SENSOR INTEGRATION BY ADDITIVE MANUFACTURING

INTEGRATION VON SENSOREN MITTELS ADDITIVER FERTIGUNG

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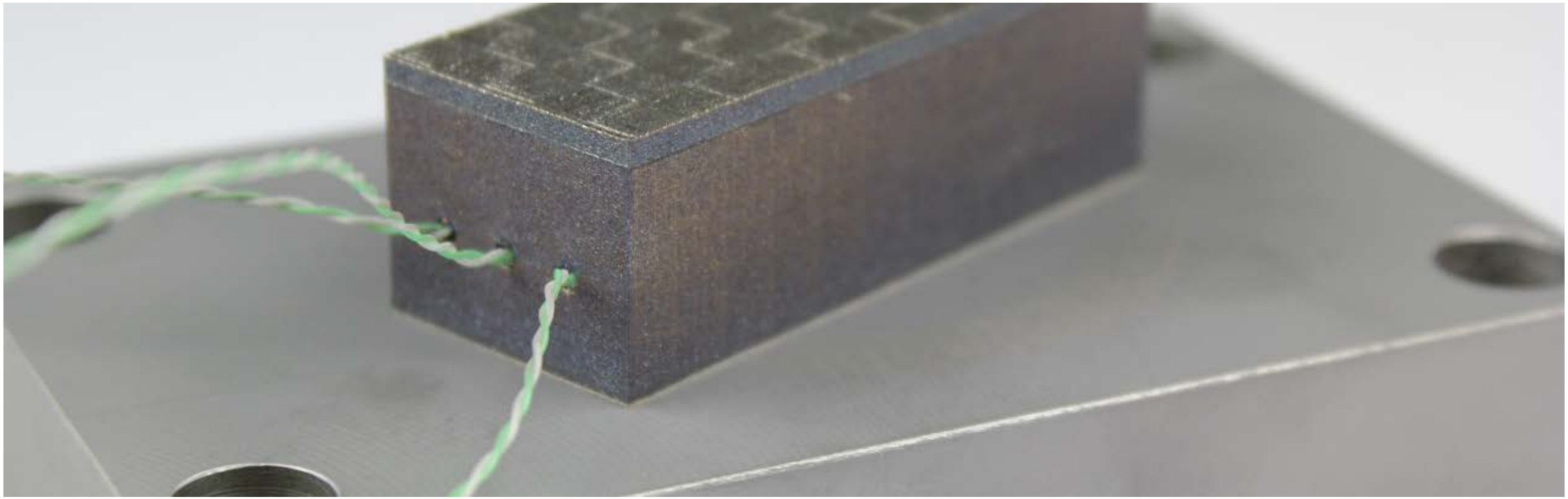

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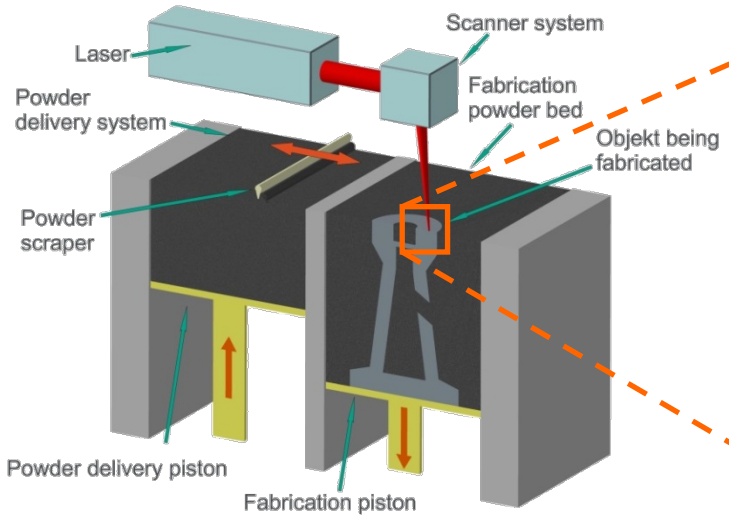
AGENDA

- Laser Beam Melting
- Functionalization of additive components
  - Motivation
  - Integration procedure
  - Functionalization in general
  - Sensor integration in tools and dies
  - Applications
- Poject Uddeholm AM insert
  - Objectives
  - Parameter qualification
  - Approach and challenges
  - Post process
  - Summary
- Outlook & further research activities

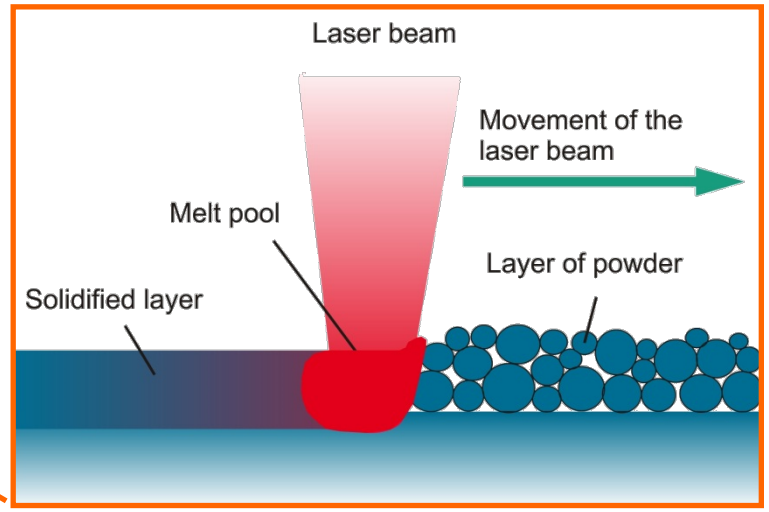
Laser Beam Melting

Laser Beam Melting

- **Direct, single step process**, creating parts out of **series-like metallic material**
- Complete local melting of the metal powder to a 99.5 - 100 % **dense microstructure**



Principle sketch of a laser melting machine



Schematic diagram of Selective Laser Melting

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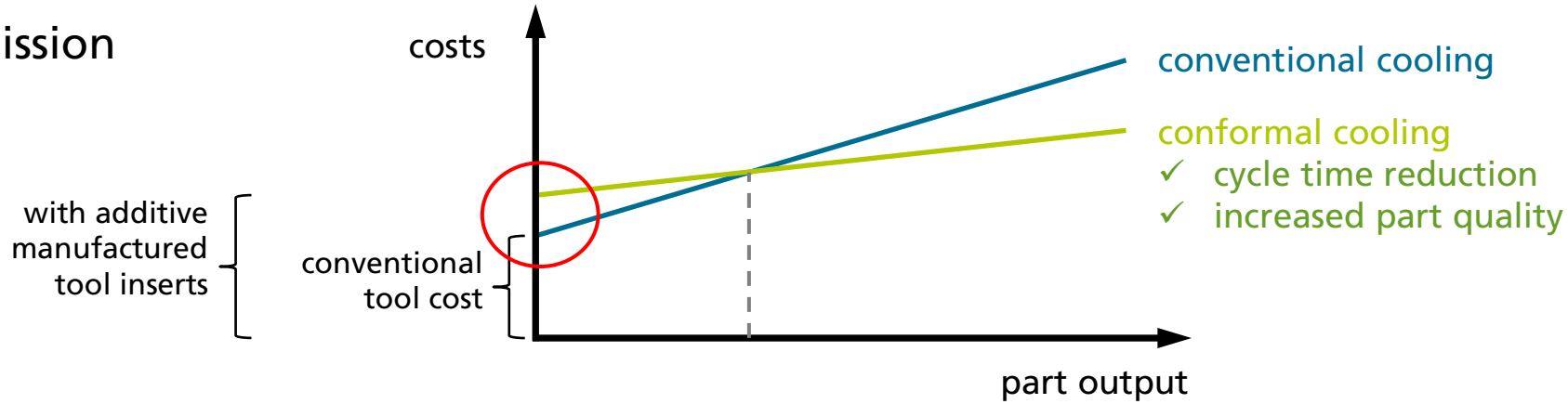
Functionalization of additive components

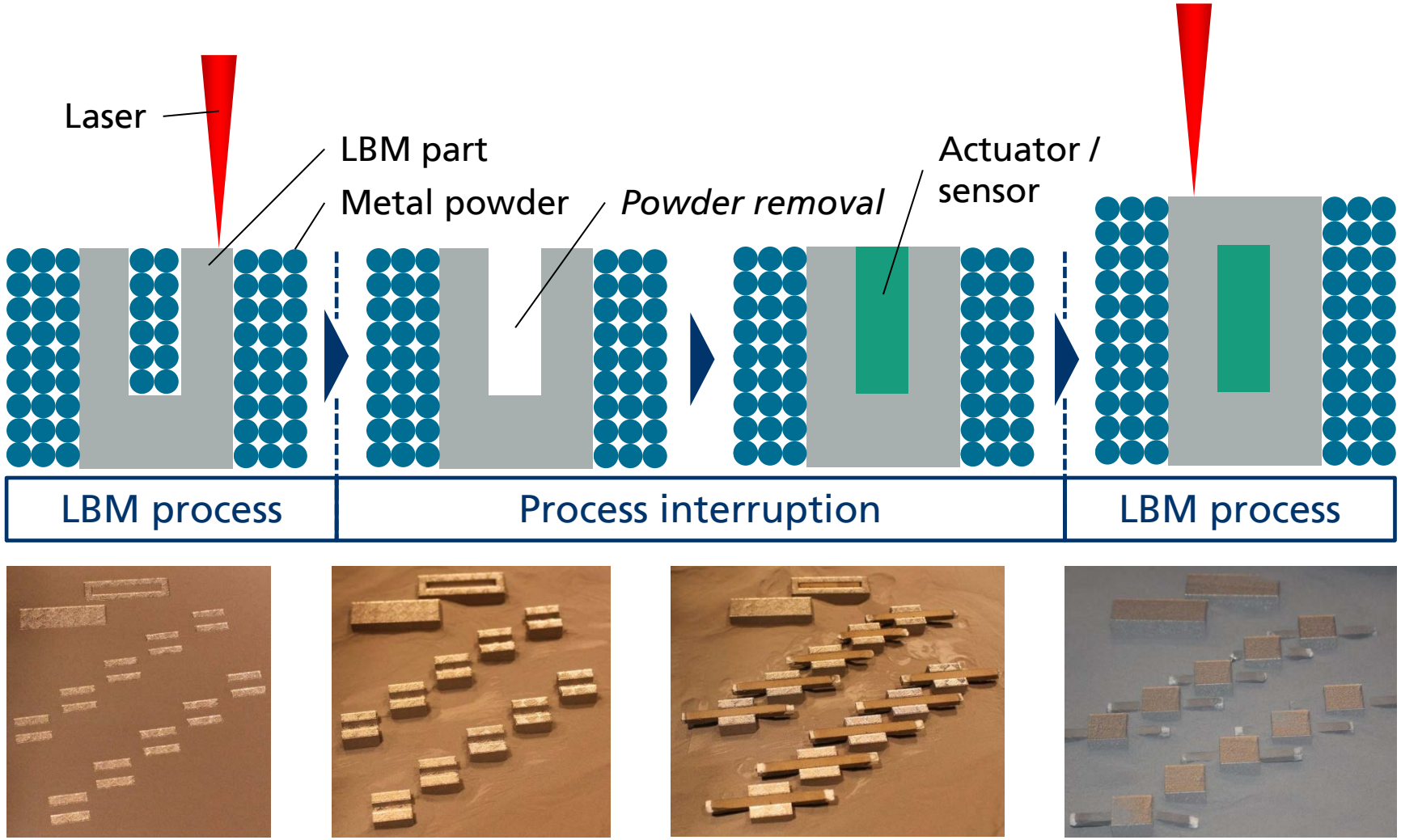
Functionalization of additive components
Motivation

- AM manufacturing costs are still high due to long manufacturing time
  - Maximize added value
- Industry demands
  - Condition monitoring for additive manufactured parts
  - Process monitoring e. g. in tools and dies
  - Process control by real time data
  - Wireless data transmission



Functionalization of additive components

Integration procedure



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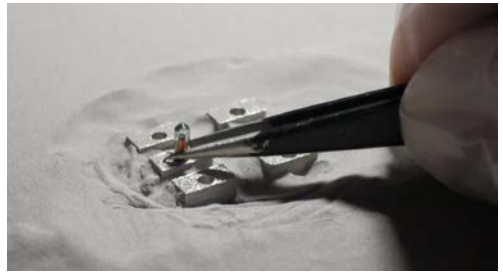
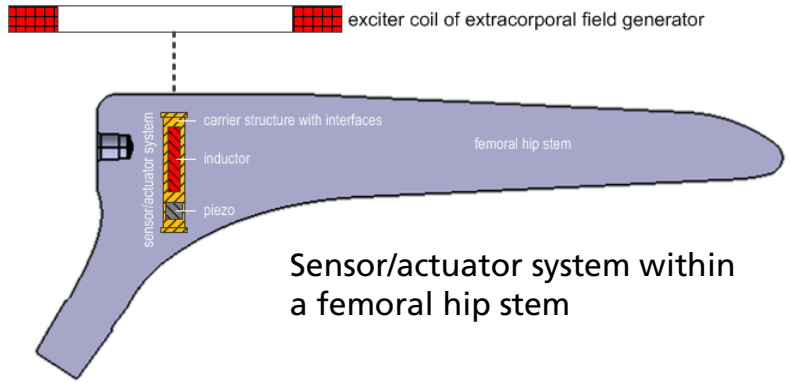
Functionalization of additive components
Functionalization in general

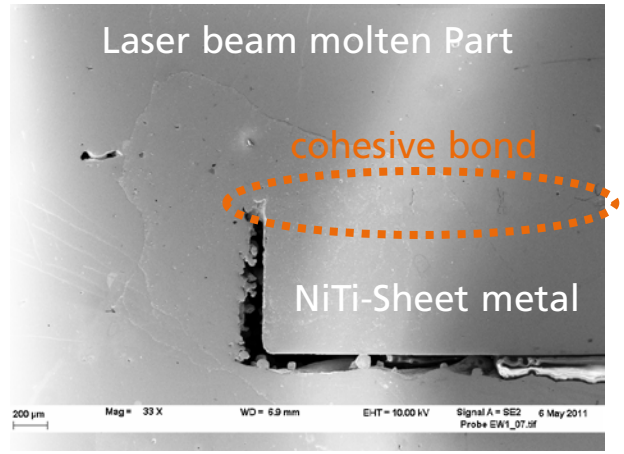


RFID integration

- Examples
  - Integration of thermocouples in different materials (AlSi10Mg, Corrax®, 1.2709, TiAl6V4)
    - ➢ Temperature measurement
  - RFID-Tag integration (1.4404)
    - ➢ Attaching digital information to a component
  - Sensor/actuator system (TiAl6V4)
    - ➢ Detecting and creation vibrations
  - Magnetic functionality in non-magnetic components (1.4404)
    - ➢ Positioning, holding function, energy harvesting
  - Integration of shape memory alloy (TiAl6V4, 1.2709)
    - ➢ Actuator component



Sensor/actuator system within a femoral hip stem



Shape memory alloy molten in 1.2709

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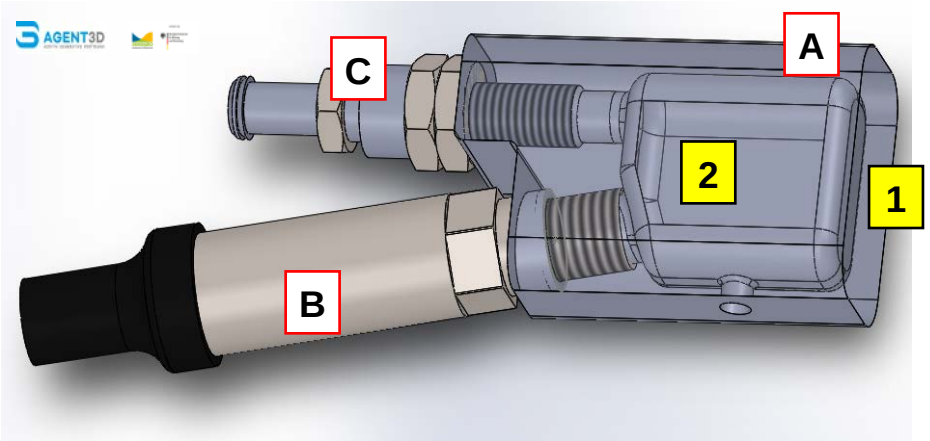
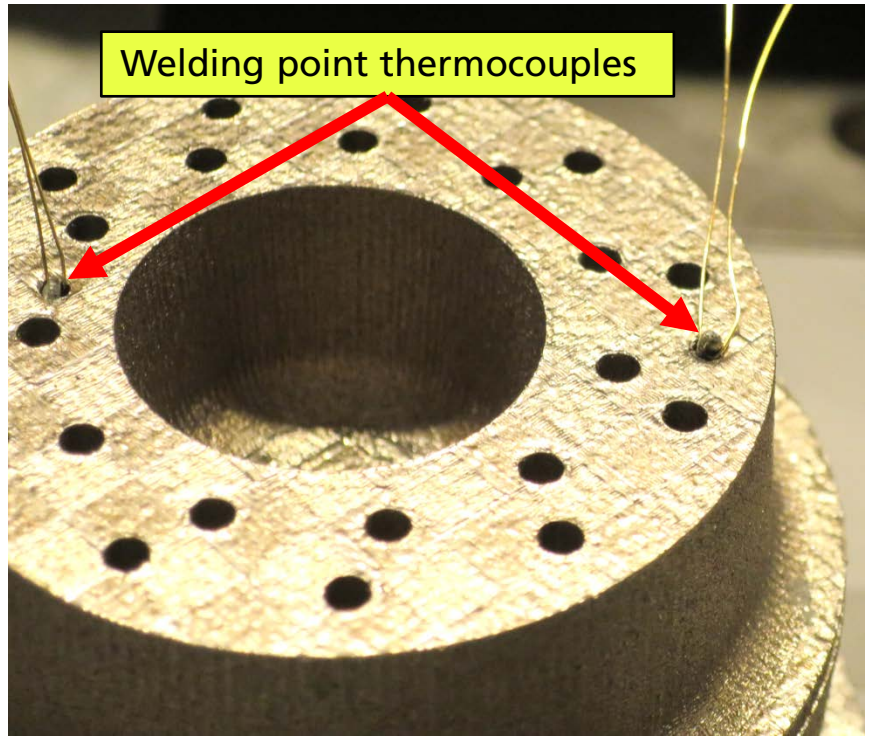
Functionalization of additive components
Sensor integration in tools and dies

- Temperature measurement
  - Thermocouples (1.2709, Corrax®)
- Pressure measurement
  - Strain gauges (1.4404)
  - Fluid based (1.2709)



CAD-Modell Fluid based pressure Sensor



Uddehlom
AM Insert
(Corrax®)

- Additive measuring insert [A] with membrane [1] and reservoir [2]
- Electronic pressure sensor [B]
- Venting valve [C]

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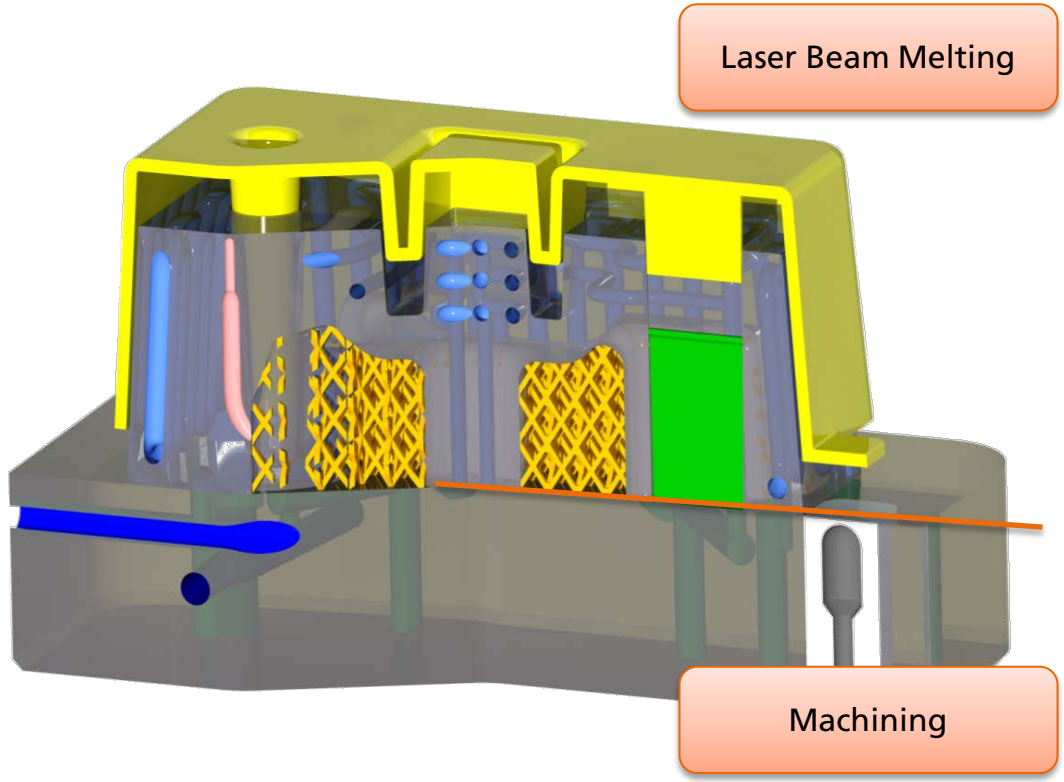
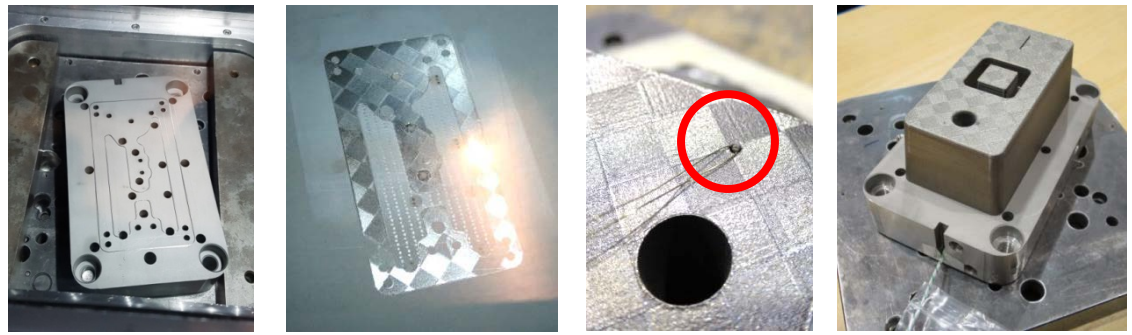
Functionalization of additive components
Applications

- AGENT-3D FunGeoS – Plastic injection mold
  - Lightweight design for material and cost reduction
  - Hybrid tooling
    - machined base body
    - additive manufactured structure on the base body
  - Integration of thermocouple and pressure sensor
  - Porous structures for tool venting



CAD-Model of the plastic injection mold FunGeoS



Hybrid process chain of the mold manufacturing

AGENT3D ADDITIV GENERATIVE FERTIGUNG
zwanzig20 PARTNERSCHAFT FÜR INNOVATION
GEFÖRDERT VOM Bundesministerium für Bildung und Forschung
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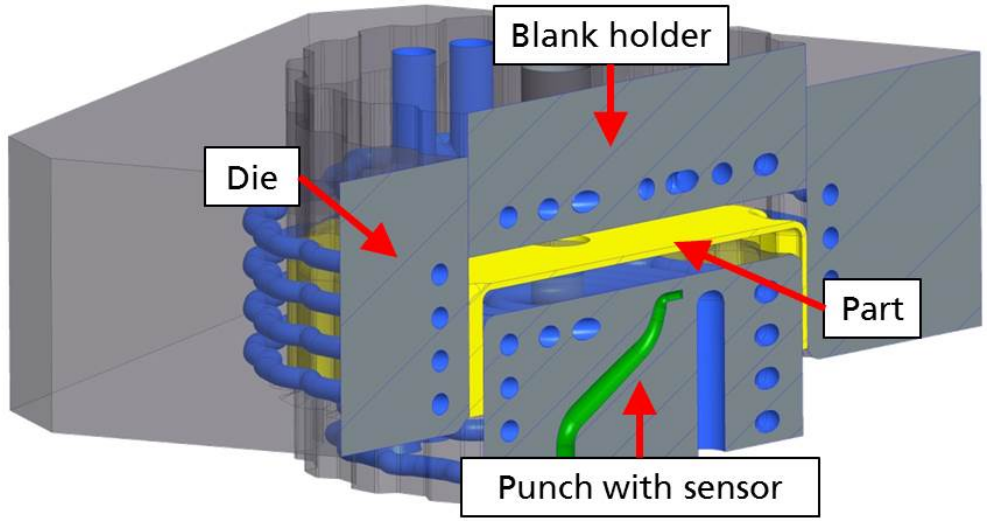
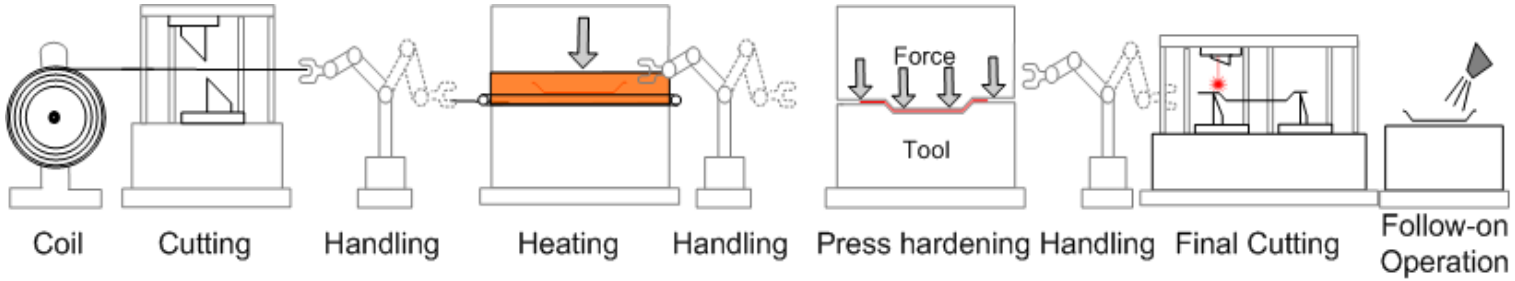
Functionalization of additive components
Applications

- MANUNET project “HiperFormTool”
  - Increasing the performance of different sheet metal forming technologies by AM tooling
  - Added value and integration of additional functionalities
  - Depending on target application cooling, heating, lubrication and sensor integration



Assembly with innovative cooling system (CAD model)



Press hardening process

Source: Stoll, Philipp: “High Performance Sheet Metal Forming Tooling by AM”; iCAT2016; Nürnberg; 30.11.2016

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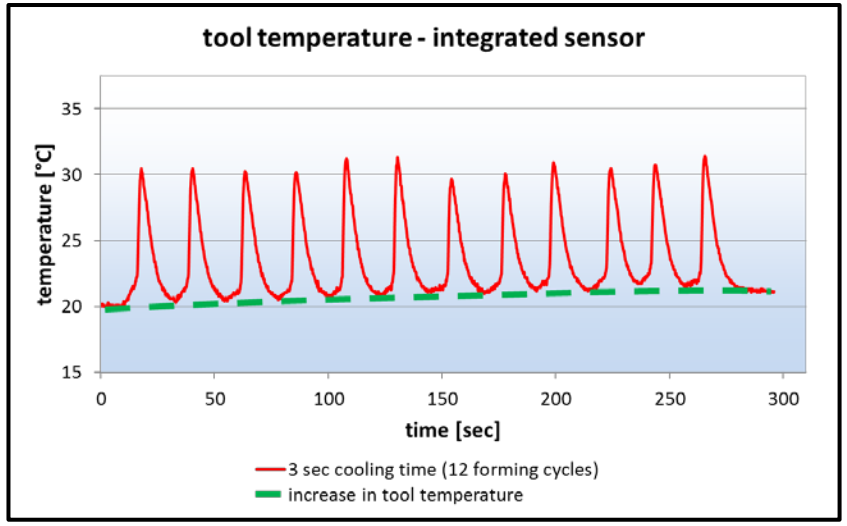
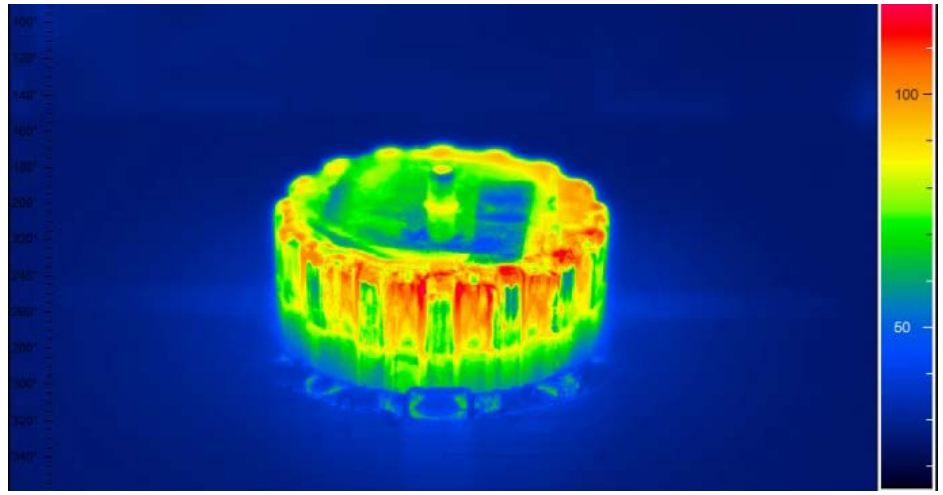
Functionalization of additive components
Applications

- MANUNET project “HiperFormTool”
  - Integration of a thermocouple into the punch → proof of concept
  - Only 3 mm distance to the surface
  - Significant reduction of cooling/holding time from 10 s to 3 s



Temperature profile over 12 forming cycles at 3 seconds holding/cooling time



Re-cooling additively manufactured tool punch

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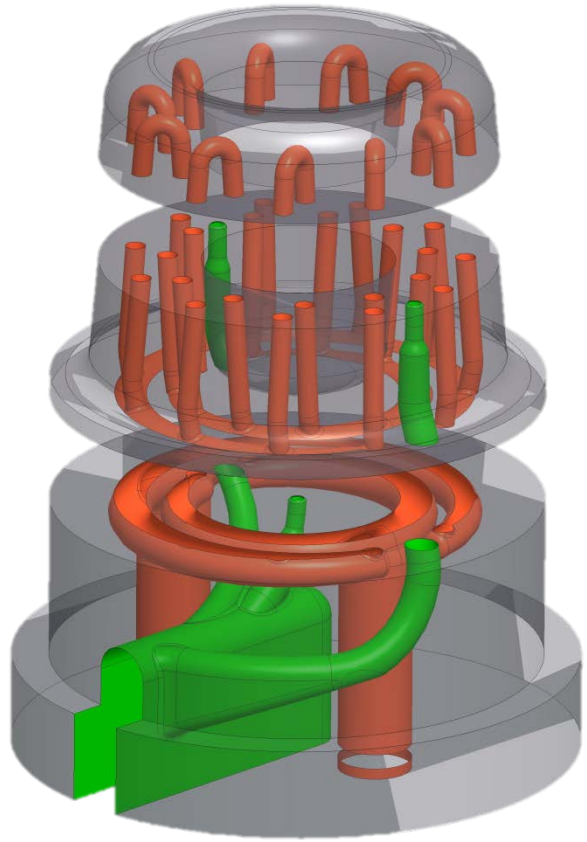
Uddeholm AM insert

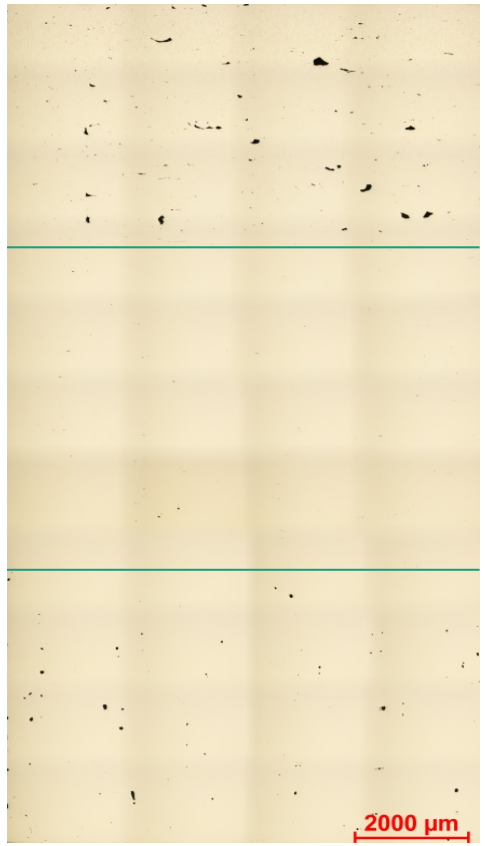
Uddeholm AM insert
Objectives

- Parameter qualification for Corrax® material (M2 Cusing)
- CAD-design of a geometry for easy integration of the thermocouples
- Manufacturing of two high pressure die casting inserts with thermocouples
- Integration of 3 thermocouples (3 different positions) in each insert



Uddeholm AM insert
Parameter qualification

- Examples of parameter variations



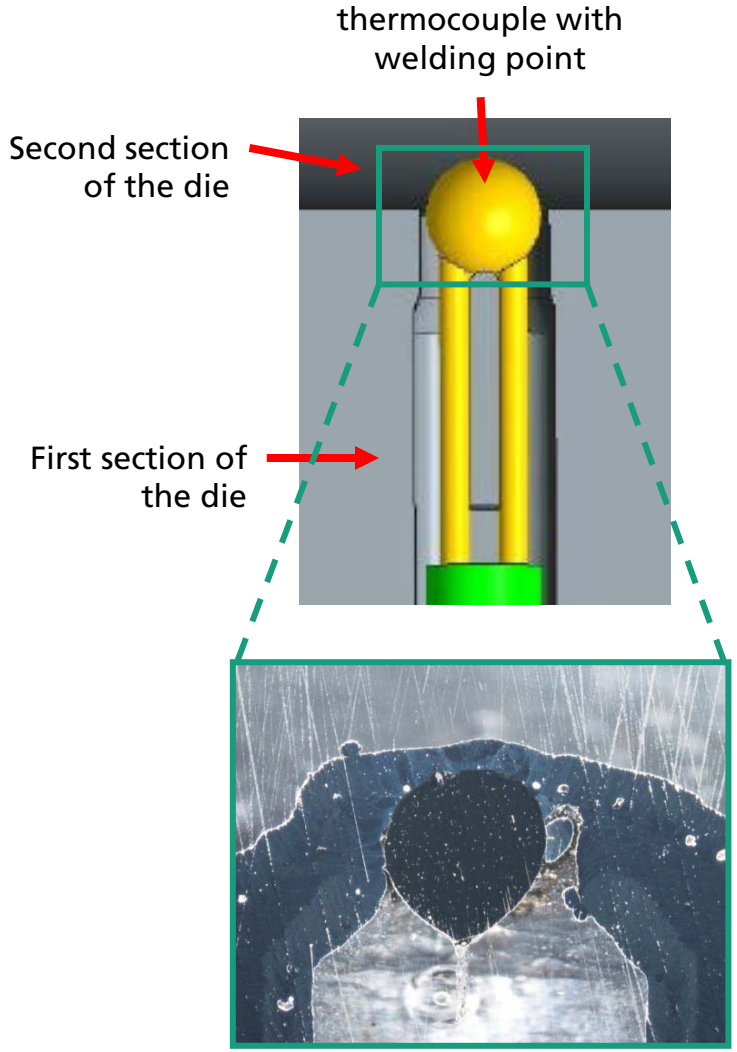
Layer thickness 60 µm, Laser Power 370 W

Layer thickness 25 µm, Laser Power 370 W

Layer thickness 45 µm, Laser Power 370 W

Uddeholm AM insert
Approach and challenges

- Thermocouple properties:
  - Thermocouple type K (min. -270 °C, max. 1300 °C)
  - Insolation up to 700 °C temperature resistance
- Costs equipment:
  - 100 m wire thermocouple type K ~ 90,00 €
  - Price for a plug ~ 2,00 €/unit
  - Costs for a appropriate reader/amplifier with 8 or 16 channels varies from 300,00 € up to 5000,00 €
- Preparation before integration:
  - Cut to size
  - Welding the leads together

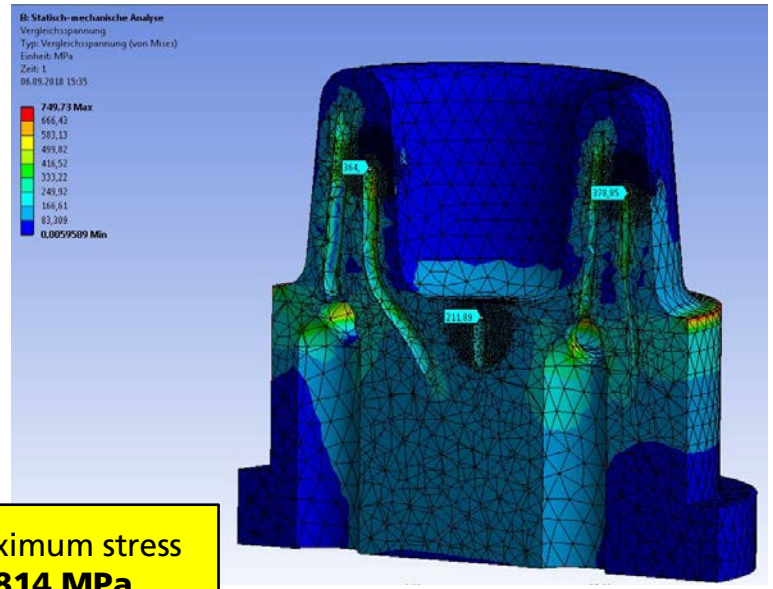


Thermocouple integration, CAD model and microscopic image (exemplary)

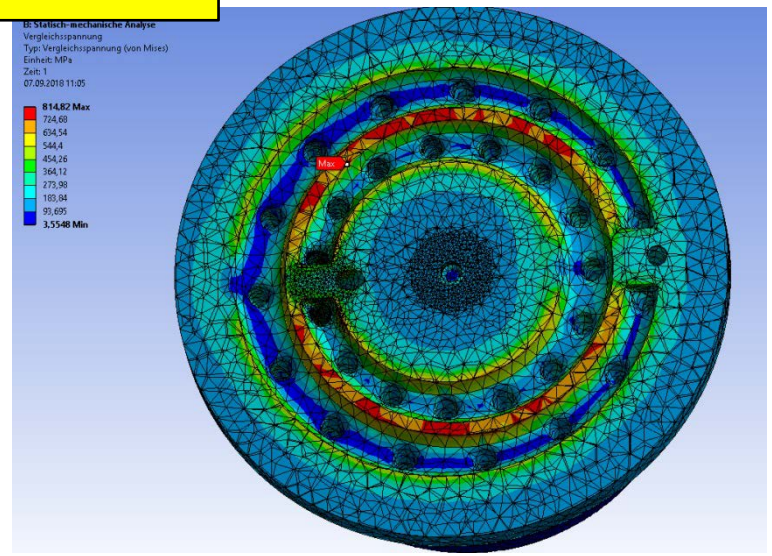
Uddeholm AM insert
Approach and challenges

- CAD design including cooling channels and the position of the thermocouples as well as the powder material provided by Uddeholm
- Parameter qualification for Corrax® material (Concept Laser M2 Cusing)
- Design of the geometry for thermocouple integration
- FE analysis to verify integrity
- Build job and thermocouple integration
  - First iteration: two thermocouples couldn’t be integrated
  - Second iteration: successful integration of all thermocouples

Redesign



Maximum stress
814 MPa



Results FE analysis second iteration

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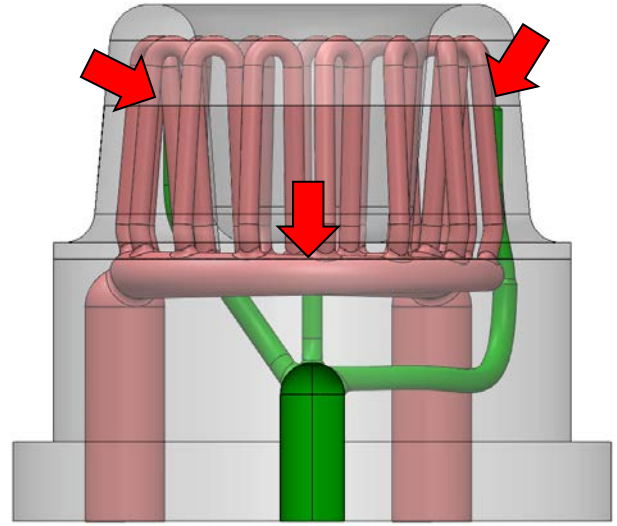
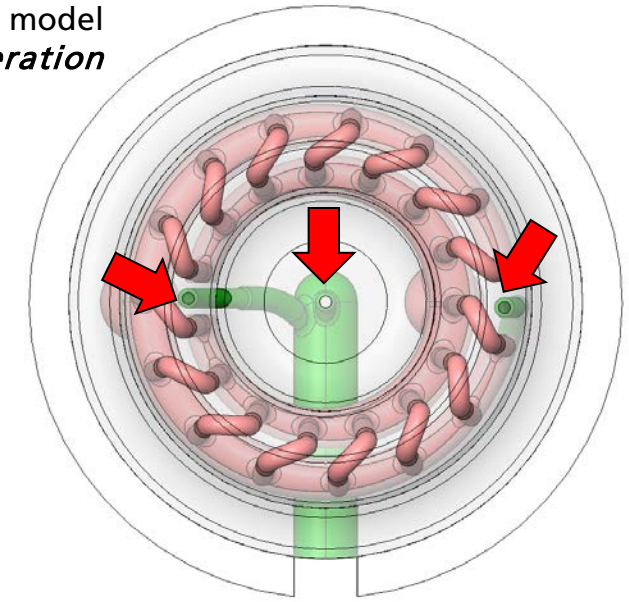
Uddeholm AM insert
Approach and challenges

- CAD design first iteration:
  - Design of the geometry for thermocouple integration
  - 16 parallel cooling channels
  - Smallest space between cooling and integration geometry ~ 1 mm
  - Diameters:
    - Thermocouple: 2,2 mm
    - Channel for thermocouple: 3,0 mm 2,5 mm
- Result
  - Because of the limited space between the cooling channels 2 thermocouples couldn’t be integrated

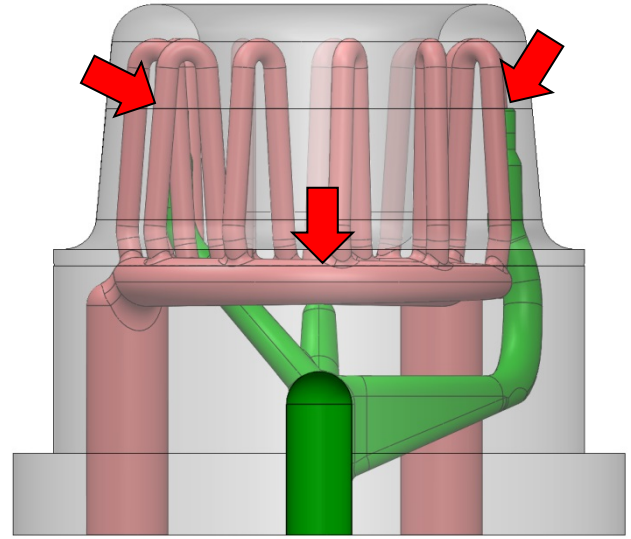


3D CAD model
first iteration

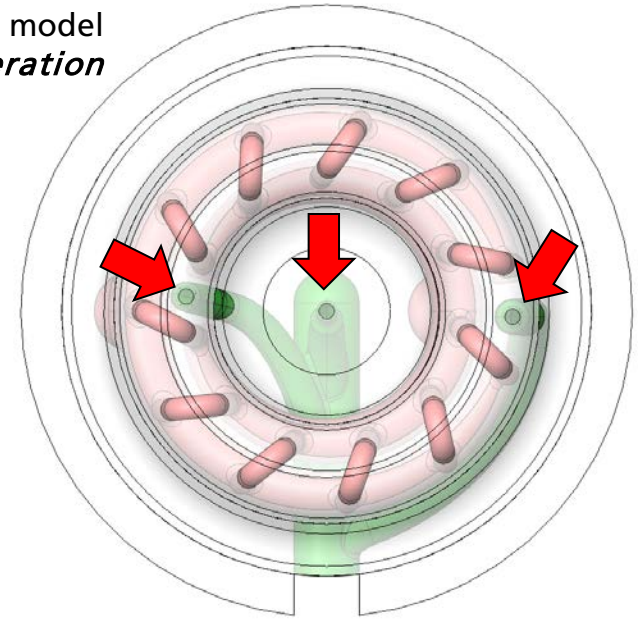


Uddeholm AM insert
Approach and challenges

- CAD design second iteration:
  - Reduction of the parallel cooling channels
  - 11 parallel cooling channels
  - More space for thermocouple integration
  - Smallest space between cooling and integration geometry ~ 1 mm
  - Diameters:
    - Thermocouple: 2,2 mm
    - Channel for thermocouple: 3,7 mm 2,5 mm
- Results
  - All thermocouples could be integrated



3D CAD model
second iteration

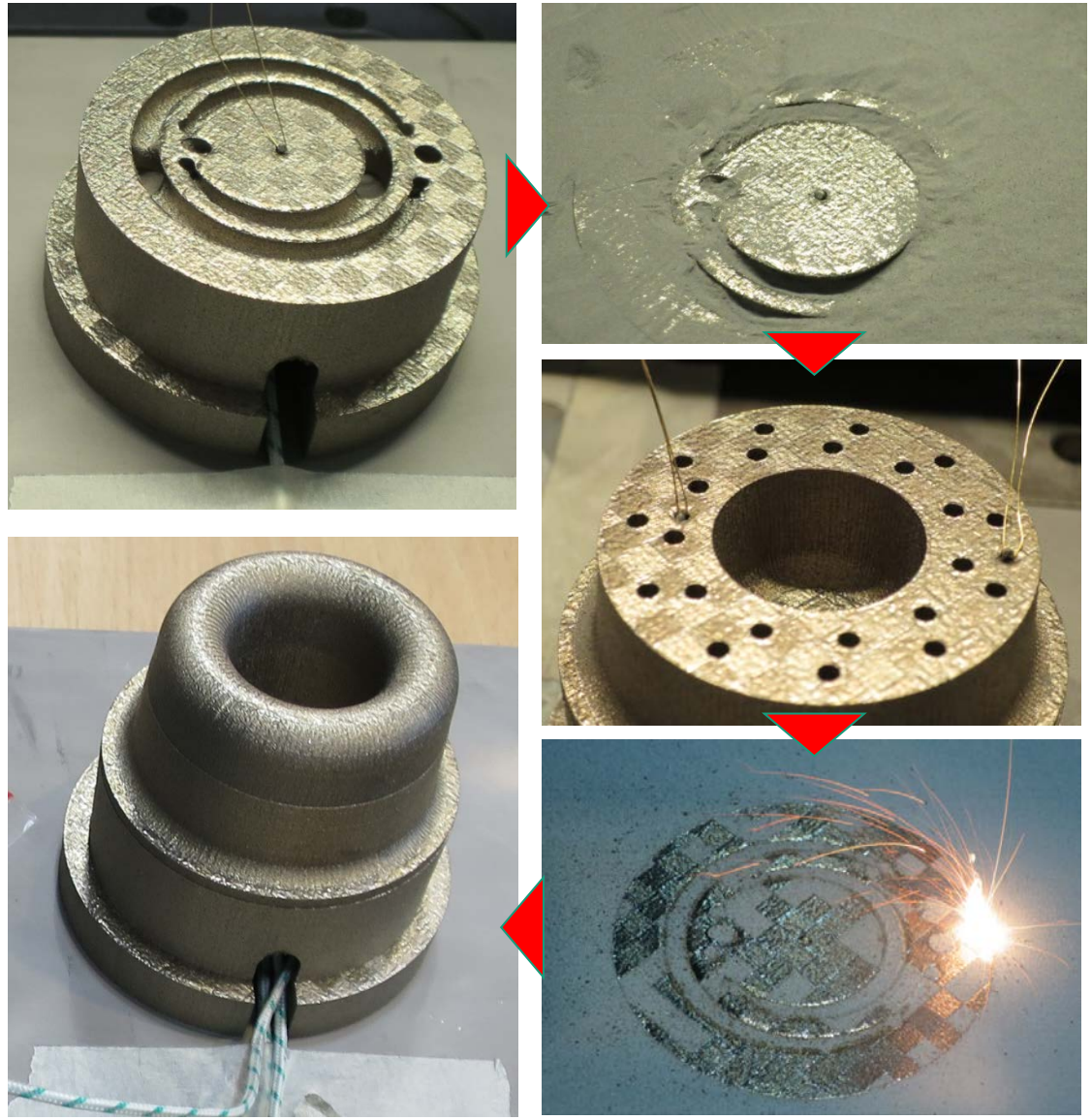


Uddeholm AM insert
Approach and challenges

- Manufacturing of the inserts
  - Total build time 29:15
  - Layer thickness 25 µm
  - Laser Power 370 W

Additively manufactured insert *first Iteration*

Process chain sensor integration



Additively manufactured insert *second Iteration*

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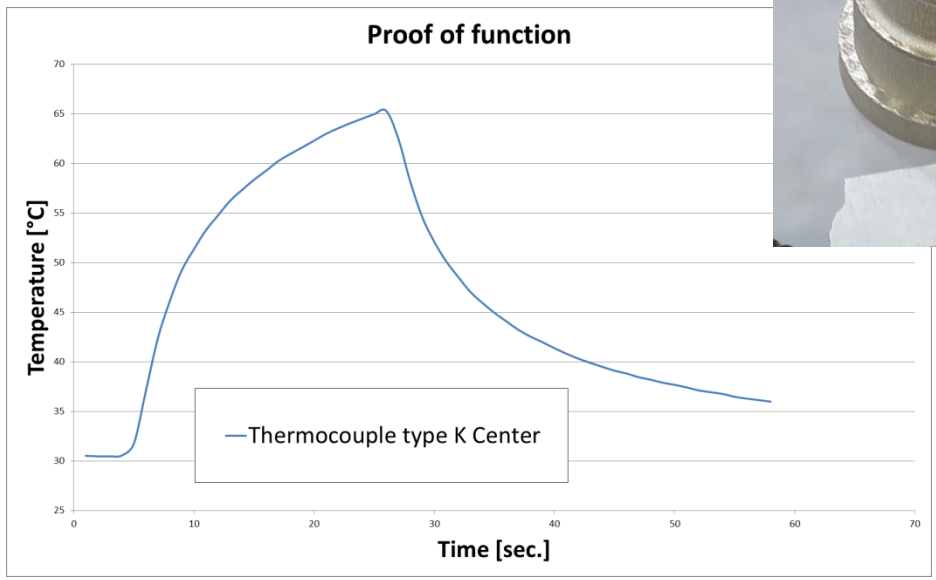
Uddeholm AM insert
Post process

1. Powder removal
2. Proof of function by using a heat gun
3. Separating the insert from the build plate using wire EDM

Testing thermocouples

Insert ready for EDM



Uddeholm AM insert
Summary

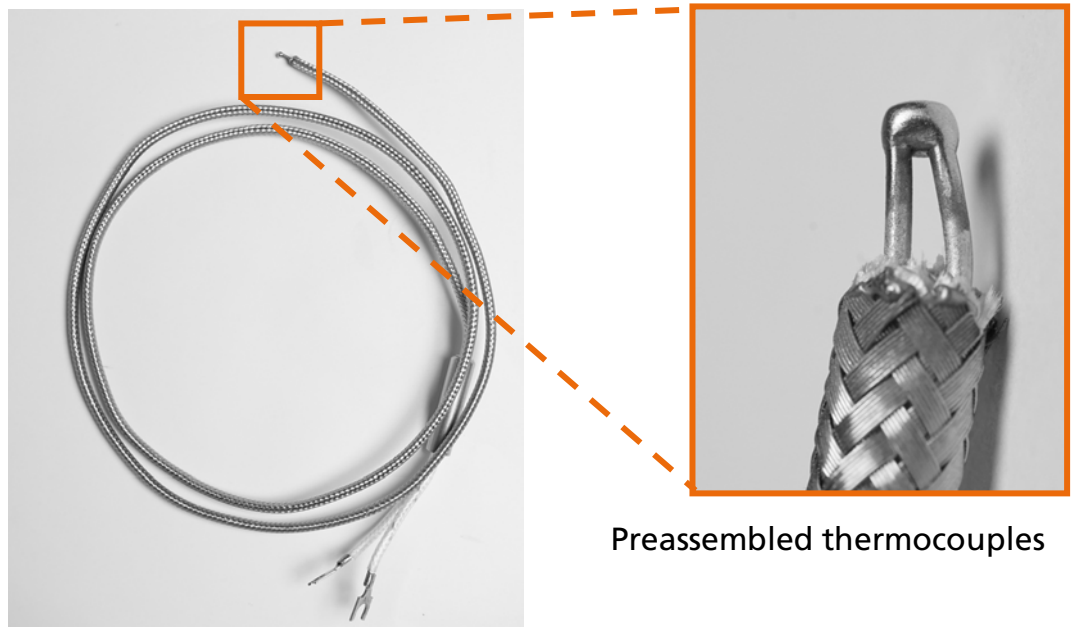
- Successful parameter qualification for Corrax® material (Concept Laser M2 Cusing)
- After the CAD- data optimization all thermocouples could be integrated
- Two Uddeholm AM inserts were manufactured by LBM
  - One insert with 1 thermocouple
  - One insert with all 3 thermocouples
- Proof of function was done after the LBM process
- Uddeholm AM inserts removed successfully form the build plate by wire EDM

Additiv manufactured Uddeholm AM insert with 3 thermocouples

Outlook & further research activities

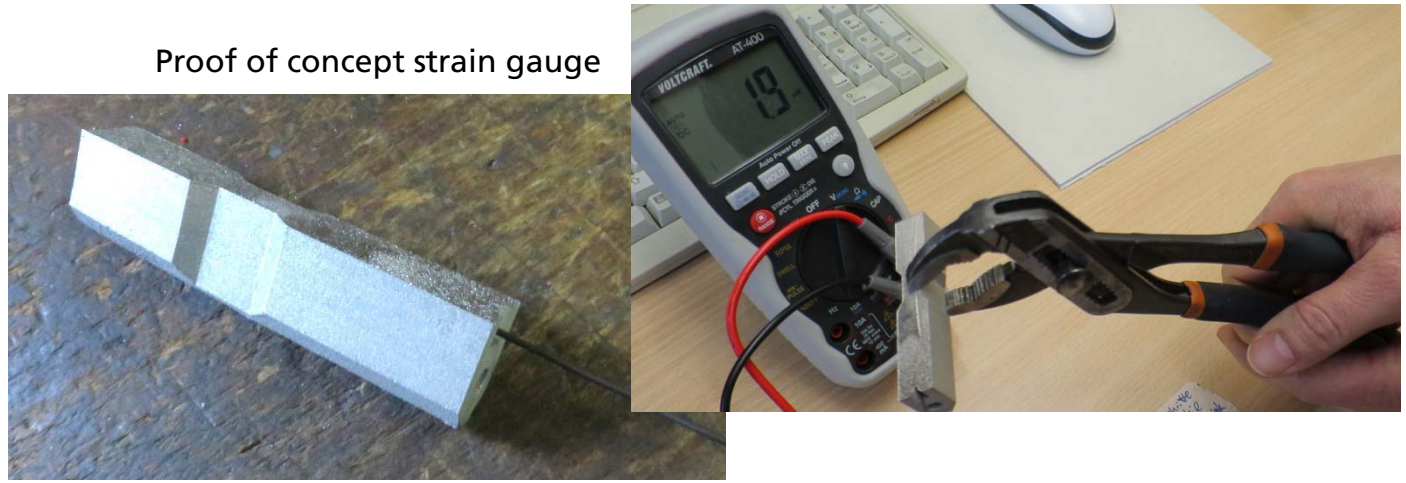
Outlook & further research activities

- Thermocouples:
  - Smaller preassembled thermocouples
    - ➢ Short preparation
    - ➢ Easier handling
  - Plug in solution (at the tool)
    - ➢ Easier post processing
      “no getting caught in the milling machine!!!”
- Different sensor types:
  - Direct write → tool wear
  - Acoustic → tool life
  - Strain gauge → tool load
- Automation of the integration process
- Wireless data transmission



Preassembled thermocouples

Proof of concept strain gauge



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Range of Service

- Assistance in the selection or development of a demanding series component
- Development and design of cooling systems
- Support for the overall tool design, independent design of the tool inserts for additive manufacturing
- Additive manufacturing of tooling inserts using laser beam melting at the IWU
- Implementation of the laser beam melted inserts in the tool
- Production ramp-up support, gathering of relevant manufacturing data for benchmark with conventional tool
- Evaluation of cycle time, tool life and dimensional accuracy and quality of molded/casted parts to a comparable, conventionally manufactured tool
- Integration of sensors within additively manufactured tools and tool inserts
- Specific trainings regarding additive manufacturing

Thank you for your attention

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»Additive Manufacturing«

Fraunhofer-Institute for Machine Tools and Forming Technology IWU

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