WEBINAR: Introduction to Additive Manufacturing (AM) using metal to medical technology

Lars Nyborg, Emmanuel Onillon, Eduard Hryha, Paul Häyhänen, Karolina Kazmierczak
## Agenda

<table>
<thead>
<tr>
<th>Time</th>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>09.00 – 09.05</td>
<td>Introduction – Karolina Kazmierczak / Paul Häyhänen (Chalmers Industriiteknik)</td>
</tr>
<tr>
<td>09.05 – 09.25</td>
<td>Additive Manufacturing possibilities in MANUELA project – Lars Nyborg (Chalmers)</td>
</tr>
<tr>
<td>09.25 – 09.35</td>
<td>Presentation of a real med tech case (cranial implant) – Emmanuel Onillon (CSEM)</td>
</tr>
<tr>
<td>09.35 – 09.50</td>
<td>Benefits of AM, Unique Selling Points – Eduard Hryha (Chalmers)</td>
</tr>
<tr>
<td>09.50 – 10.00</td>
<td>Info about Open Call (MANUELA) – Paul Häyhänen (Chalmers Industriiteknik)</td>
</tr>
<tr>
<td>10.00 – 10.30</td>
<td>Discussion, questions, open points – All</td>
</tr>
</tbody>
</table>

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement n° 820774.
Introduction

• Aim:
  • To introduce AM possibilities for medical technology through the EU project MANUELA
  • MANUELA - Additive Manufacturing using Metal Pilot Line – offerings for companies via “Open Call”
Additive Manufacturing using Metal Pilot Line

Lars Nyborg, Chalmers
This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement n° 820774.
Why

BENEFITS OF METAL AM

- Innovative and flexible product design enabling complex geometries
- Optimized material utilization reducing waste generation
- Energy cost savings
- Reduced lead times
- Enhanced product differentiation
# KEY INNOVATIONS OF MANUELA

<table>
<thead>
<tr>
<th>MANUELA project</th>
<th>Post-MANUELA pilot line offering</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TAILORED RECYCLABLE METAL POWDER</strong></td>
<td>Pre-industrial testing for specific AM products</td>
</tr>
<tr>
<td><strong>PILOT LINE DASHBOARD</strong></td>
<td>Full manufacturing chain available</td>
</tr>
<tr>
<td><strong>WORKFLOW OPTIMIZATION AND AUTOMATION</strong></td>
<td>Turn-key delivery/One-stop-shop</td>
</tr>
<tr>
<td><strong>REAL-TIME PROCESS MONITORING</strong></td>
<td>Time to market reduction</td>
</tr>
<tr>
<td><strong>QUALIFICATION AND CERTIFICATION STANDARD</strong></td>
<td>First-time-right product design</td>
</tr>
<tr>
<td></td>
<td>Qualified products for new segments</td>
</tr>
<tr>
<td></td>
<td>New materials integration into manufacturing line</td>
</tr>
<tr>
<td></td>
<td>‘Green’ technology approved by Life Cycle Analysis</td>
</tr>
<tr>
<td></td>
<td>Definition of AM guidelines</td>
</tr>
<tr>
<td></td>
<td>Advanced quality control process</td>
</tr>
</tbody>
</table>

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Chalmers IndustriTeknik (CIT) acts as single point of entry for the future customers to the MANUELA Pilot Line.

Chalmers IndustriTeknik will perform all front activities including marketing, customer relationship, evaluation of opportunities, requirements, offers, management and sourcing of complementary services, quality control, invoicing, and continuation of ecosystem building.

The Pilot Line will provide Open Access services according to the following flow:

**CLIENT**

- Brings idea and requirements to CIT

**CIT**

- Provides design, model, simulation, 3D printed product with characterization, as well as optimized process based on online monitoring and machine learning based data processing.

- Can act as neutral node
- Will not need to carry the infrastructure
- Can start as project office
- Can form agreements with the nodes (CSEM, POLITO, FU, CHALMERS) and others
- Possible to create a legal entity
Design flow

Design & Optimization

Process simulation

Testing

Analysis

Experimental Data

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement n° 820774.
Dashboard and Digital Thread Management

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RESOURCES AT CHALMERS

<table>
<thead>
<tr>
<th>Printer</th>
<th>Picture</th>
<th>Build Vol. (mm)</th>
<th>Method</th>
<th>Material</th>
<th>Software</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>EOS M100 (1 unit)</td>
<td><img src="image" alt="EOS M100" /></td>
<td>Ø 100 x 95 (incl. build plate)</td>
<td>LPBF</td>
<td>Ni-base, steel, tool steel, Al-alloy, bronze, HEA</td>
<td>Magics</td>
<td>N2 or Ar</td>
</tr>
<tr>
<td>EOSM290 (1 unit)</td>
<td><img src="image" alt="EOSM290" /></td>
<td>250 x 250 x 325 (incl. build plate)</td>
<td>LPBF</td>
<td>Ni-base, steel, tool steel Stainless steel</td>
<td>Magics</td>
<td>N2 or Ar EOSTATE process monitoring</td>
</tr>
<tr>
<td>ZYYX+ (3 units)</td>
<td><img src="image" alt="ZYYX+" /></td>
<td>265x225x195</td>
<td>FDM</td>
<td>ProPLA, ProABS, ProFLEX</td>
<td>Simplify3D</td>
<td>Z-layer: 50 um x-y: 13 um positioning</td>
</tr>
<tr>
<td>Markforged (1 unit)</td>
<td><img src="image" alt="Markforged" /></td>
<td>320x132x154</td>
<td>FDM</td>
<td>Nylon, Onyx, Glass fibre, Carbon fibre, Kevlar</td>
<td>Via Markforged web service</td>
<td>Z-layer: 100 um</td>
</tr>
<tr>
<td>Zortrax Inspire (1 unit)</td>
<td><img src="image" alt="Zortrax Inspire" /></td>
<td>132x74x175</td>
<td>UV photopolymerization</td>
<td>Resins</td>
<td>Z-suite</td>
<td>Z-layer: 25 um x-y: 50 um</td>
</tr>
</tbody>
</table>

- Dedicated printers (metals, polymers and composites)
- CAM2 competence centre (hosted by Chalmers)
- Application centre under development (hosted by RISE IVF)
- Design, pre-processing and process modelling software (CAD, Magics, Ansys, Simufact,...)
- Materials and powder characterisation
- Materials testing
- Post-processing
## RESOURCES AT POLITO

<table>
<thead>
<tr>
<th>Printer</th>
<th>Picture</th>
<th>Build. Vol (mm)</th>
<th>Method</th>
<th>Materials</th>
<th>Software</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>EOS M270</td>
<td><img src="image1.png" alt="Picture" /></td>
<td>250<em>250</em>215</td>
<td>LPBF</td>
<td>Al-based, Ni-based, Ti-based, Steels</td>
<td>Magics</td>
<td>N₂ or Ar</td>
</tr>
<tr>
<td>EOS M400</td>
<td><img src="image2.png" alt="Picture" /></td>
<td>400<em>400</em>400</td>
<td>LPBF</td>
<td>CoCr alloy In718 AlSi10Mg</td>
<td>Magics</td>
<td>N₂ or Ar</td>
</tr>
<tr>
<td>Concept Laser MLab</td>
<td><img src="image3.png" alt="Picture" /></td>
<td>90<em>90</em>80</td>
<td>LPBF</td>
<td>Al-based, Ni-based, Ti-based…</td>
<td>Magics</td>
<td>N₂ or Ar</td>
</tr>
<tr>
<td>Printsharp 250</td>
<td><img src="image4.png" alt="Picture" /></td>
<td>250<em>250</em>300</td>
<td>LPBF</td>
<td>Al-based, Ni-based, Ti-based, Steels</td>
<td>Magics</td>
<td>N₂ or Ar</td>
</tr>
<tr>
<td>Arcam A2X</td>
<td><img src="image5.png" alt="Picture" /></td>
<td>200<em>200</em>280</td>
<td>EBM</td>
<td>Ti-based Ni-based</td>
<td>Magics</td>
<td>Vacuum</td>
</tr>
</tbody>
</table>

- Dedicated printers (metals, polymers and composites)
- CIM4.0 Competence Center
- Design, pre-processing and process modelling software (CAD, Magics...)
- Material development (gas atomisation)
- Materials and powder characterisation
- Materials testing
- Post-processing (Heat treatments, HIP and finishing)
RESOURCES AT POLITO

WHAT

Other metal equipment
- PSI Gas atomisation system
- Quintus Hot Isostatic Pressing (HIP)
- Ovens for post processing

Polymer based AM systems
- SLS EOS Formiga (Nylon and Nylon matrix composites)
- FDM (ABS, PC, PLA, Nylon…)
  - 3ntr A4
  - Stratasys F370 and Dimension Elite
  - Markforged Mark Two
- DLP
- Stereolithography
### RESOURCES AT FAU

**WHAT**

<table>
<thead>
<tr>
<th>Printer</th>
<th>Picture</th>
<th>Build. Vol. (mm)</th>
<th>Method</th>
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<th>Software</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Athene</td>
<td><img src="image" alt="Athene" /></td>
<td>120 × 120 × 200</td>
<td>EBM</td>
<td>Ti-based alloys</td>
<td>Freely programmable</td>
<td>Vacuum, 6 kW, BSE-detector (online monitoring)</td>
</tr>
<tr>
<td>A2</td>
<td><img src="image" alt="A2" /></td>
<td>200 × 200 × 200</td>
<td>EBM</td>
<td>Ni-based superalloys; high temperature materials</td>
<td>Arcam &amp; Magics</td>
<td>Vacuum</td>
</tr>
<tr>
<td>Q10 plus</td>
<td><img src="image" alt="Q10 plus" /></td>
<td>200 × 200 × 200</td>
<td>EBM</td>
<td>Ti-based, Cu-based, Co-based alloys</td>
<td>Arcam &amp; Magics</td>
<td>High brightness cathode: LaB$_6$ (higher print resolution, long service time)</td>
</tr>
<tr>
<td>Freemelt One</td>
<td><img src="image" alt="Freemelt One" /></td>
<td>130 × 200 (Ø × H)</td>
<td>EBM</td>
<td>Unlimited</td>
<td>Freely programmable</td>
<td>Vacuum, 6 kW, LaB$_6$ cathode online monitoring, small build tank</td>
</tr>
</tbody>
</table>

- Dedicated printers (metals, composites)
- Design, pre-processing and process modelling software (CAD, Magics...)
- Application centre (ZMP)
- Materials and powder characterisation
- Materials testing
- Post-processing (Heat treatments)
## RESOURCES AT FAU

<table>
<thead>
<tr>
<th>Device/Device</th>
<th>Picture</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FEI – Helios NanoLab 600i FIB Workstation</strong></td>
<td><img src="image1.png" alt="Picture" /></td>
<td>High-resolution Scanning Electron Microscope (SEM) equipped with Energy-Dispersive X-ray spectroscopy (EDX), Electron BackScatter Diffraction (EBSD) and Focused Ion Beam (FIB).</td>
</tr>
<tr>
<td><strong>Microprobe Jeol JXA 8100</strong></td>
<td><img src="image2.png" alt="Picture" /></td>
<td>Electron Probe MicroAnalyzer (EPMA) for the chemical analysis with high local resolution.</td>
</tr>
<tr>
<td><strong>Frauenhofer EZRT CT Alpha system</strong></td>
<td><img src="image3.png" alt="Picture" /></td>
<td>Computed Tomography (CT) for three-dimensional imaging of complex parts.</td>
</tr>
<tr>
<td><strong>Ovens (vacuum, inert gas) for heat treatments</strong></td>
<td><img src="image4.png" alt="Picture" /></td>
<td>FCT - Pressure sintering furnace; Gero – HTK 25 sintering furnace; Gero – LHTM 250/300 vacuum glowing furnace</td>
</tr>
<tr>
<td><strong>Optical &amp; laser microscopes</strong></td>
<td><img src="image5.png" alt="Picture" /></td>
<td>Carl Zeiss – Axio A1m Imager; Carl Zeiss – SteREO; Olympus – Lext OLS 4000; Carl Zeiss – Axio M1m Imager</td>
</tr>
<tr>
<td><strong>Malvern – Mastersizer 3000</strong></td>
<td><img src="image6.png" alt="Picture" /></td>
<td>Laser diffraction for the determination of particle size distribution from 0.01 to 3500 µm</td>
</tr>
<tr>
<td><strong>Sigmatest – Creep tester</strong></td>
<td><img src="image7.png" alt="Picture" /></td>
<td>Characterization of creep properties of metallic compounds</td>
</tr>
</tbody>
</table>

- Dedicated printers (metals, composites)
- Design, pre-processing and process modelling software (CAD, Magics... )
- Application centre (ZMP)
- Materials and powder characterisation
- Materials testing
- Post-processing (Heat treatments)
## RESOURCES AT RISE IVF

### WHAT

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<tr>
<th>Printer</th>
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</thead>
<tbody>
<tr>
<td>SLM15SHL</td>
<td><img src="image1.png" alt="Image" /></td>
<td>115 x 157 x 130</td>
<td>LINS</td>
<td>Ni-base, steel, Ti-6Al-4V, Inconel</td>
<td>Magics</td>
</tr>
<tr>
<td>SLM280</td>
<td><img src="image2.png" alt="Image" /></td>
<td>300 x 200 x 300</td>
<td>LINS</td>
<td>Ni-base, steel, Ti-6Al-4V, Inconel</td>
<td>Magics</td>
</tr>
<tr>
<td>Formlabs Form 2</td>
<td><img src="image3.png" alt="Image" /></td>
<td>145 x 145 x 175</td>
<td>SLA</td>
<td>Resin</td>
<td>Form</td>
</tr>
<tr>
<td>Ceramtec 7500</td>
<td><img src="image4.png" alt="Image" /></td>
<td>76 x 131 x 170</td>
<td>LCM</td>
<td>Ceramics</td>
<td>Form</td>
</tr>
<tr>
<td>RBAM</td>
<td><img src="image5.png" alt="Image" /></td>
<td>Ca. 302 x 302</td>
<td>Laser</td>
<td>Thermoplastics, metal, ceramic</td>
<td>Simplify</td>
</tr>
</tbody>
</table>

An assortment of multi-material desktop printers.
Thank you
Use Case – cranial implant (CEIT)

Emmanuel Onillon, CSEM
Overview

• Which tools will be available?
• What will be the design flow?
• Cranial implant device example
Design tools

• Covers the full development process:
  • Design analysis
  • Design optimization (APEX GD)
  • Process simulation (Simufact)
  • Manufacturing following
Design flow

Design & Optimization

Process simulation

DEVELOP

General architecture → Define Boundary conditions → Optimization algorithms

QUALIFY

Testing → Analysis → Experimental Data

Experimental Data

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Med.tech design example – cranial implant

• Ti6Al4V ELI 1 mm thickness part
• Printing orientation optimization for deformation minimization
Thank you
AM benefits – medical technology applications

Lars Nyborg, Chalmers
Additive Manufacturing

- ASTM categorizes additive manufacturing into seven process categories:
  - Binder jetting
  - Directed energy deposition
  - Material extrusion
  - Material jetting
  - **Powder bed fusion**
  - Sheet lamination
  - Vat photopolymerization
Powder bed fusion

- Powder bed fusion — an additive manufacturing process in which thermal energy selectively fuses regions of a powder bed
- Materials: Metal, polymer and ceramic powder
- Powder bed fusion:
  - the most growing technique
  - laser or electron beam is used to melt and fuse material powder together layer by layer
  - presence of the support structures – needs to be removed after AM fabrication
  - anisotropy – grain growth in the built direction
  - typically requires post-treatment – heat treatment, hot isostatic pressing, etc. in order to relieve residual stresses and minimize number of defects (pores, lack of fusion, etc.).
Laser Based Powder Bed Fusion - Metal

- LB-PBF/m:
  - performed under protective gas
  - larger built plates - 800 x 400 x 500 mm (x,y,z)
  - variety of materials available
  - powder reusability
  - fine powder – 20-80 µm is used – possibility to built small channels and obtain finer surfaces
  - possibility to use number of lasers simultaneously – increase productivity
Key features of materials produced by AM

- Fine columnar microstructure
- Anisotropy in Z (build) direction
- Typically densities of $\geq 99.9\%$ are reached for optimized processes
316L Stainless Steel

Properties similar or better than wrought material for established materials/processes

C. Pauzon et al., Materials and Design, V179(2019), 107873
Microstructure of AM materials – LPBF-316L

- Large elongated grains in building direction
- Small grains close to the surface
- Random orientation

Design of the component taking into account AM microstructure

A. Leicht etc., Materials Characterisation, V143, pp.137-143
# Robust Powder for Additive Manufacturing

<table>
<thead>
<tr>
<th>Technology</th>
<th>Alloys</th>
<th># of Alloys</th>
</tr>
</thead>
</table>
| PBF-L      | **Aluminum**: Al-10Si-Mg, Al-12Si, Al-7Si-0.6Mg, Al-9Si-3Cu, Scalmalloy  
**Cobalt**: Co-Cr, Co-Cr-WC  
**Copper**: Cu, Cu-10Sn  
**Nickel**: IN625, IN718, IN939, HX  
**Titanium**: Ti, Ti-6Al-4V  
**Stainless Steels**: 15-5 PH, 17-4 PH, 316L SS, INVAR 36  
**Tool Steels**: Maraging Steel, H13  
**Miscellaneous**: Gold, Platinum, Silver | 24 |
| PBF-EB     | **Cobalt**: Co-Cr  
**Nickel**: IN718  
**Titanium**: Ti, Ti-6Al-4V | 4 |

**Absence of powder developed for AM!**

Design of the powder material for AM!
Additive Manufacturing
Robust Powder for Additive Manufacturing

Powder recycling – Powder Bed Fusion - Laser

Virgin

Sputter

Reused

AM Material design for the robust powder recycling
Additive Manufacturing

• Electron Based Powder Bed Fusion (EB-PBF):
  • requires vacuum
  • used solely for metals and alloys
  • build plate 2000*200*180 mm and up to Ø350×380 mm
  • robust processing for some materials – application in biomedical and aerospace
  • low number of materials available (Ti, Ti6Al4V, CoCr, In718)
  • powder bed “pre-sintering”
  • lowers recyclability of the powder
  • restricts possibility to produce small channels
Additive Manufacturing

Manufacturing readiness level in various industry sectors

Aerospace
- Fuel injection
- Structural elements
- Blades

Tooling
- Tooling inserts

Automotive
- Air ducts
- Formula 1 components

Medical
- Crowns and copings
- Artificial hip joints
- Medical instruments

Examples

Courtesy of Roland Berger, Source: Introduction to additive manufacturing technology, EPMA
EBM technology

- Medical:
  - Standard implants
  - Customized implants

Courtesy: Arcam

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EBM technology – customized implants

EOS – medical

• Dental
• Tools
• Pre-operational
• Customized implants
Markets - Dental

- Dental sector:
  - Dental instruments $6 Billion
  - Dental consumables $25 Billion
This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement n° 820774.
Thank you
Open Call

Paul Häyhänen, CIT

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Open Call for Business Development Cases - info

- Targeting European companies
- 10 business use cases to be selected in total
- Each case will be co-funded by the applicant and the MANUELA project at 50/50%
- Application through portal: https://apply.manuela-project.eu/
- Helpdesk and any questions about the Open Call: helpdesk@manuela-project.eu
Open Call for Business Development Cases - info

- Evaluation criteria
  - Concept and level of innovation
  - Impact and market potential
  - Implementation
Open Call for Business Development Cases – Schedule

• **Start 1 December -20** – The Call is open!

• **30 March -21** – First cut off for Applications and evaluation and selection of 5 use cases for Implementation

• **30 September -21** – Second and last cut off for Applications and evaluation and selection of 5 use cases for Implementation

• Winners will be notified directly, and planning of implementation will start

• **1 November –22** – All cases shall be processed and closed
Open Call for Business Development Cases – info

• Implementation
  • CIT is the interface with the company and project manages the implementation of the business development case
  • User requirements, process flows charts, resource allocation, budgeting, contract will be setup for each use case
  • Planning tool will be ProjectPlace
Business Development Cases

If you are interested in the Open Call contact us already now- the Call is open!
Contact

manuela@chalmersindustriiteknik.se

www.manuela-project.eu
Q&A Discussion