

[18] Müller, B. ; Hund, R. ; Malek, R.: Added Value in Tooling for Sheet Metal Forming through Additive Manufacturing. In: N.N. (Hrsg.): *Green Manufacturing for a Blue Planet*. Stellenbosch, 2013, S. 51–57

[19] Zäh, Michael ; Hagemann, Florian: *Wirtschaftliche Fertigung mit Rapid-Technologien* : *Anwender-Leitfaden zur Auswahl geeigneter Verfahren*. München : Hanser, 2006 (Kostengünstig produzieren)

[20] Meiners, Wilhelm ; Hinke, Christian ; Schrage, Johannes ; Bremen, Sebastian ; Merkt, Simon ; Poprawe, Reinhart: Selective Laser Melting on the way to production: Recent research topics at Fraunhofer ILT. In: N.N. (Hrsg.): *Metal Additiv Manufacturing Conference*, 2014

[21] Brackett, D. ; Ashcroft, I. ; Hague, R.: *Topology optimization for additive manufacturing*. Leicestershire, UK, Wolfson School of Mechanical and Manufacturing Engineering, Loughborough University, Research Center for Advanced Manufacturing. August/2011

[22] Beckmann, F.: *Neue Ansätze durch hybride Bauteilgestaltung - flexible Großstrukturen profitabel gestalten* (3. Internationale Fachkonferenz - 3D-Druck - Additive Fertigung in der Automobilindustrie). Bremen, 05.04.2017

→ Complete Study available at:
http://canadamakes.ca/design-additive-manufacturing-guidelines-case-studies-metal/

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WORKSHOP @ AM 4 AEROSPACE & SPACE

FRAUNHOFER ADDITIVE MANUFACTURING ALLIANCE

9:00	**Opening and Welcome** (Mueller)
9:10	**Introduction to Fraunhofer and AM Alliance** (Mueller)
10:20	**Design for Additive Manufacturing – Guidelines and Case Studies for Metal Applications** (Mueller, Kloeden)
10:50	**Powder for PBF AM – how to assess it & recent developments in analysis** (Aumund-Kopp, Kloeden)
11:20	**Additive Manufacturing for Space Applications – Challenges and Chances for Surface Technology** (Dietz)
11:50	**Q&A Session** (all speakers with auditorium)
12:15	**End of Workshop**
12:30	Bus transfer to EOS

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Powder for Additive Manufacturing

- Dr. Burghardt Klöden, Claus Aumund-Kopp
- Fraunhofer Additive Manufacturing Alliance (Fraunhofer IFAM)

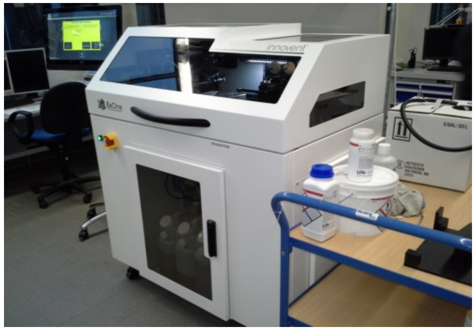
Fraunhofer GENERATIV

Outline

- Introduction
  - AM @ IFAM
  - Relevance of Powder
- Powder Production – Powders during AM proscessing
- Assessment of Powder Quality
- Powder-related case studies
  - LBM
  - EBM

AM @ IFAM

- Laser beam Melting (LBM) [HB]
- Electron Beam Melting (EBM) [DD]
- 3D Screen Printing (3DMP) [DD]



- Fused Filament Fabrication (FFF) [DD, HB]
- 3D Binder Jetting (3DP) [HB]
- Powder Bed Metal Printing - Layer Quality Testing) [DD, HB]

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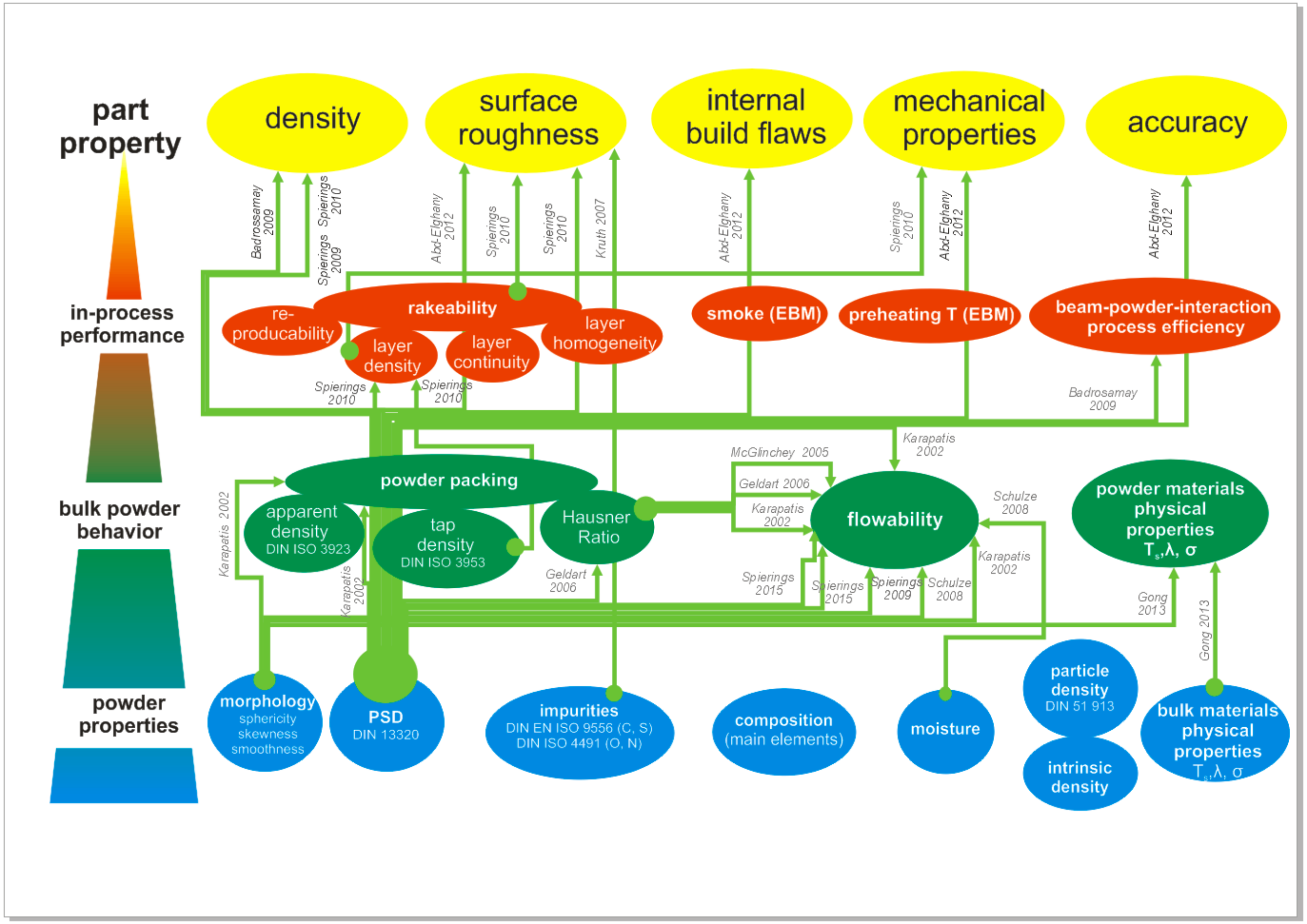
Introduction
Relevance of Powder for AM



Vock et al., to be published

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Powder production

Different Sources – different AM Processes

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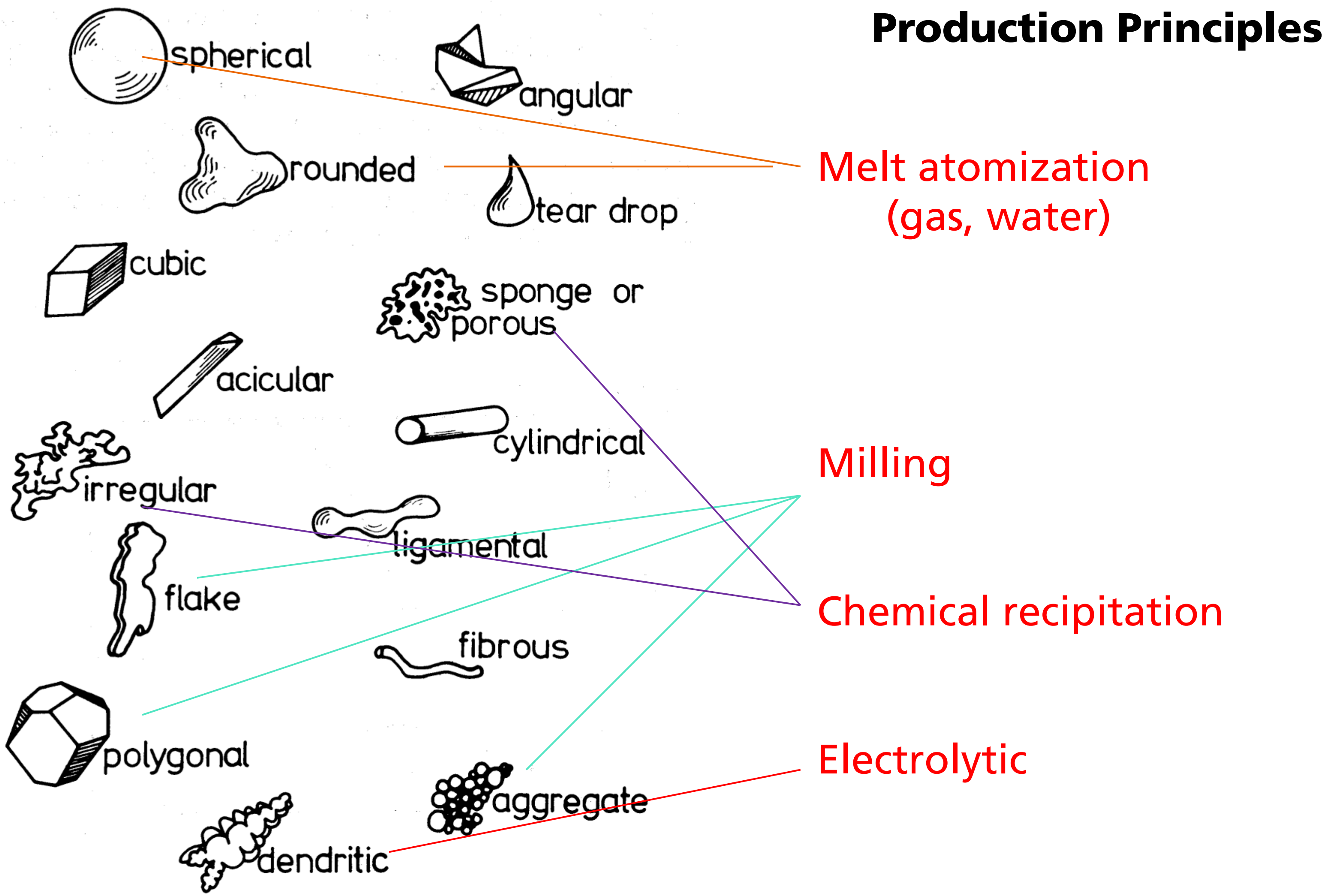
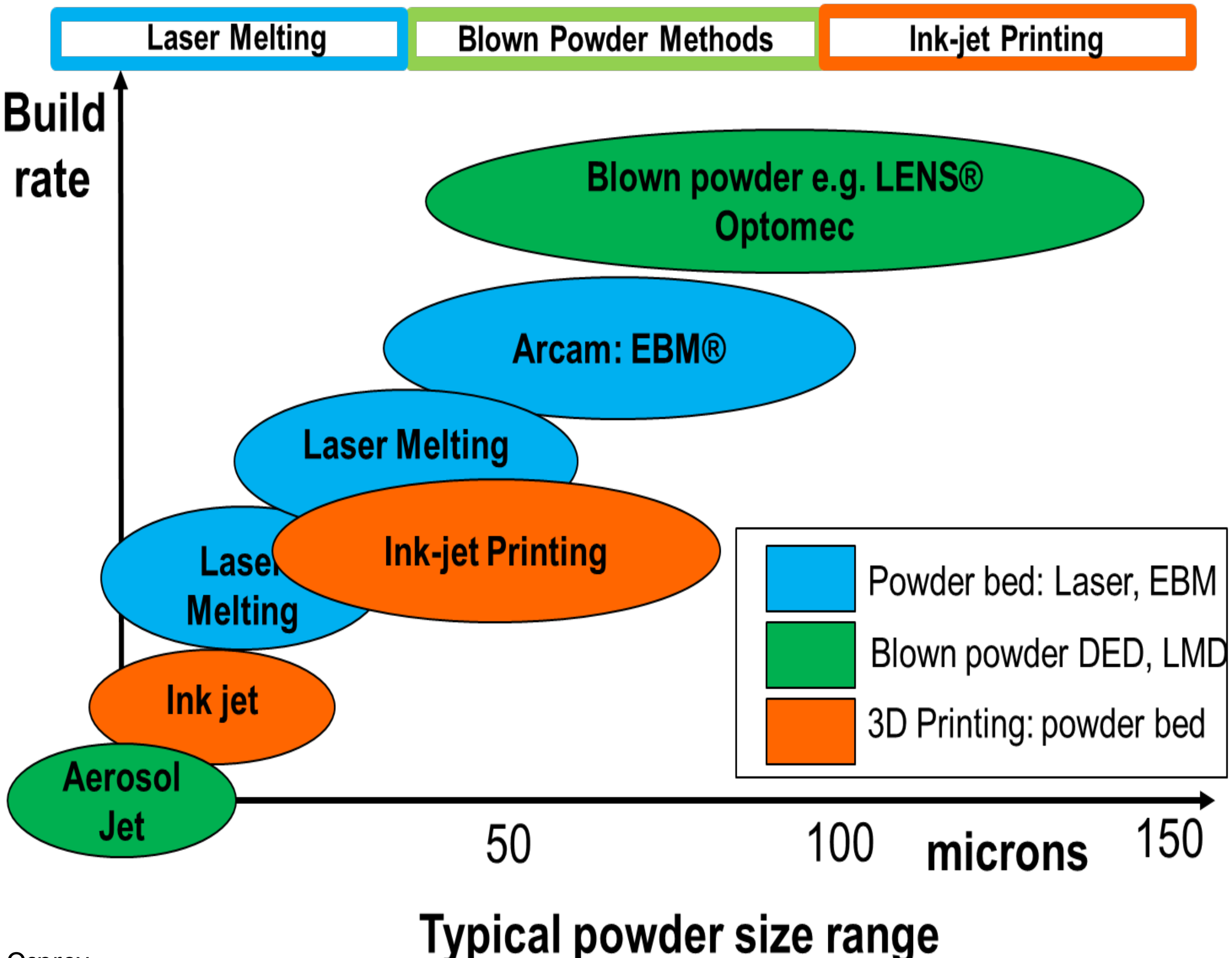
Powder morpholgies



Application – Particle size spectrum



Source: Sandvik-Osprey

Assessment of powder quality

Standard Methods

Property	Norm	Relevance
Particle Size Distribution	DIN 13320	Flowability (feeding & raking)
Hall Flow (time)	DIN ISO 4490	Flowability (feeding & raking) Layer Homogeneity
Morphology (SEM)		Flowability (feeding & raking)
Apparent Density	DIN ISO 3923/DIN ISO 3953	Layer Homogeneity
Composition (impurities)	DIN EN ISO 9556 (C, S) DIN ISO 4491 (O, N)	Contamination before & during process, part quality & properties
Composition (main elements)		Part quality & properties
density	DIN 51 913	Part quality (internal build flaws)

Assessment of powder quality

Sample drawing and sample preparation

- Sample divider (by Fritsch)

- Sample drawing with sampling lances

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Assessment of powder quality

Moisture Determination

(in accordance with DIN 51006)

- Thermo gravimetric approach
  - Powder weighed in
  - Heat up
  - Powder weighed back

Moisture Analyser (SARTORIUS)

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Non-Standard Methods – Optical Particle Measurement (I)

- Optical Particle Measurement
  (by Retsch - Camsizer XT)

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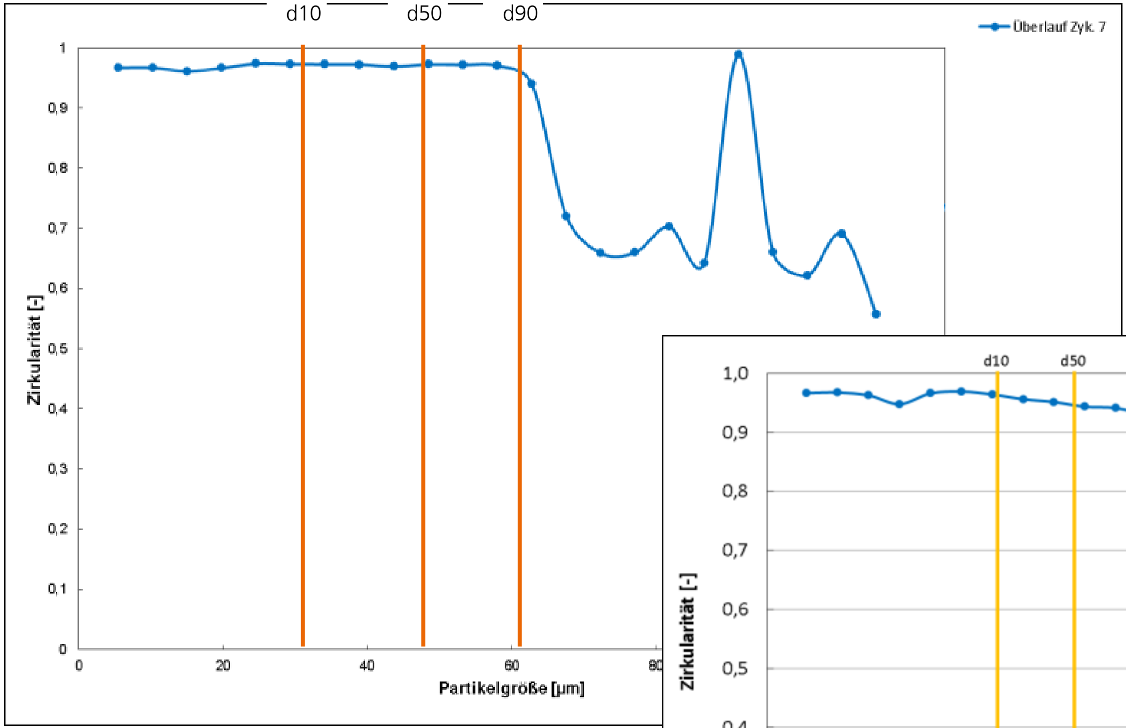
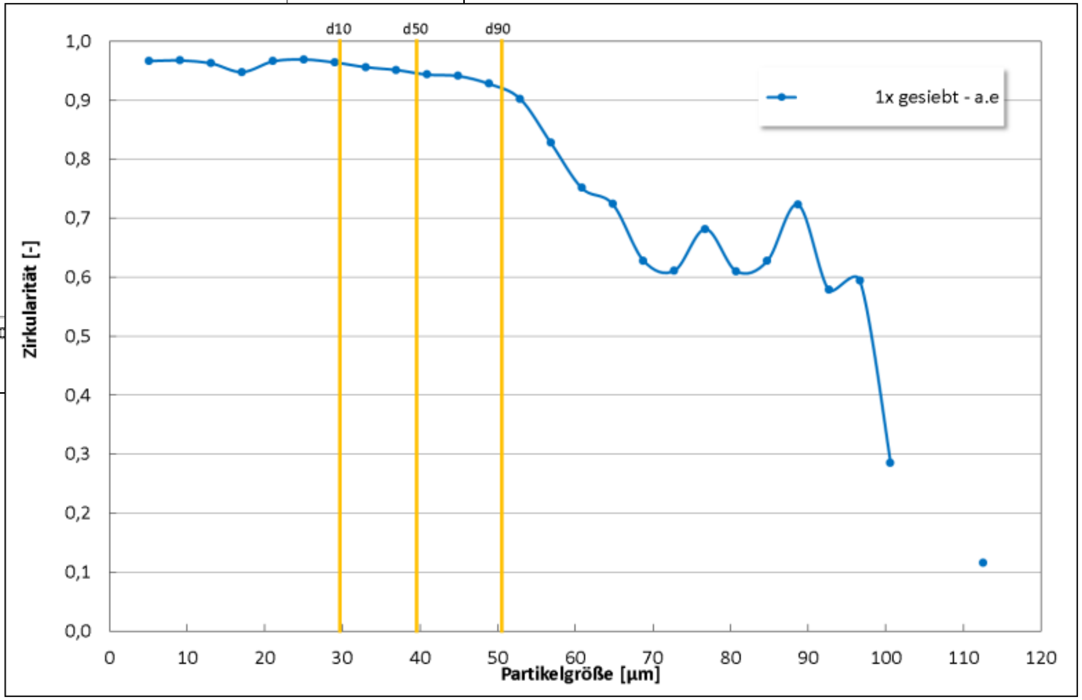
Assessment of powder quality

Non-Standard Methods – Optical Particle Measurement (II)





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Assessment of powder quality

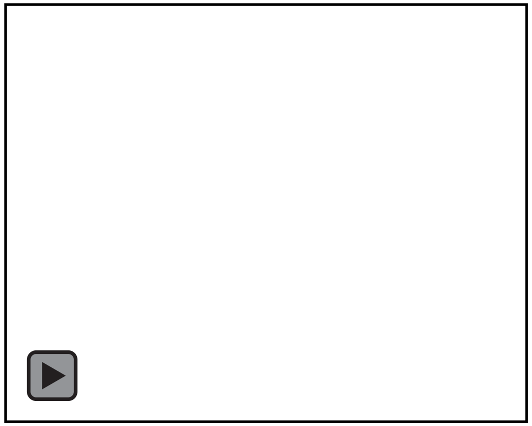
Non-Standard Methods – Rheometer

- **Different scenarios**:
  - during downwards movement → forced flow in confined volume

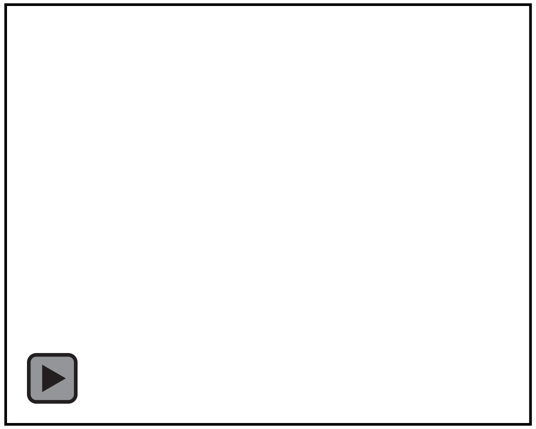
    BFE (basic flow energy, mJ)
  - During upwards movement → forced flow in free volume

    SE (specific energy, mJ/g)

- **further parameters** can be assessed from the above scenarios, e.g.:
  - *Flow Rate Index* (FRI)
  - *Aeration (cohesivity, segregation, …)*



source: https://www.youtube.com/watch?v=QgdMgJsHpGk&list=PLRSJ8livbAAu4NZly7l3gtB2KWsB3df1D&index=5



source: https://www.youtube.com/watch?v=zyKheUGGmU4&list=PLRSJ8livbAAu4NZly7l3gtB2KWsB3df1D&index=6

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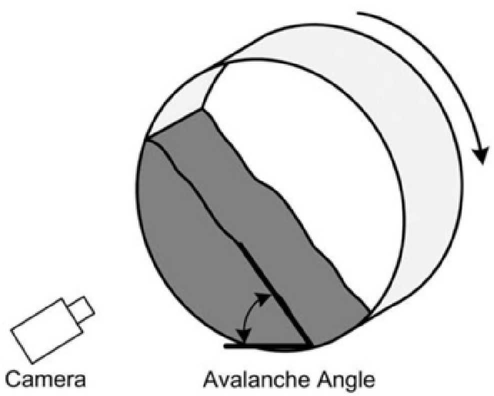
Assessment of powder quality

Non-Standard Methods – RPA (I)

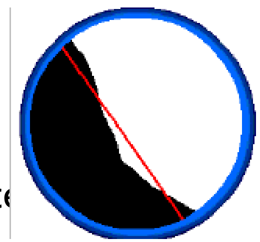
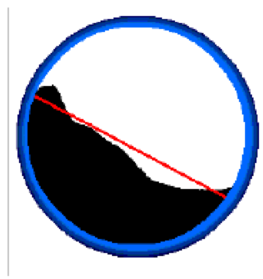
- Dynamic avalanche measurement
- Transparent rotating drum, partially filled with powder
- Camera behind drum recordes powder movement
- Different parameters can be measured from the camera images



Source: https://www.youtube.com/watch?v=DlhgPMEjNV8

Assessment of powder quality

Non-Standard Methods – RPA (II)

- avalanche energy (kJ/kg) – potential energy of powder
- avalanche duration (s)
- avalanche angle (°), rest angle (°) → difference between both angles
- surfac  ghnes  ce

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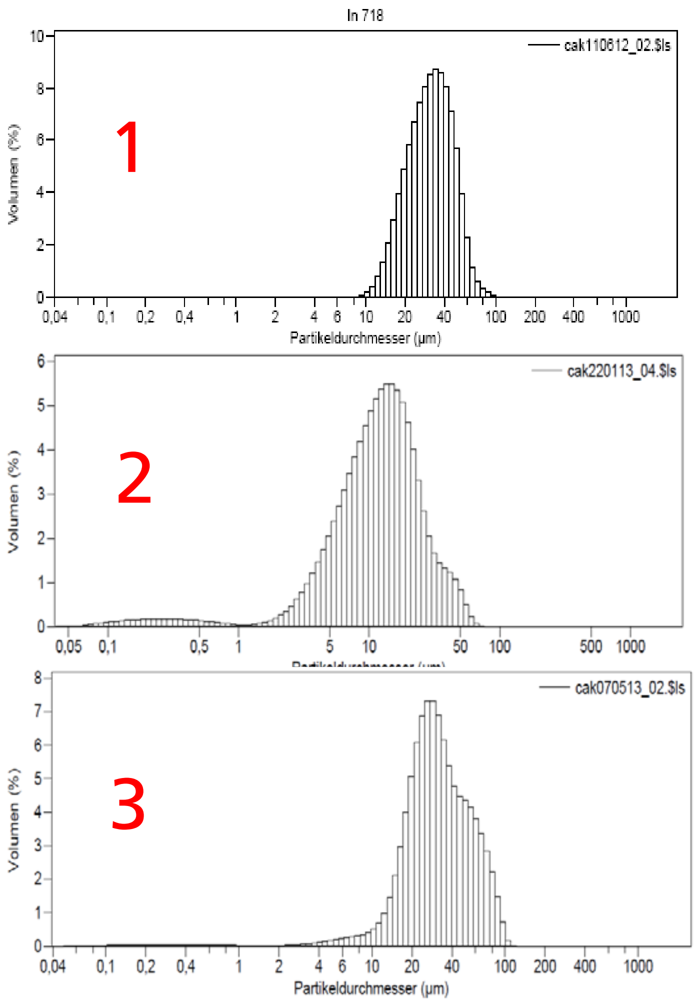
Case Studies

Powders during AM processing- Importance of powder consistency



	1	2	3
D10 [µm]	17,9	4,2	15,6
D50 [µm]	31,6	12,3	29,7
D90 [µm]	51,0	28,6	63,7
Ø Angle of repose [°]	59	68	55
Ø bulk density [g/cm³]	4,23	4,42	4,54
Ø Tap Density [g/cm³]	4,74	5,15	5,12

With powder 2 it is not possible to spread out smooth and even powder layers
due to agglomeration of fine particles

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Case Studies

Powder Flowability (I)

Powder A

Powder B

Powder C

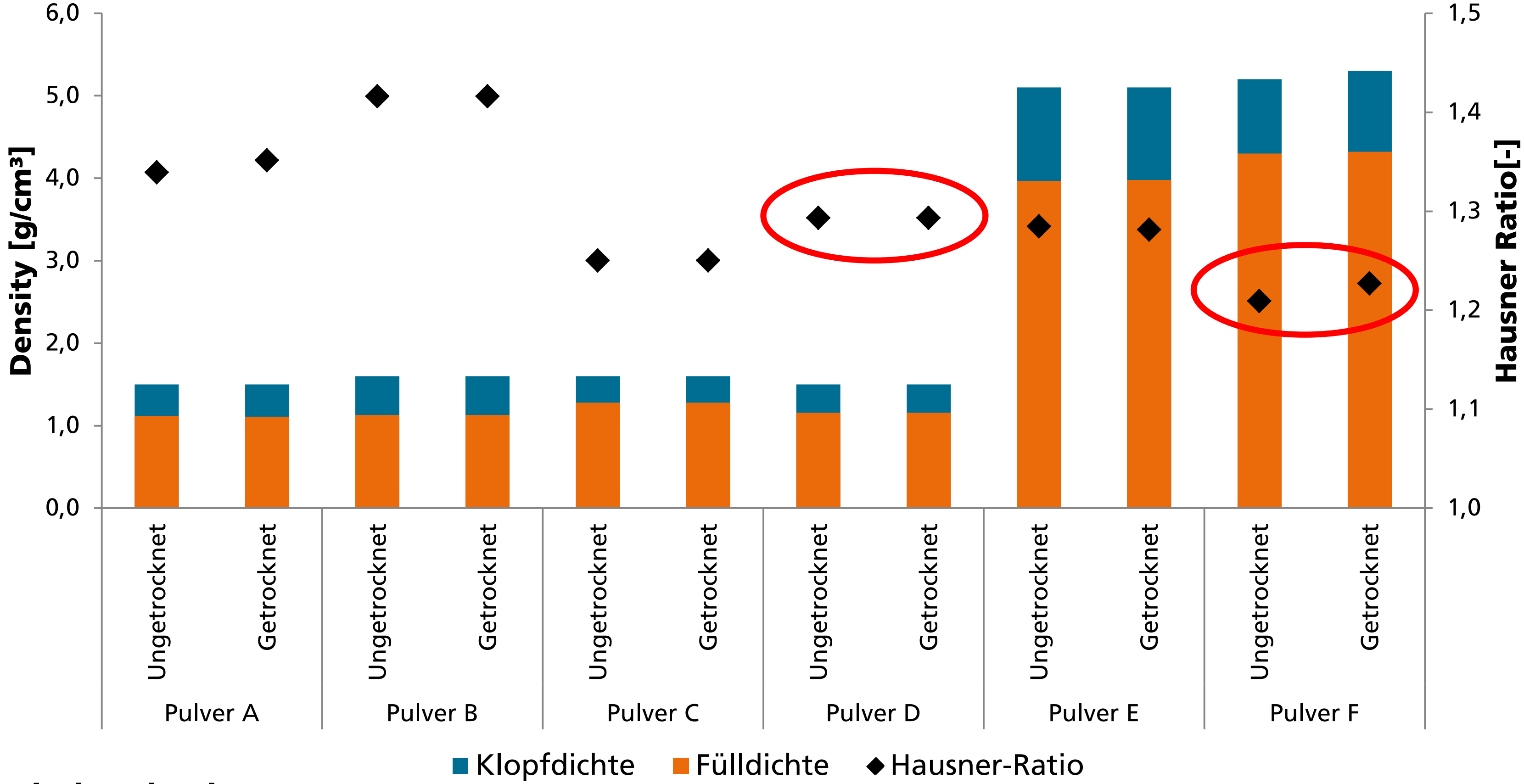
Powder D

Powder E

Powder F

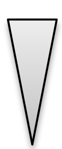
Case Studies

Flowability: Tap density vs. Bulk density = Hausner Ratio



Optical evaluation:

- Powder D ≈ Powder F
- Powder C ≈ Powder E
- Powder A ≈ Powder B



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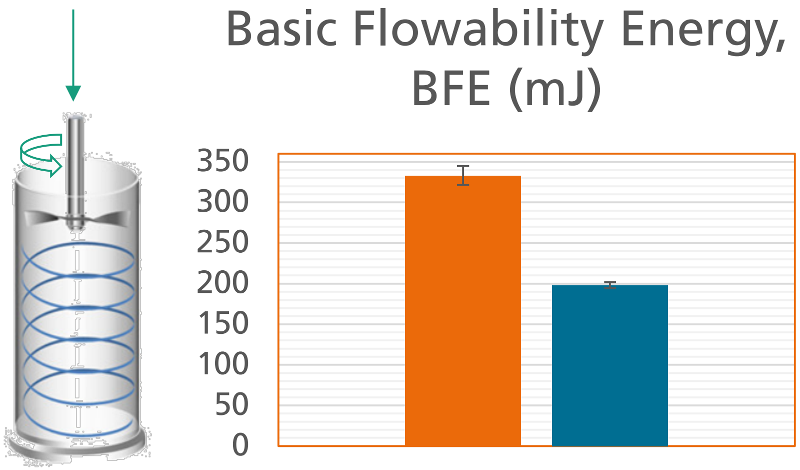
EBM - Standard Methods (I)

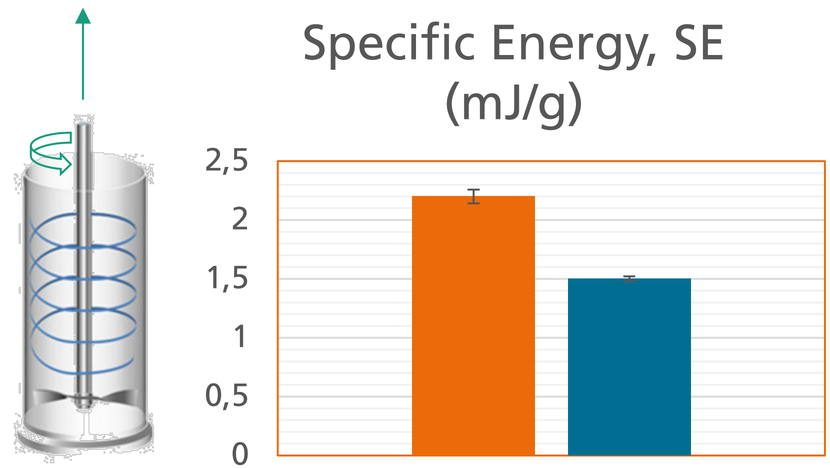
- problems with EBM processing of non-standard-powder (TiAl): smoke events occurred repeatedly
- flowability was identified as being not sufficient – powder got stuck on the rake, non-uniform powder layers can lead to smoke
- idea: adding a fraction of larger particles to the powder (wider PSD) → this improved flowability noticeably and processing became possible
- Packing density increased

	Batch 1 (45 – 120 µm)	Batch 2 (45 – 150 µm)
Hall Flow Test	28±2 s	22.5±0.2 s
Apparent Density	2.18 g/cm³	2.23 g/cm³

Case Studies

EBM - Non-Standard Methods (rheometer)





Pulver	BFE	SE	Processability
TiAl-Pulver 45-125 µm	high	high	Not qualified
TiAl-Pulver 45-150 µm	low	low	applicable

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Case Studies

EBM - Non-Standard Methods (RPA)

- two fractions of TiAl – powder: 45-150 µm (not qualified) and 45-125 µm (applicable)
- Basic test procedure with RPA

Sample ID	Rotation Rate	Avalanche Energy	Energy Std Dev	Avalanche Time	Avalanche Angle	Rest Angle	Surface Fractal
TLS-TiAl-45-150	0.5 rpm	9.69 kJ/kg	5.30 kJ/kg	2.0 sec	31.0 deg	26.6 deg	2.28
TLS-TiAl-45-150	0.5 rpm	9.78 kJ/kg	5.00 kJ/kg	2.0 sec	31.4 deg	27.0 deg	2.37
TLS-TiAl-45-150	0.5 rpm	10.15 kJ/kg	4.90 kJ/kg	2.1 sec	31.4 deg	26.9 deg	2.36
TLS-TiAl-45-125	0.5 rpm	12.78 kJ/kg	6.20 kJ/kg	2.4 sec	31.5 deg	25.5 deg	2.14
TLS-TiAl-45-125	0.5 rpm	12.80 kJ/kg	6.00 kJ/kg	2.4 sec	31.8 deg	25.7 deg	2.27
TLS-TiAl-45-125	0.5 rpm	12.99 kJ/kg	5.80 kJ/kg	2.4 sec	31.8 deg	25.6 deg	2.28

- some of the parameters show principal feasibility to differentiate different levels of processability
- but: more testing & powders needed for more reliable conclusions

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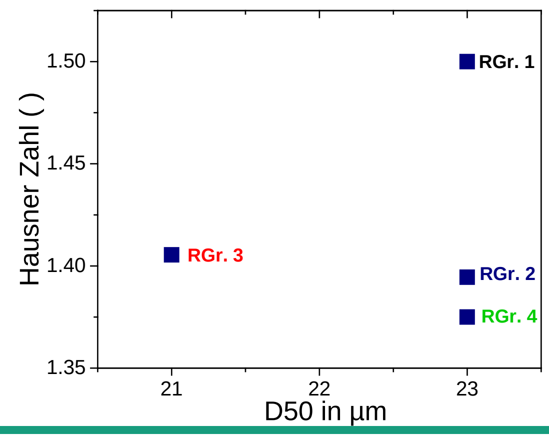
Case Studies

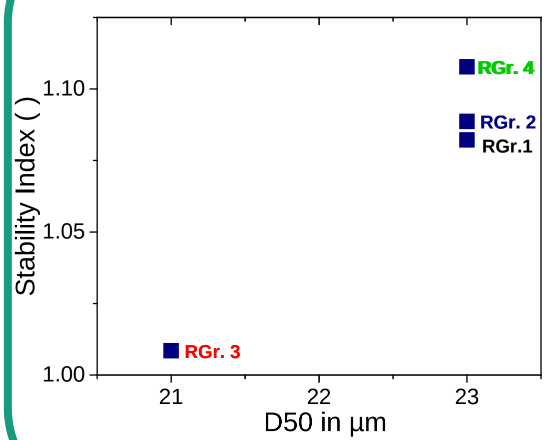
LBM – standard powder (Al)

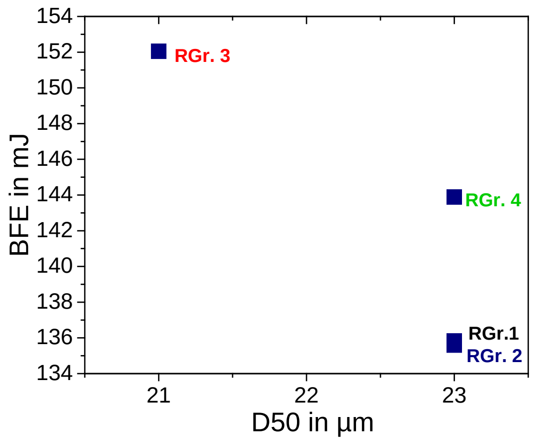
Standard analysis

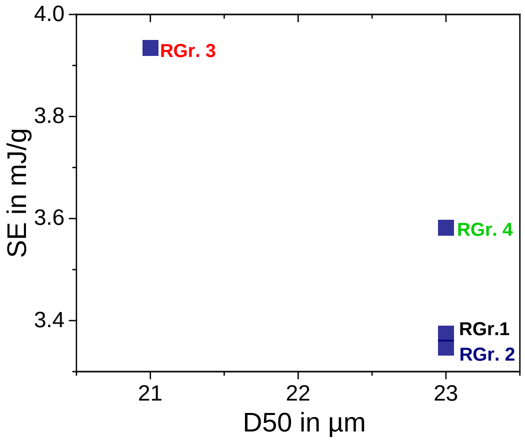
- apparent density
- tap density



Rheometer







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Outlook

Future questions (I) - specific

- how is powder flowability and spreadability (layer quality) influenced by:
  - Particle size distribution?
  - Particle morphology?
  - Humidity content?
- … how is powder degradation influenced by:
  - AM machine venting system set-up?
  - Size of built volume?
  - No. of build-jobs and sieving/screening/classification steps?

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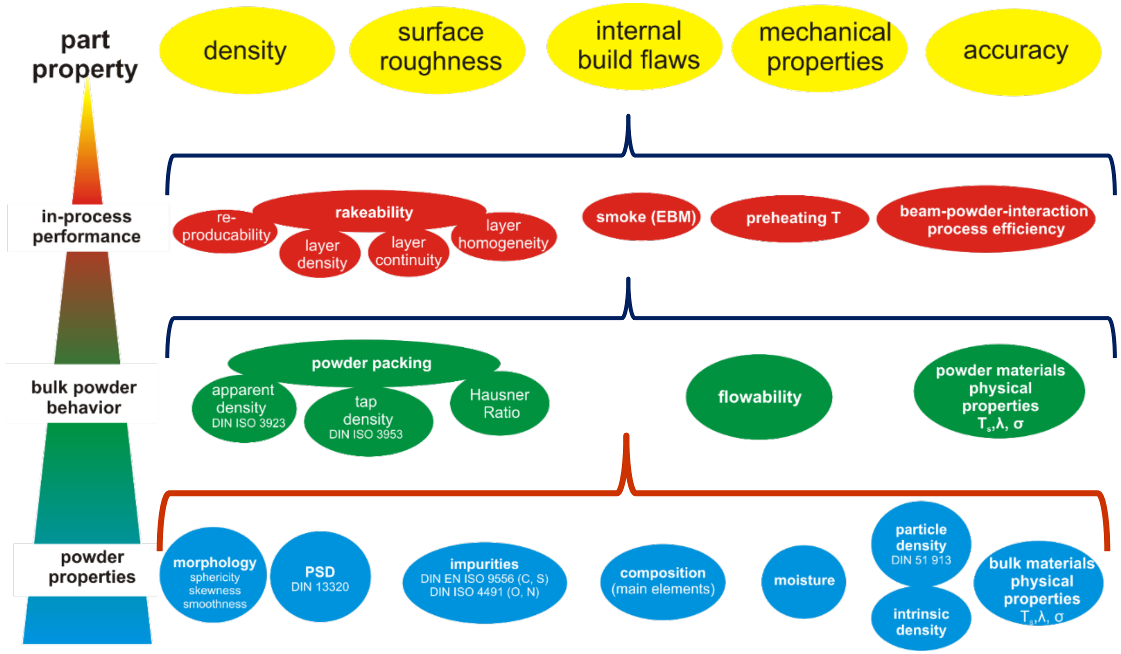
Outlook

Future questions (II) - broad



1. Which flow properties are most sensitive to changes in powder quality? → **Correlation**

2. How are process parameters and part properties determined by powder properties? → **Prediction**

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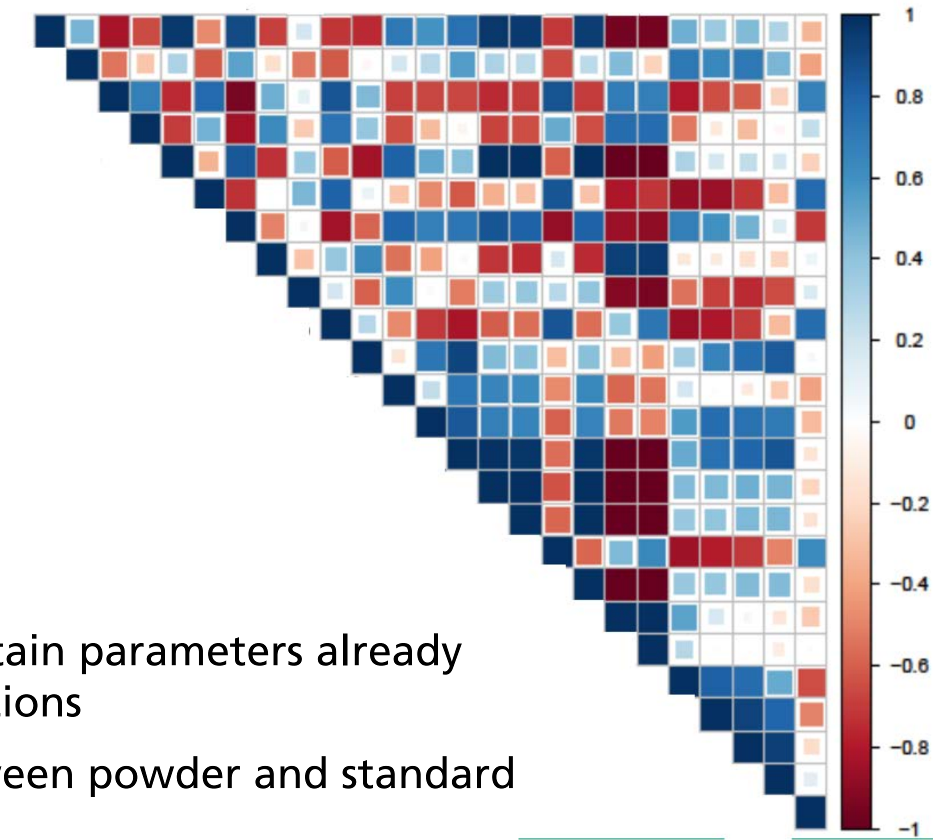
The bigger picture (correlation)

- **analysis of correlation for different powder families**:
  - Al (LBM)
  - Steel (LBM & EBM)
- **Correlation parameters**:
  - Powder properties
  - Standard analysis
  - Rheometer



- **Correlation results:**
  - strong correlation of certain parameters already observable in both directions
  - known correlations between powder and standard analysis confirmed
  - new strong correlations between powder and rheometer detected

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Our offers on AM @ Fraunhofer IFAM

- Development of material and processing parameters
- Testing and qualification of AM powder materials
- Optimization of processing parameters
- Consulting on system selection, material selection and part design
- Benchmark studies
- Pilot-scale production
- Planning of production lines
- Support during start-up phase
- AM Training and Consultancy

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Additive Manufacturing for Space Applications – Challenges and Chances for Surface Technology

- 19. February 2018

A. Dietz, Fraunhofer IST
Egbert van der Veen, OHB System AG
Bernd Rauch, Rauch CNC Manufactur GmbH
Reinhard Schlitt, Engineering Services

Polymer part via FDM, copper plated with PVD
Source: Fraunhofer IST 2017

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Outline

- Surface Treatment of AM Parts
    - Metals
    - Polymers
- Benefits of Coatings on AM Parts
- Coating Processes
- Challenges of Plastic Metallization
- Some Results
- Conclusions

God made the bulk; surfaces were invented by the devil

W. Pauli, Nobel Prize winner 1945

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Do we need coatings on Polymers?
Metallic coatings

- Undefined surface
- Tribological aspects
  - Increased wear resistance
  - Low friction coefficient demanded
  - No lubricants allowed
- Optical aspects
  - Very glossy surface (mirror quality, heat reflection, light reflection)
  - Rough surface (light absorption)
- Electrical and thermal aspects
  - Permanent electrical grounding for non-conductive parts
  - Flash protection
  - Heat dissipation (polymers)
- Missing mechanical stiffness
- Avoid the outgassing in vacuum
- …..

Most common Coating Processes

- Varnishes
  - Benefits
    - Homogeneous distribution of layer thickness on parts with complex geometries (liquid paints)
  - Drawbacks
    - Danger of outgassing
    - Thermal and mechanical unstable
    - Electrically non conductive
- PVD-Coatings
  - Benefits
    - Wide range of coating and substrate materials
  - Drawbacks
    - Not for complex geometries
    - Expensive (Vacuum process)
    - Sometimes problems with adhesion

FDM-Part; metal coated via PVD
Source : Fraunhofer IST 2017

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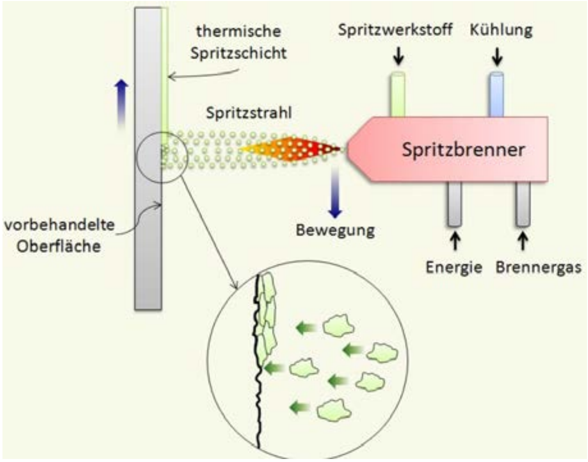
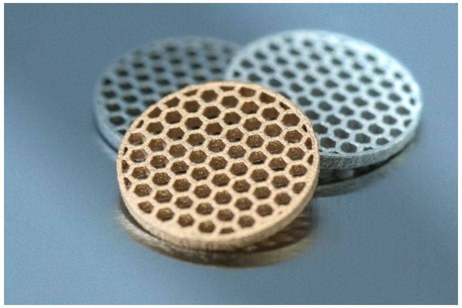
Most common Coating Processes

- Thermal Spraying
  - Benefits
    - Simple process
    - Wide range of coating materials
    - Thick layers possible (> 100 µm)
  - Drawbacks
    - Only for simple geometries
- Electroplating
  - Benefits
    - Suitable for complex structures (electroless processes)
    - Wide range of layer thicknesses
  - Drawbacks
    - Only for metal deposition
    - Complex process for the deposition on light metals (passivation)



Source :https://de.wikipedia.org/wiki/Thermisches_Spritzen



Metallic components, produced via SLS, coated with gold, platinum, silver
Source: Fraunhofer IST 2016

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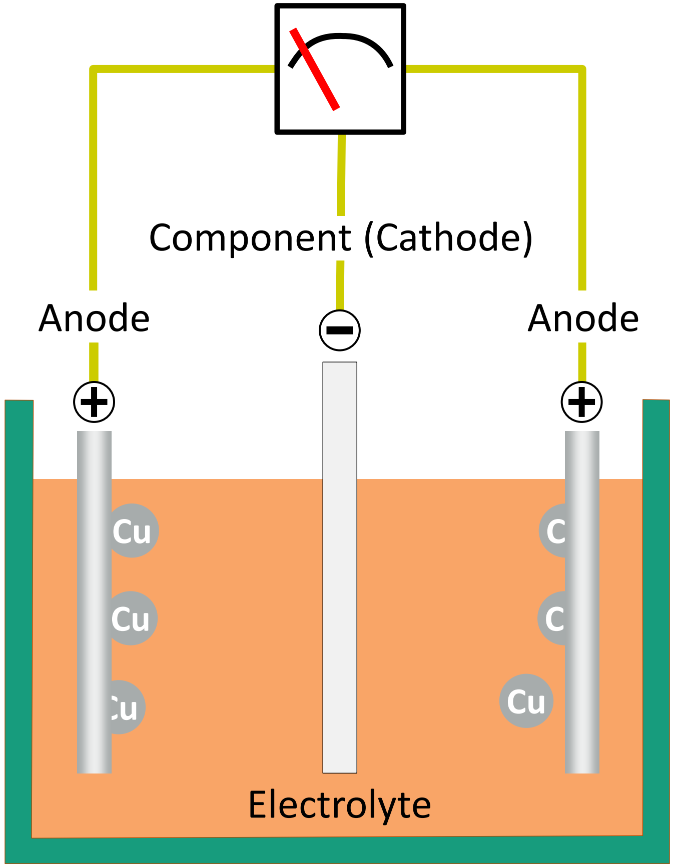
Fundamentals of Electroplating

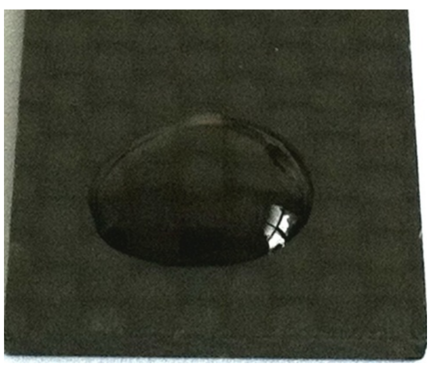
Quelle: ZVO Zentralverband Oberflächentechnik e.V.



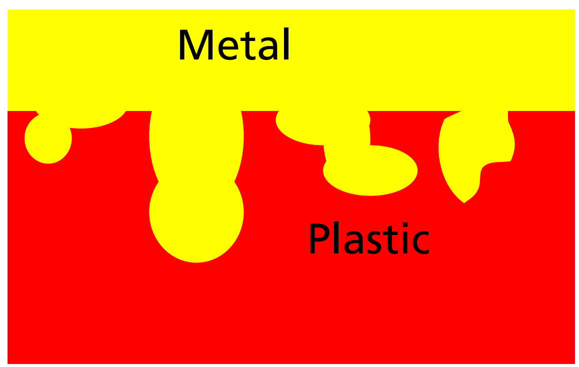
Galvanic Metallization of polymer devices

Metal deposition on plastics

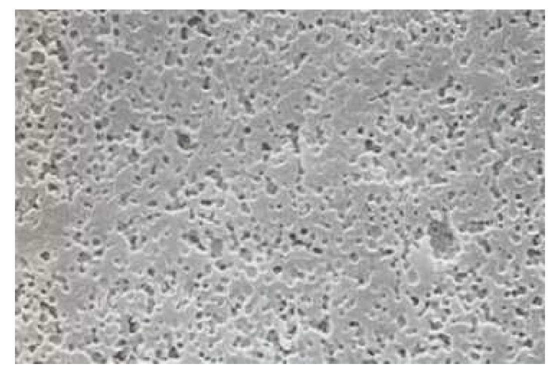
- Challenges of the plastic metallization
  - Hydrophobic surface – no wetting
  - Electrically insulating surface – no direct metallization
  - Different atomistic properties between plastic substrate and metallic coating → bad adhesion
  - Different CTE can cause delamination



Non-wetted polymer surface



Schematic push button effect



SEM: Etched plastic surface

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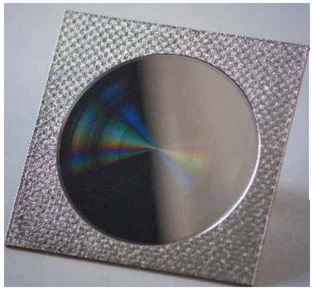
Surface Technology of metallic parts

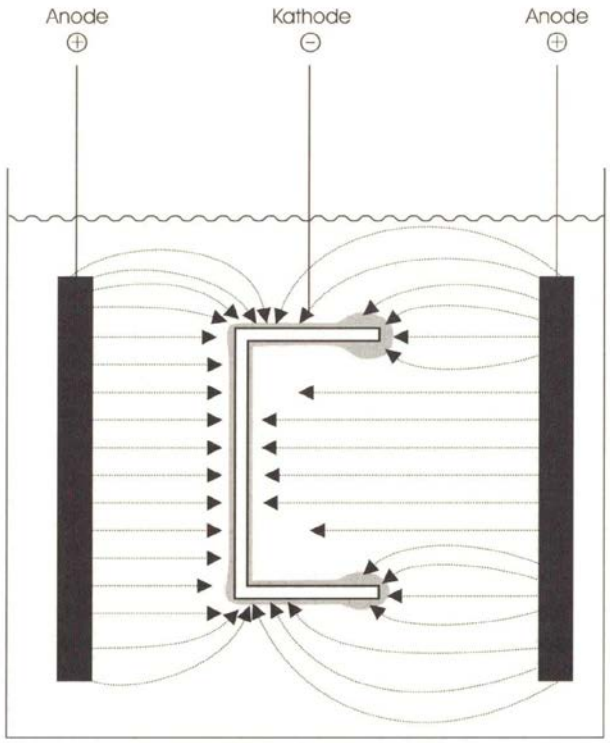
- Metallic Materials
  - Rough surface and burrs
  - Pores
  - Missing function of the surface (Corrosion resistance, tribological properties, optical properties…)
  - Light metals (Ti, Al, Mg) passivate due to the negative electrochemical potential → Problems with adhesion
  - Contact of different metals can cause corrosion (galvanic element)



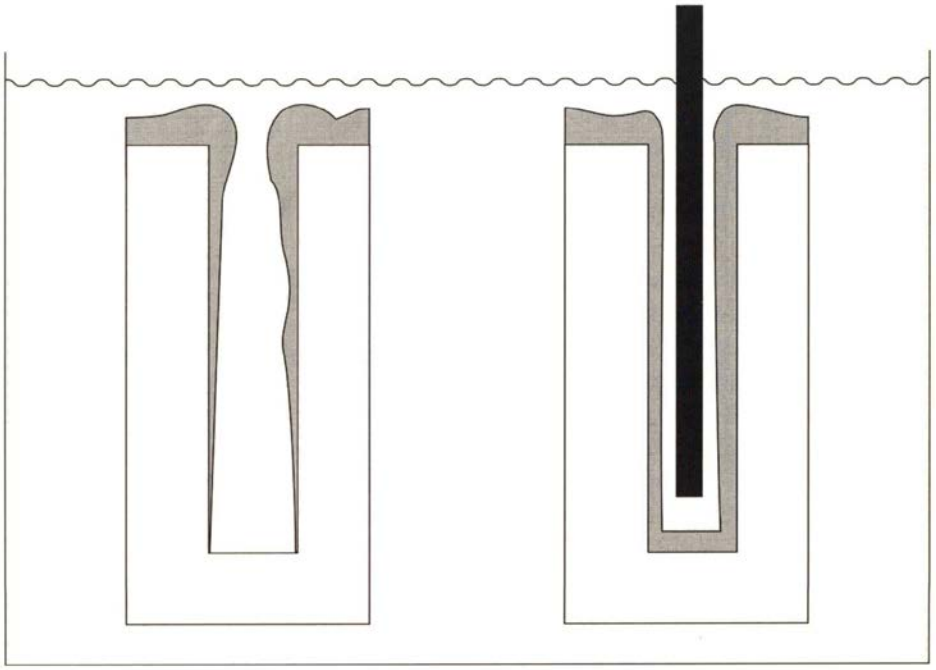
Light weight mirror: CFRP; nickel coated, ultra-precise machined; Ra: ~3 nm
Source: Fraunhofer IST 2017

Galvanic Metallization of parts with complex geometry

Homogeneous deposition



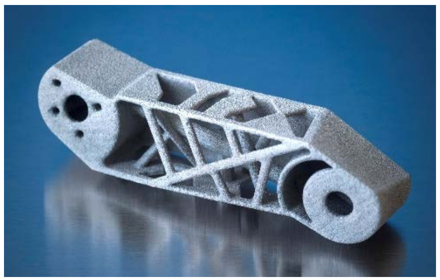
„Dog bone effect“ due to the electrical field



Homogeneous deposition by means of auxiliary anodes

Metallized PEEK-parts

~30 µm nickel, electrodeposited



- Chemical Pre-treatment
- Activation (Adsorption of Palladium)
- Electroless nickel (NiP)
- Electrolytic nickel (Reinforcement, ~30 µm)

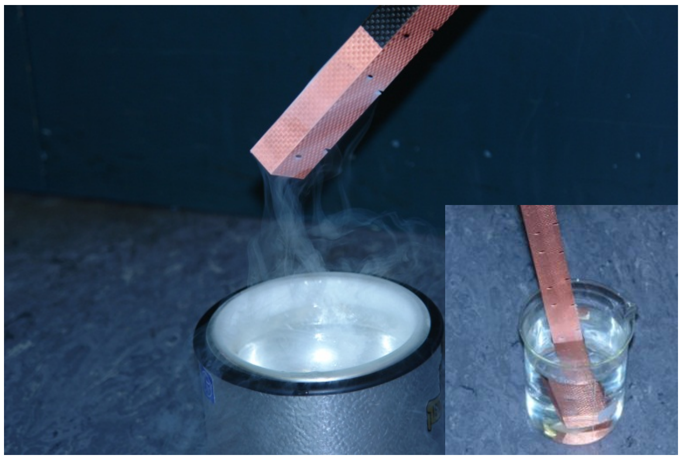
Metallized brackets, made from PEEK via Additive Manufacturing

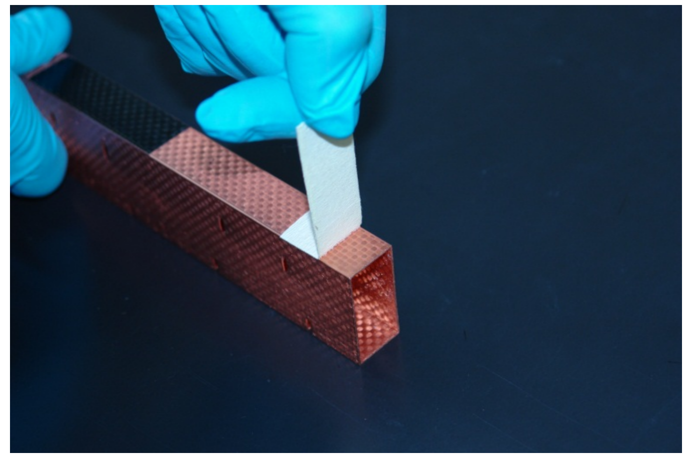
Adhesion test according ECSS-Q-ST-70-17C (Thermoshock): passed

PEEK-parts delivered by
RAUCH CNC

Adhesion tests under severe conditions
Quality Management

Example: metallized CFRP waveguides tested according ECSS-Q-ST-70-17C





Adhesion testing according to ECSS-Q-ST-70-17C:

Thermal shock test by dipping the WG in liquid Nitrogen (b.p. -196 °C) and boiling water (b.p. +100 °C) (5X)

The Scotch tape with very high adhesive power must not show any metal pieces

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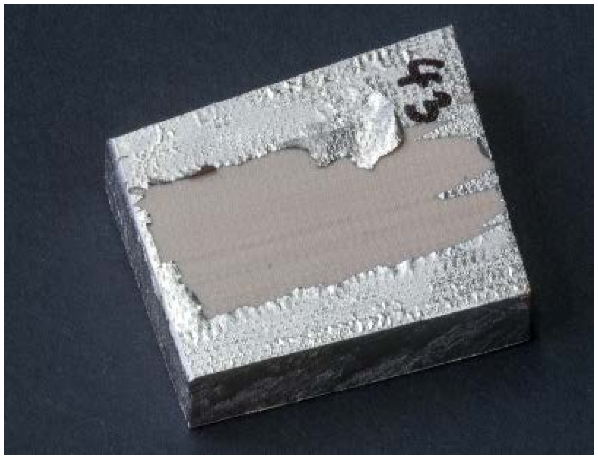
Metallized PEEK-parts

~30 µm nickel, electrodeposited

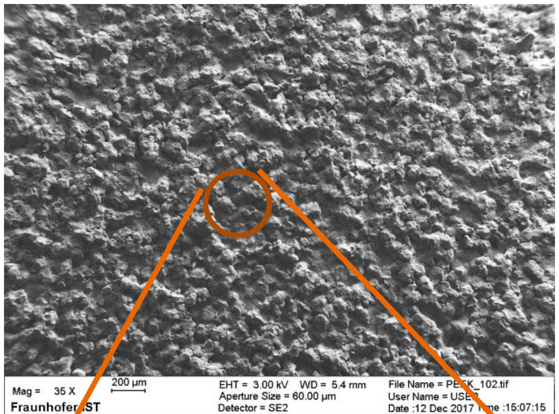


Metallized PEEK part, produced
by Injection Moulding:
No adhesion

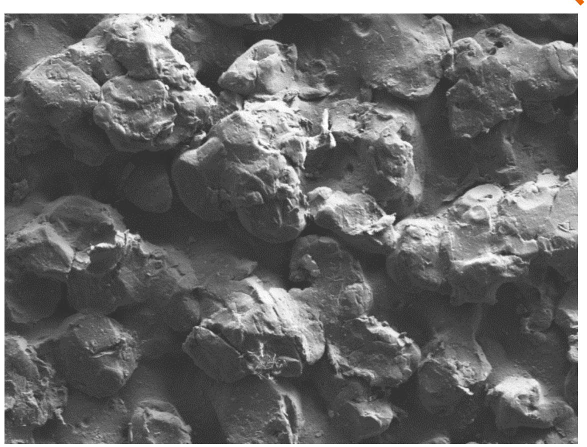
- Chemical Pre-treatment
- Activation (Adsorption of Palladium)
- Electroless nickel (NiP)
- Electrolytic nickel (Reinforcement, ~30 µm)

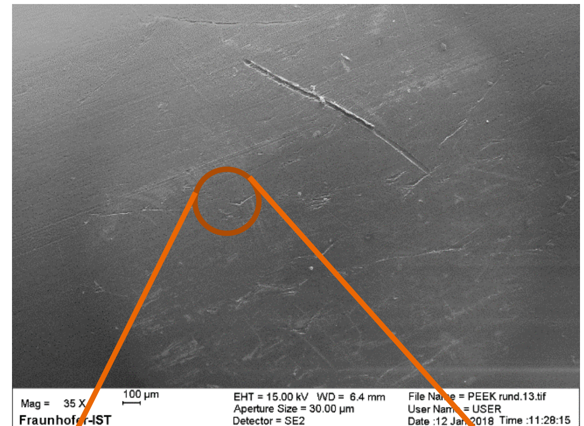
Surface of AM-PEEK vs. traditional PEEK

SEM image



SEM-image: uncoated PEEK, produced by Additive Manufacturing (SLS)





SEM-image: uncoated PEEK, produced by Injection Moulding

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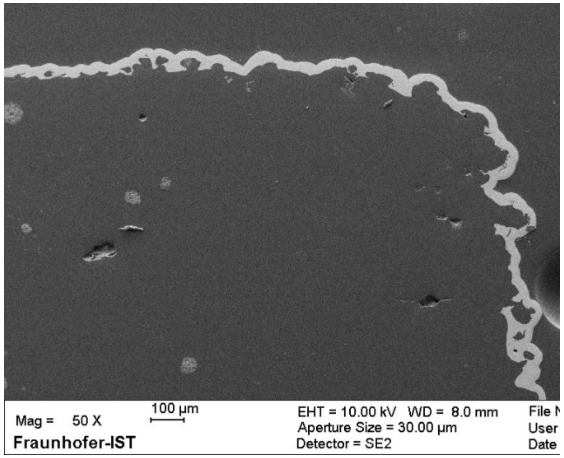
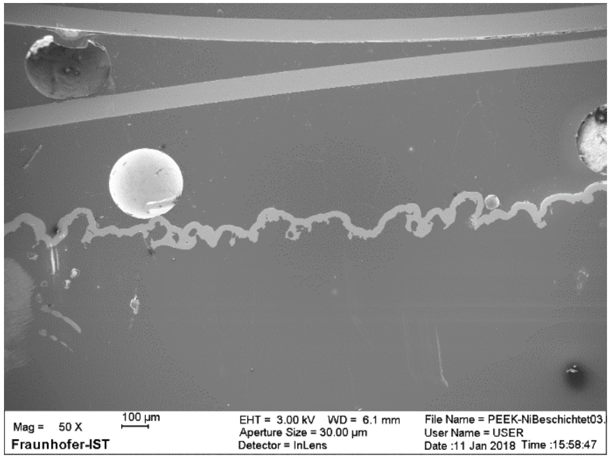
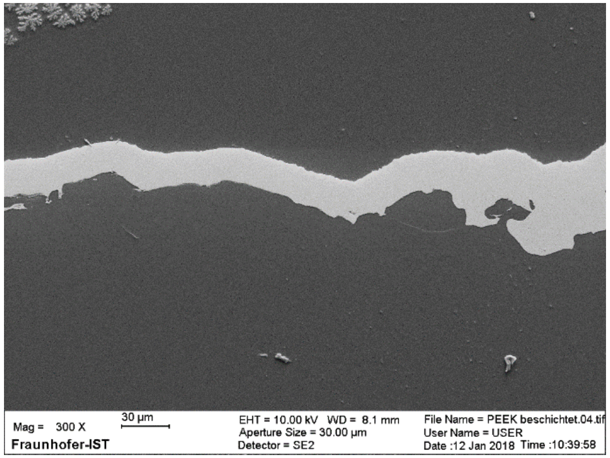
Metallization of PEEK (AM)
SEM images







SEM-image: Cross section of a metallized PEEK part, made by Additive Manufacturing

Practical applications

Replacement of metals by coated polymers

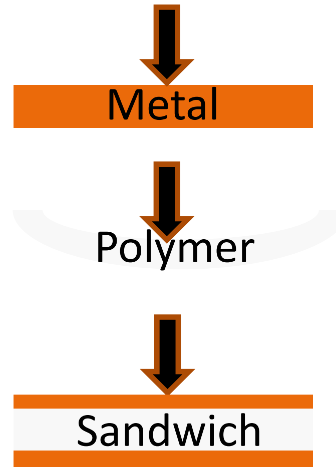
Bracket (PEEK):
above: traditional Design
below: AM-optimized Design

Source: Rauch GmbH

High cost
Big mass
High strength
High conductivity

Low cost
Low mass
Low strength
No conductivity
Outgassing

Low cost
High strength
High conductivity
No outgassing



The solution:
Combination of the benefits of metals and polymers

Source: OHB System

▲ Polymers can substitute metallic structural parts from aluminum

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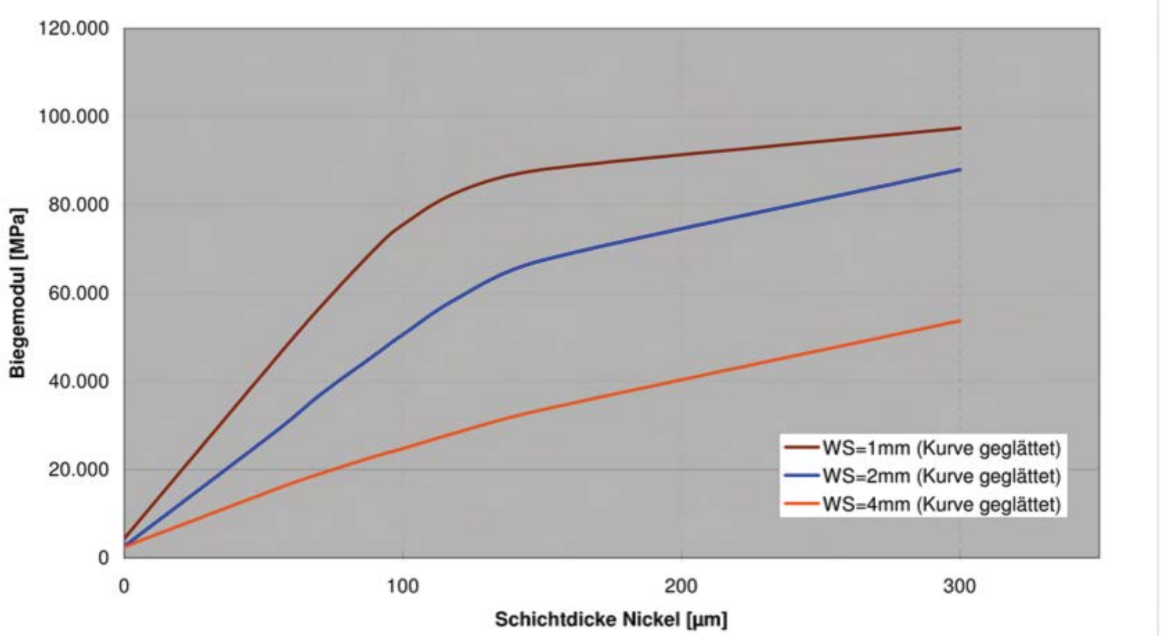
Some properties of light weight materials

Material	Tensile strength	E-module	Density	Melting point	Standard potential
	[Mpa]	[Gpa]	[g/cm3]	[°C]	[V] vs. NHE
Magnesium	275	42	1,74	650	-2.63
Aluminium	600	70	2,7	660	-1.66
Steel	2 000	200	7,86	< 1536	< -0.04
Ti6Al4V	1 300	113.8	4,43	1668	-1.21
PEEK	115	3.6	1,32	343	---
PEI	85	3.2	1.27	217	---
CFRP Composite	1 240	240 - 930	1,58	---	Positive

Practical applications
Replacement of metals by coated polymers

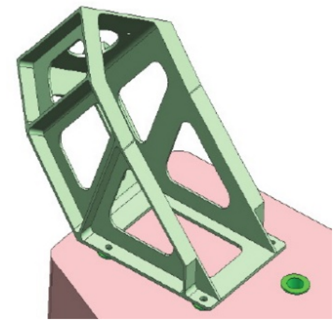


WS = Thickness of polymer

Quelle: Alphaform (DE)

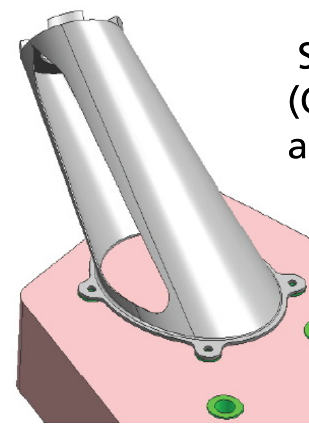
Flexural modulus of a polymer sample, reinforced with electrodeposited nickel

Technology and Performance



- High-strength polymer substitutes metallic parts
- Additive manufacturing (SLS) substitutes substractive machining: optimized design, high complexity of parts, reduced mass, lower manufacturing time, overall cost saving
- Metal cladding of surfaces provides sandwich-like structures: higher strength, increased thermal and electrical conductivity, avoidance of outgassing effects
- 20% expected mass reduction for a typical structure subsystem
- 50% expected reduction in manufacturing and verification cost

S-Band –Support (Original: Aluminium)



S-Band – Support (Optimized for AM and PEEK)

Source: OHB System

Space craft	Element	Material	Estimated mass reduction
Telecommunication - Satellite	**S-Band Antenna Support**	**Original: Aluminium (machined out of bulk material) => Optimized: PEEK additive manufactured and metallized**	**~50 %**

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Conclusions

- The surface technology for AM-parts and traditionally produced parts (turning, milling..) is similar
- AM-processes result very often in a rough and undefined surface
- The rough surface of the SLS process allows the metallization of a wide range of polymers
- Complex geometries are a challenge for coating technologies
- Coating of polymeric parts avoid the outgassing in vacuum
- AM-parts from polymers can substitute metallic parts and save mass and costs
- Surface Technology should be part of the AM design

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Mail: andreas.dietz@ist.fraunhofer.de

Source: Fraunhofer IST 2017

WORKSHOP @ AM 4 AEROSPACE & SPACE

FRAUNHOFER ADDITIVE MANUFACTURING ALLIANCE

9:00	**Opening and Welcome** (Mueller)
9:10	**Introduction to Fraunhofer and AM Alliance** (Mueller)
10:20	**Design for Additive Manufacturing – Guidelines and Case Studies for Metal Applications** (Mueller, Kloeden)
10:50	**Powder for PBF AM – how to assess it & recent developments in analysis** (Aumund-Kopp, Kloeden)
11:20	**Additive Manufacturing for Space Applications – Challenges and Chances for Surface Technology** (Dietz)
11:50	**Q&A Session** (all speakers with auditorium)
12:15	**End of Workshop**
12:30	Bus transfer to EOS

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