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RIGA TECHNICAL UNIVERSITY

Additive manufacturing in-situ repair solutions for the FCC

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Outline

- current achievements in the additive manufacturing
- in-situ and multi-material repair solutions
- future trends and potential application within the FCC

Additive manufacturing state-of-play

Additive Manufacturing (AM)
Comparison of technologies



Powder Bed

Selective Laser Melting SLM

- part‘s complexness
- accuracy
- build rate
- repair

Electron Beam Melting EBM

- high-performance materials
- part‘s complexness
- precision
- repair

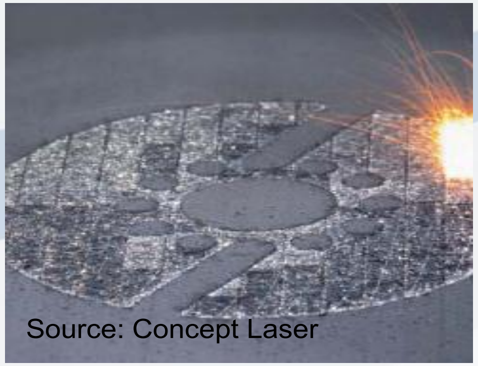
Direct Laser Deposition

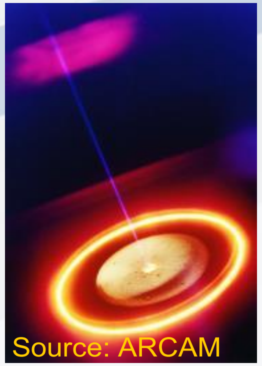
Laser Powder Deposition

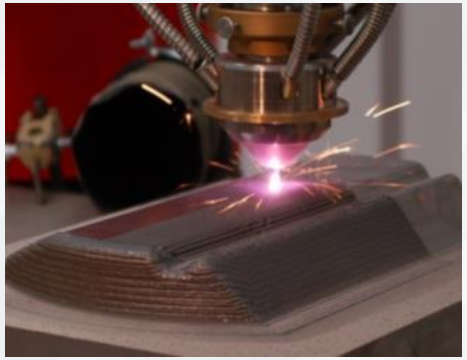
- productivity
- large parts
- geometrical restrictions
- powder utilization

Laser Wire Deposition

- clean and productive
- 100% material utilization
- geometrical and
- materials restrictions

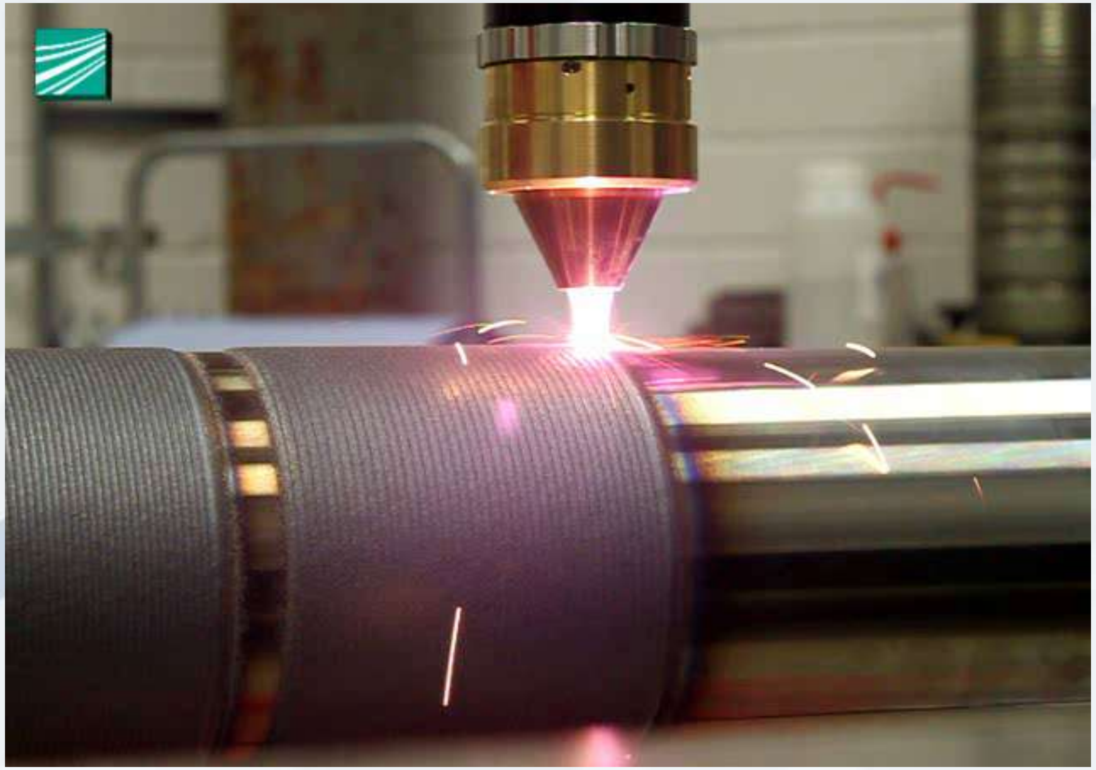

Source: Concept Laser


Source: ARCAM




Additive Manufacturing (AM)
Laser Metal Deposition (LMD)

- direct material deposition within a one-step build-up welding process
- continuous supply of the feedstock material in the form of powder and wire
- dense coatings, metallurgically bonded to the substrate
- near net shape material deposition in 2D, 2.5D, and 3D
- large spectrum of materials combined as substrate and coating



Laser surface cladding process for the corrosion protection of large cylindrical parts

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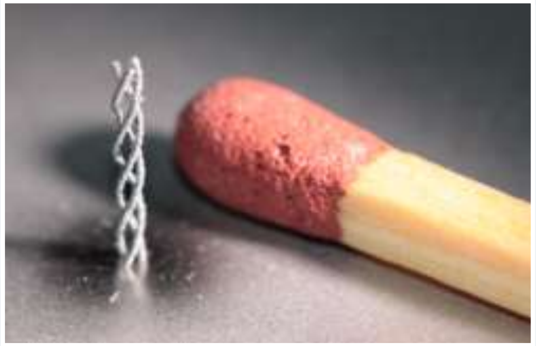
Additive Manufacturing (AM)
usage of Laser Cladding / LMD

- **Surface cladding**
  - 100 µm … 2 mm thickness
  - 100 µm … 45 mm single track width
  - cladding area up to range of m²

- **Repair**
  - 30 µm … 8 mm single track with
  - re-generation of damaged parts by multi-layer buildup
  - exactly localized material deposition

- **Generative manufacturing**
  - 2.5D and 3D material build-up
  - 30 µm to 5 mm lateral resolution
  - part’s size not generally limited



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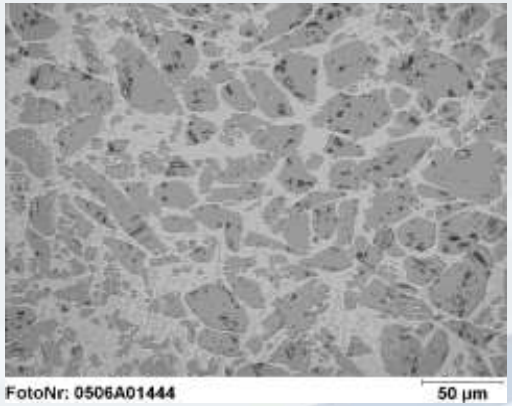
Laser Metal Deposition
Functionally graded material (FGM)

multi-material

- gradients
- material mixture
- compounds

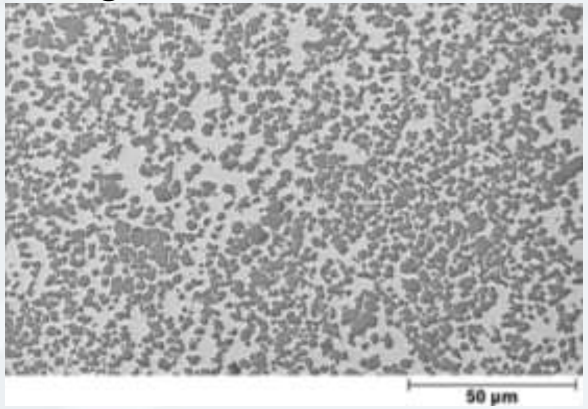
objects with varying:

- densities
- thermal expansions
- magnetism
- conductivities
- strengths
- melting temperatures



Coarse-grained WC-NiBSi

Fine-grained TiC-Ni



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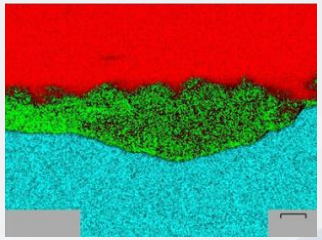
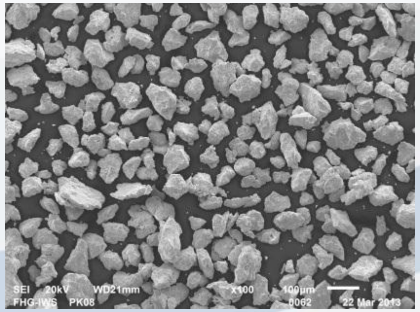
Quality management in AM
From powder to part

- characterization along whole process chain

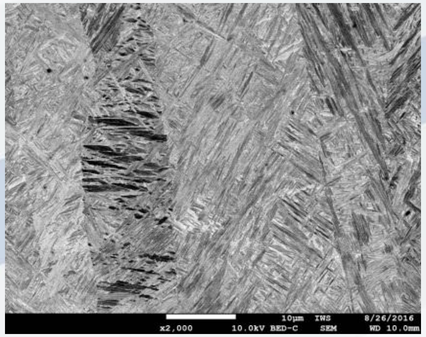
powder → process → post-processing → process interactions



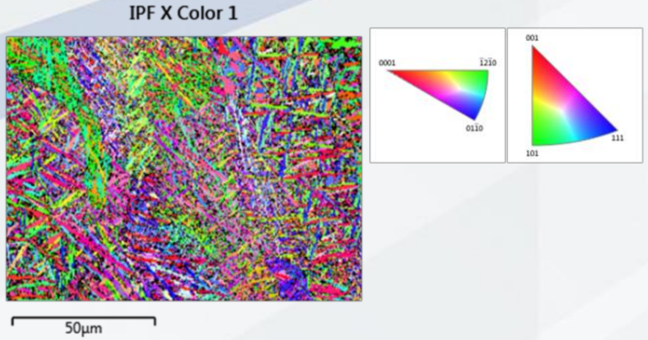
interfaces



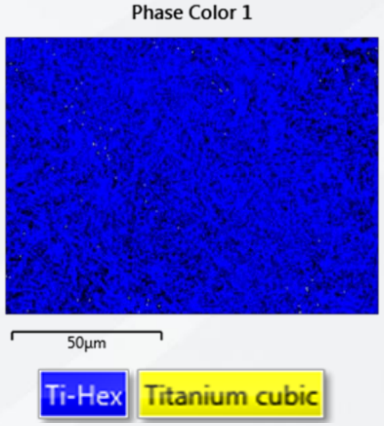
particle shape



morphology



Residual stress / EBSD pattern quality

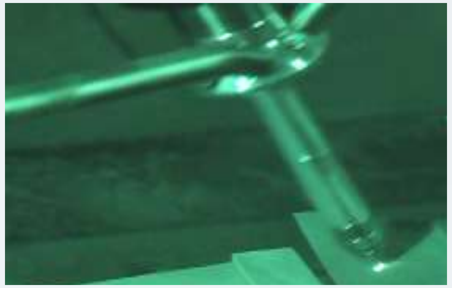


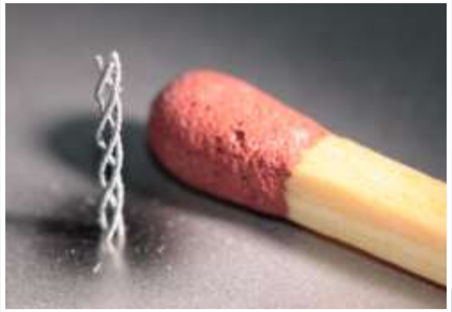
phase distributions

Additive Layer Manufacturing

From micro to large components

Micro ⟵⟶ Macro





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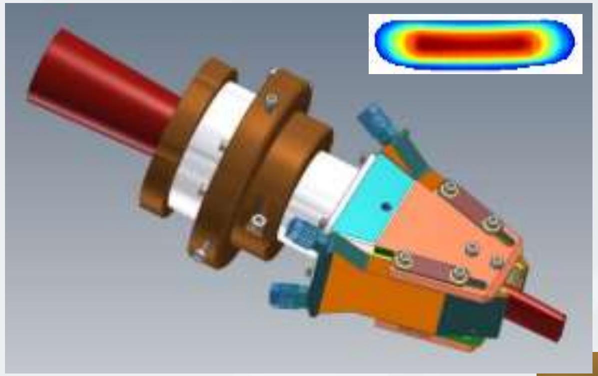
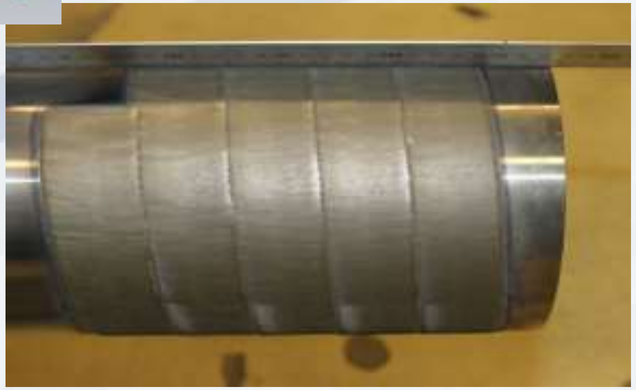
Laser Metal Deposition with powder
Large components

High-rate deposition using high power diode laser sources

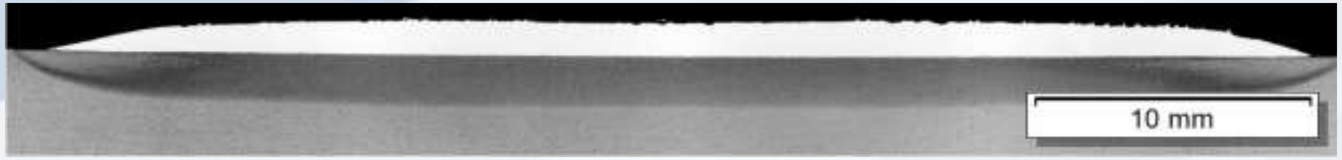
- wide single tracks
- fine-grained solidification structure
- metallurgical bonding to the substrate
- dilution only 3…5%



wide-spread nozzle system



large-area coating with reduced overlapping of the single tracks
→ increased coating rate



cross-section Ni base coating, **one single track!**

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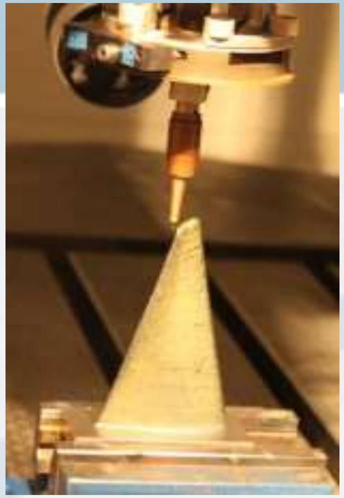
Laser Wire Deposition
Examples

- repair of components
- realization of new materials solutions in generative processes (TiAl, Ni super alloys)
- generation of lightweight structures
- generation of tool sections
- cladding of cylindrical parts with high surface quality







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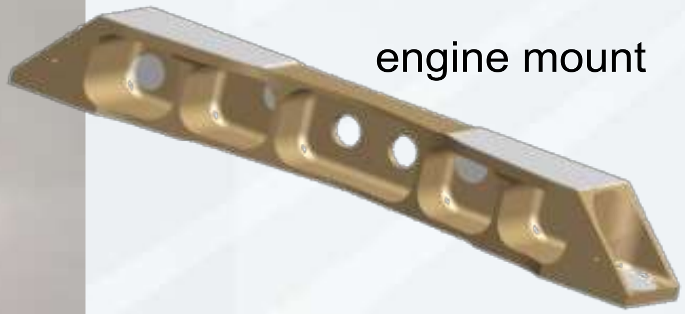
Laser Metal Deposition with wire
Large components

Manufacturing of large parts in robotic systems

- latest development: use of inexpensive and efficient diode lasers
  - 4 kW laser power; 30 mm*mrad BPP
- materials, e. g. TiAl6V4, Inconel 728, AlMg5

welding setup

expansion nozzle



engine mount

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Application

Where it is applyed today?

Proved its high efficiency, precision and economic benefits in repair sectors:

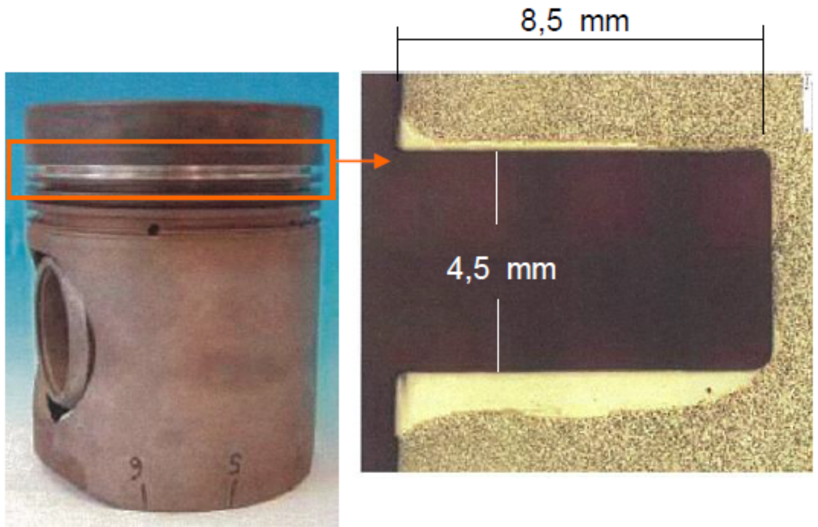
- aerospace
- automotive
- ship repair

Why industry is interested?

- very flexible
- well suited for multi-material micro and macro in-situ repairs.
- Additive manufacturing equipment, tools and technical solutions are getting more and more compact, precise, productive, versatile and… cheaper

Application of the technology

- Not any more niche product
- multipurpose manufacturing solution

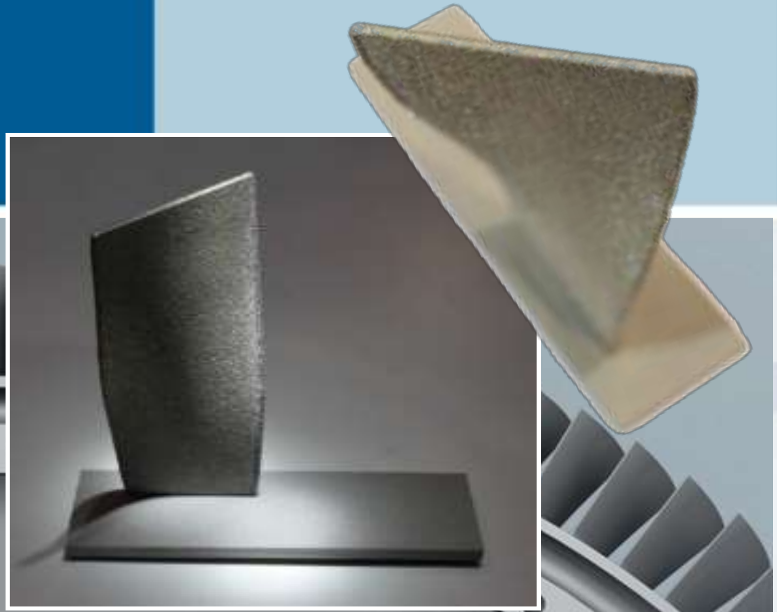


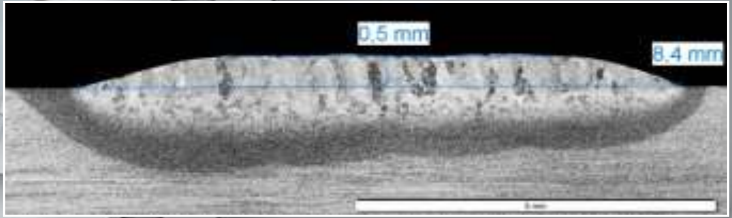
Source: TRUMPF - industrial applications of laser cladding and the equipment required

Source: http://www.gall-seitz.com

Laser Metal Deposition
Ti components

- Ti-Based alloys
- repair, new parts
- e. g. blades, (blisk)





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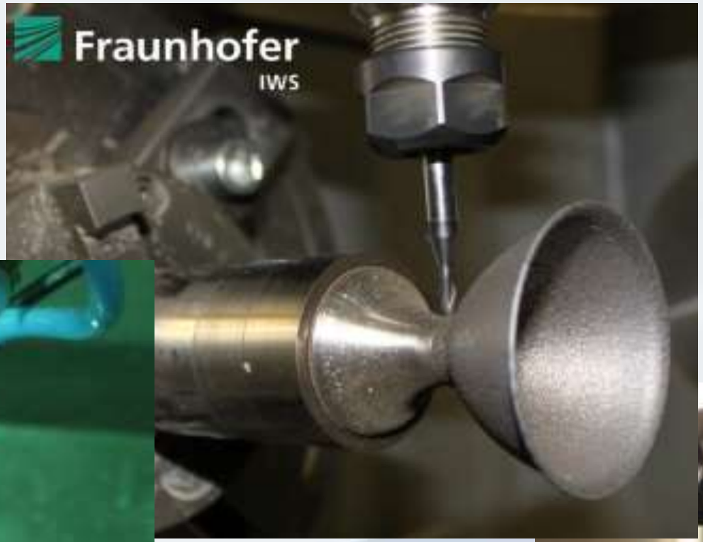
Additive Manufacturing (AM)
Fabrication of nozzle geometries



- LMD
- milling
- cutting

… in one sequence

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Comparative advantages

- minimal dilution and distortion
- enhanced thermal control
- **Heat Affected Zone** is reduced
- customised surface parameters
- low porosity and few imperfections
- high precision and **surface quality** parameters
- the resulting surface material has characteristics similar to or even better than the original

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Comparative advantages

- reduced production time (compared e.g. with welding)
- highly satisfactory repair of parts
- production of a functionally graded parts
- production of smart structures
- **Perfect technology for in-situ repairs**
- Suitable for automation

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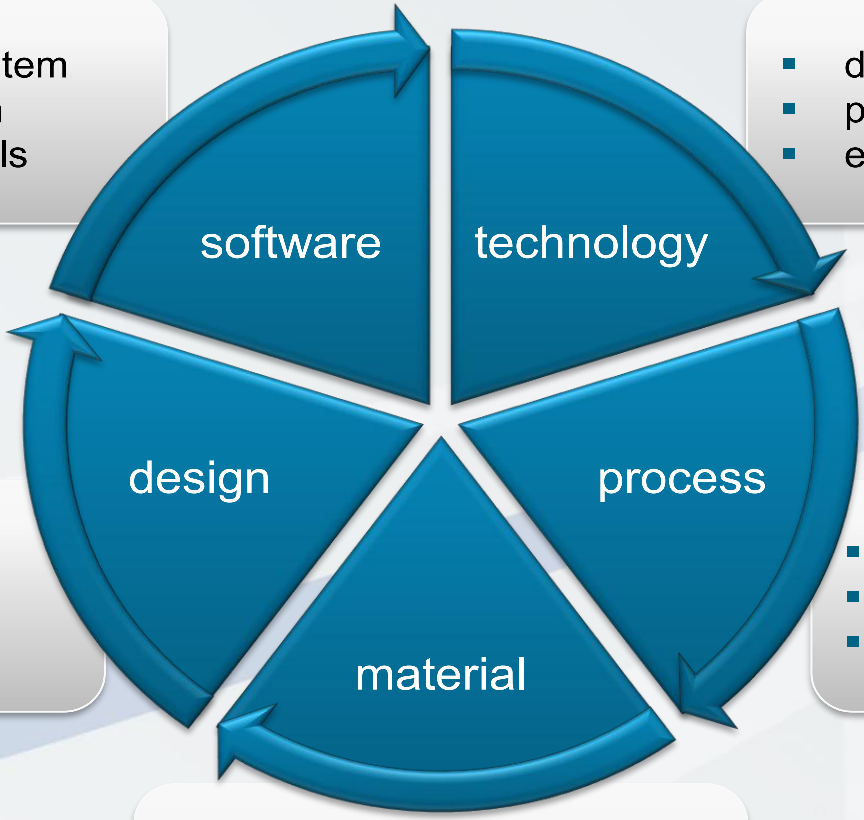
Future trends

Additive Manufacturing (AM)
Technologies at Fraunhofer IWS

- CAD/CAM system
- control system
- monitoring tools

- directed deposition
- powder bed fusion
- energy source



- simplification
- design guidelines
- function integration

- lead time
- process parameters
- operator

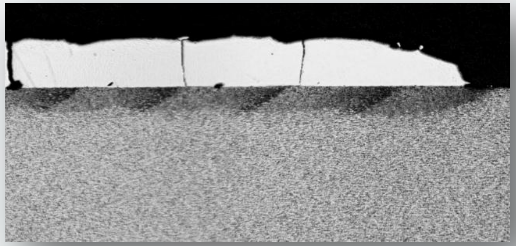
- powder/wire production
- grain size/form
- multi-material

Core Research Topics @ IWS

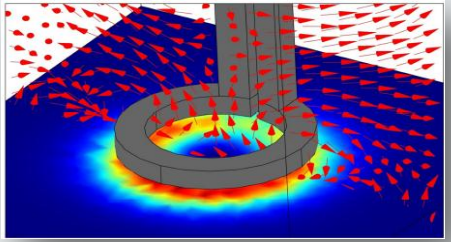
Focus Materials and Processes

amcd
Additive Manufacturing Center Dresden

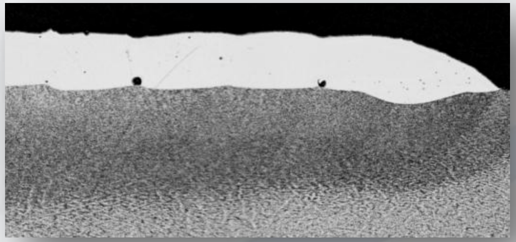
Crack-prone steel



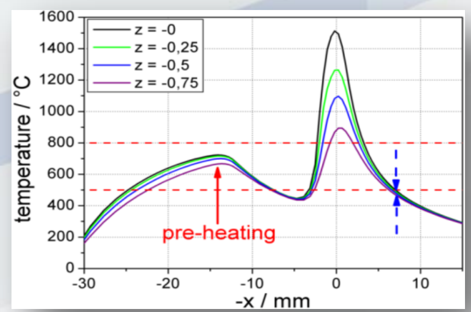
Inductive heating



Crack-free deposition



- Reduced temperature gradient
- Controlled microstructure
- Low residual stresses
- No cracking



Repair

New part

- Materials-optimized processing
- Microstructure optimization
- Load-optimized components

Future trends

- general trend - additive manufacturing equipment and appliances will continue to become smaller, cheaper, more user-friendly and flexible
- new manufacturing opportunities arise from the nature of laser processing - as it is a **non-contact process** that causes no tool wear
- able to process conventionally **untreatable materials** and discrete portions of large components as well as **precisely treat small components and selected areas**
- the laser beam is also able to access **concealed locations**

Future trends

- development of **autonomous machines** for the additive manufacturing process that can not only deposit a wide range of alloys, but also make complex shapes without the need for the presence of engineers
- the development of an automated machine may not be possible without a close collaborations between researchers from different disciplines
- hybrid technologies – e.g. additive manufacturing + milling

Potential application in FCC

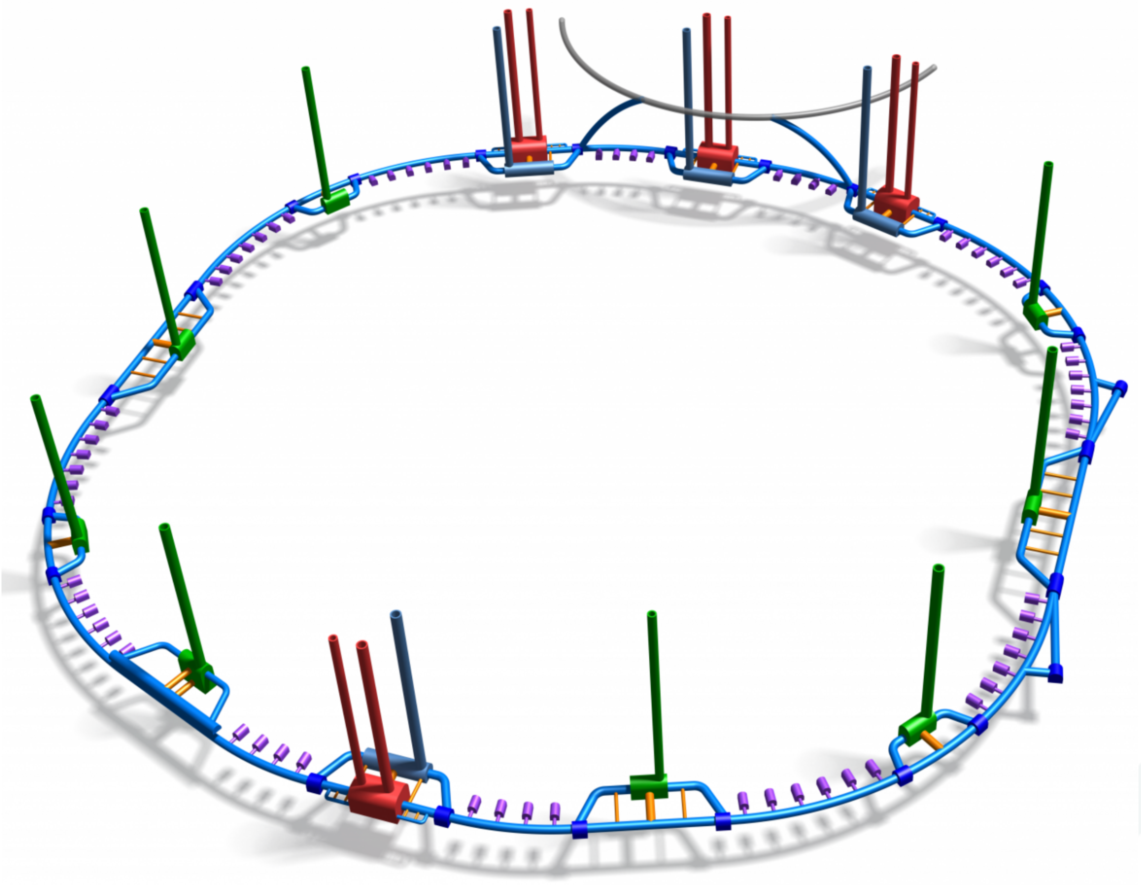
What is there for FCC?

This is about:

- **conceptual aspects** required for the FCC accelerator
- Identification of **design** and performance **limitations** for the accelerator
- Challenges v/s opportunities for **technological breakthroughs**

Conclusion is rather clear:

- due to the nature, size, scale and complexity of the environment, the deployment of **conventional repair methods and technologies will be insufficient** in the FCC



By Angel Navascues

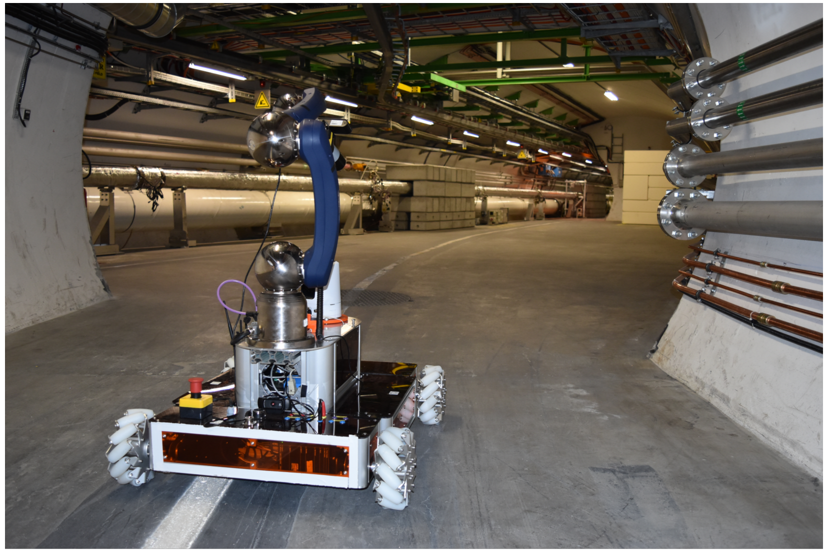
Vision – 20 years ahead

- **solution** for the FCC:
  - remote manipulations?
  - unconventional repair technologies?

- What materials we will be having within 20 years?
- Which properties?
- How we will be doing repairs?
- What will be the general maintenance and repair strategy chosen for the FCC?
  - preventive maintenance
  - or predictive maintenance
  - run-to-failure

Advanced robotic and remote manipulation systems

- **Robotics together with** novel in-situ repair technologies, offer tangible repair results.
- one of the solutions for the FCC is a remotely controlled robotic platform performing **in-situ additive manufacturing repairs**

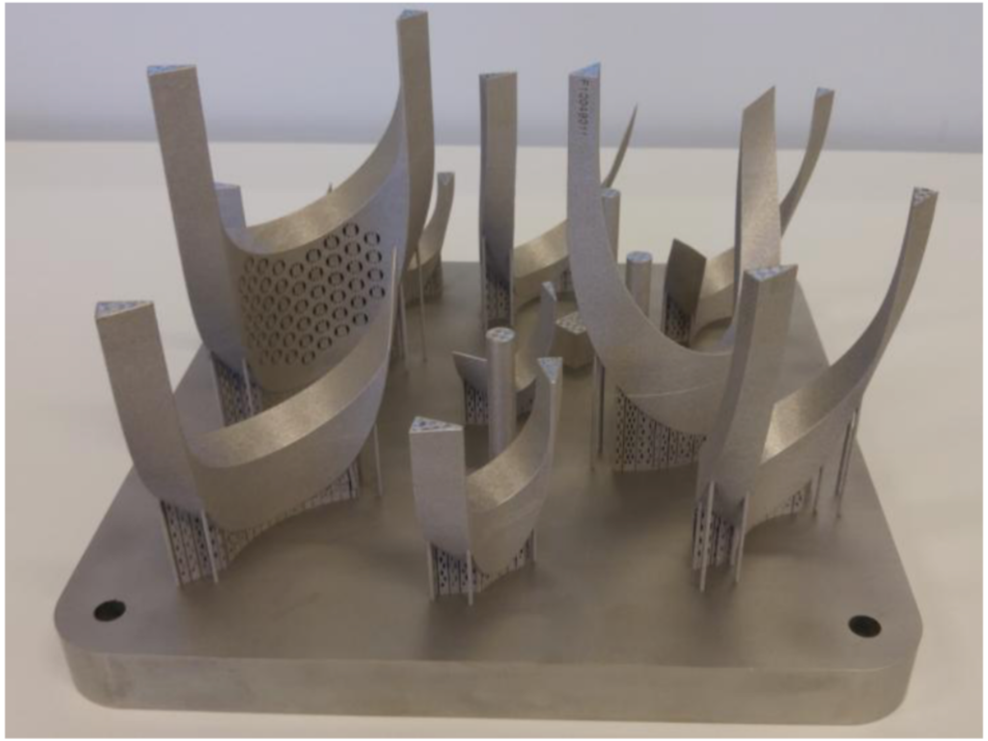


CERN EN-SMM

CERN EN-SMM

Application

Manufacturing of the components



CERN EN-MME

Repair of components, parts, structures etc.

CRANEbot for accessing "complicated" areas

CERN EN-SMM

Potential for FCC

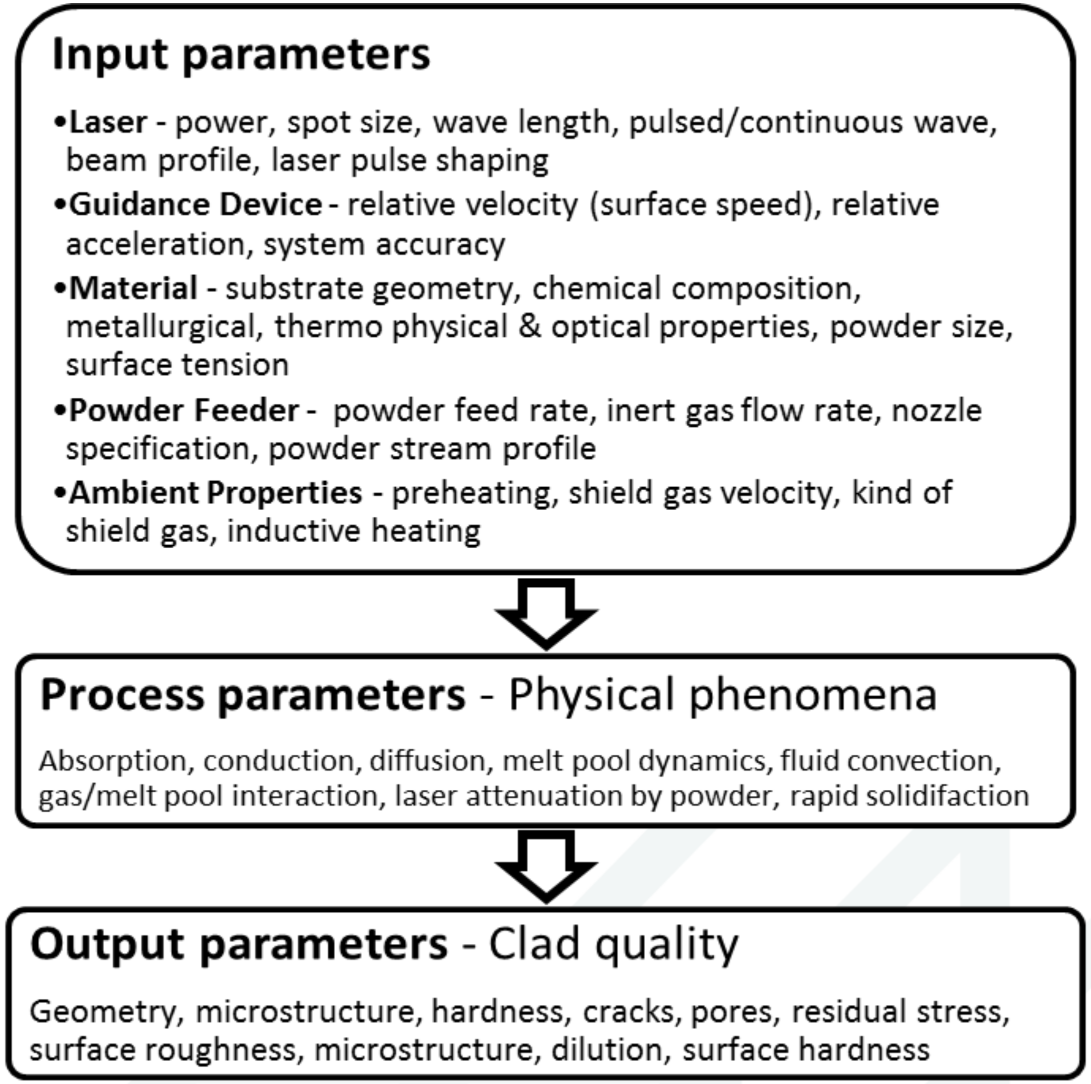
- Fire safety – is different from welding – less heat and very local impact
- Flexibility – type and material
- Large variety of materials, including composite - everything that tolerates laser melting
- Could be applied to unknown and novel materials
- From nano to macro
- Fast reaction – time-to-action
- No human intervention – automation and remote manipulation
- Reliable technology
- Can work in hazardous environment

Offers a new concept/philosophy - could be used not only during operation but also in the construction, installation and testing phase of the FCC

Challenges

there are several directions where R&D is needed:

- Environmental
- Safety
- Technological
- Process monitoring
- Interfaces
- Machine learning



Challenges - Environmental

- Radiation
- Supper high magnetic fields
- High voltage
- Oxygen deficiency
- **Fire safety / optical - laser**
- **Powder release in the tunnel**
- Recycling

Challenges - Operational

- Difficult to access
- Very limited space
- Distance from the access points
- Time to access and solution to the problem
- Time schedule – recovery
- Reliability of technology

Challenges - Technological

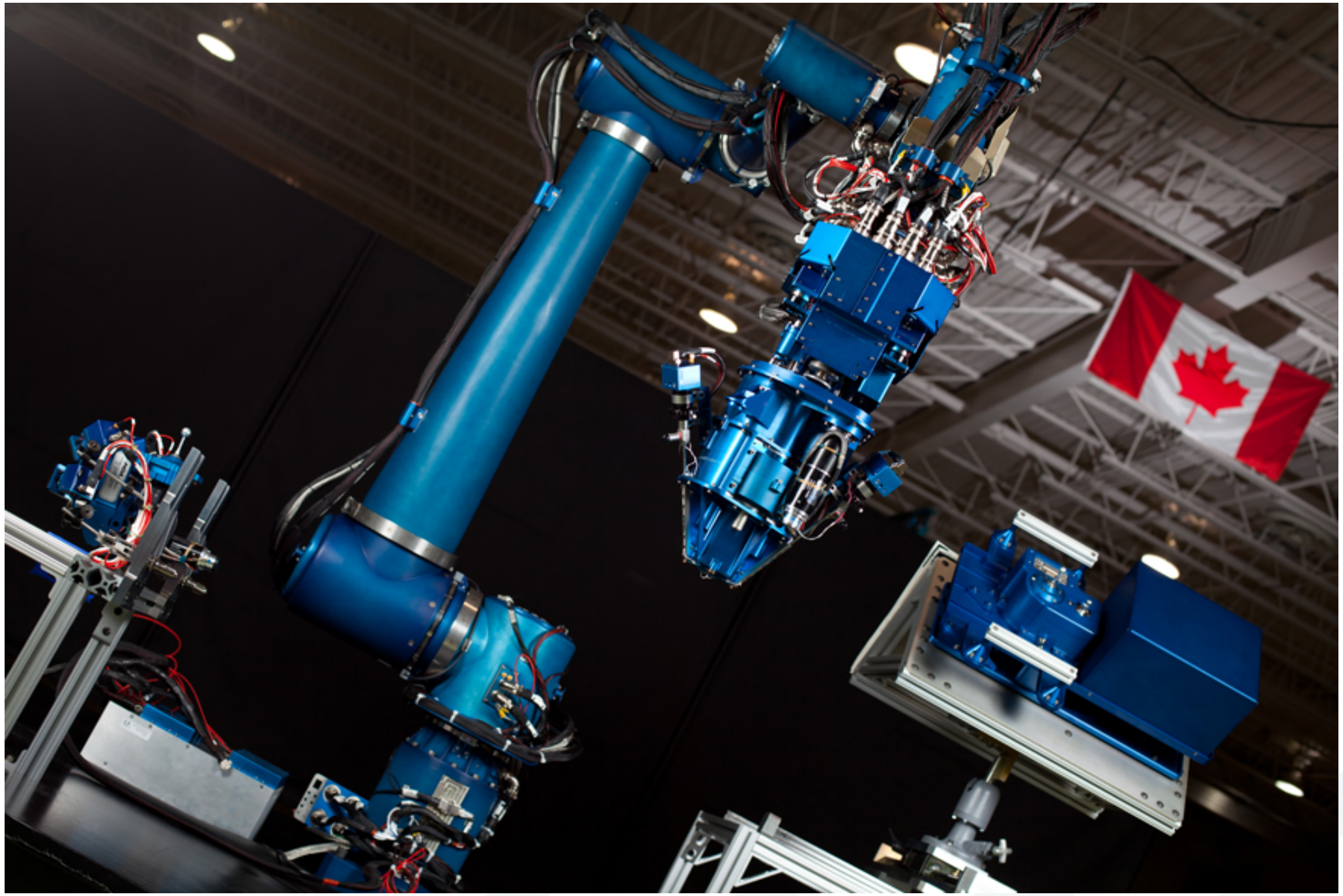
- Very delicate equipment, high precision and fine tolerances
- Complex assemblies
- Magnitude from micro to macro levels
- Variety of materials, often difficult to process and repair
- Novel and "unknown" materials

Canadian Space Agency

Outer space

v/s

Enclosed space



Take away message

- Additive Manufacturing is very fast developing and promising technology

- We don't know exactly which materials and repair tasks we will be having – but we know the potential solution – additive manufacturing

- The FCC will not be just a larger-statistics version of the LHC but a game-changer in … manufacturing technology?

Thank you for your attention!