PROCESSING OF TI-BASED ALLOYS BY EBM: POWDER TO COMPONENT

- Introduction
- Process
- Powder
- Design
- Outlook
Fraunhofer IFAM: Branch Lab Dresden

Permanent staff: 67
Student employees: 30
Budget: 7.2 Mio. €
Industry: 32 %
Projects: 51 %
Public funding: 17 %
Investments: 1.3 Mio. €
Area: 2850 m²

(Budget 2018)

Director: Prof. Dr.-Ing. Bernd Kieback
Additive Manufacturing @ IFAM

- Laser beam melting (LBM) [HB]
- Electron beam melting (SEBM) [DD]
- 3D metal printing (3DMP) [DD]
- Fused filament fabrication (FFF) [DD, HB]
- 3D binder jetting (3DP) [HB]
EBM Process

Process Animation
SEBM Selective Electron Beam Melting

created for
Neue Materialien Fürth GmbH
www.nmfgmbh.de
EBM machines at IFAM Dresden

- A2X
  - 3 kW, tungsten filament
  - Build envelope 200² x 380 mm³
  - Suitable for temperatures up to 1150°C

- Q20+
  - 3 kW, LaB₆ cathode
  - Build envelope Ø 300 x 380 mm³
  - Automatic beam calibration
  - Process monitoring by LayerQam
Comparison EBM – LBM

<table>
<thead>
<tr>
<th>Property</th>
<th>EBM</th>
<th>LBM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam source</td>
<td>Electron gun</td>
<td>Laser</td>
</tr>
<tr>
<td>Powder</td>
<td>Coarse (45 – 105…150 µm)</td>
<td>Medium (10 – 45 µm)</td>
</tr>
<tr>
<td>Atmosphere</td>
<td>Vacuum</td>
<td>Inert gas</td>
</tr>
<tr>
<td>Beam deflection</td>
<td>Coils (very fast)</td>
<td>Galvanometer (fast)</td>
</tr>
<tr>
<td>Preheating</td>
<td>Electron beam (Ti-6Al-4V: 700°C)</td>
<td>Under development: 250 – 500°C</td>
</tr>
<tr>
<td>Residual stress / support</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Surface quality</td>
<td>Poor (Ra ≈ 40µm)</td>
<td>Medium (Ra ≈ 20µm)</td>
</tr>
<tr>
<td>Internal structures</td>
<td>Limited</td>
<td>Possible</td>
</tr>
<tr>
<td>Build rate (Ti-6Al-4V)</td>
<td>~80cm³/h</td>
<td>~30cm³/h</td>
</tr>
</tbody>
</table>
## EBM competence @ IFAM Dresden

<table>
<thead>
<tr>
<th>Powder</th>
<th>Design</th>
<th>Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accredited lab for characterization</td>
<td>Design rules</td>
<td>Process development</td>
</tr>
<tr>
<td>Assessment of new powder analytics</td>
<td>„Design for AM“, e.g. topology optimization</td>
<td>New materials</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Prototypes and Components</td>
</tr>
</tbody>
</table>

![Powder Image](image1.png)

![Design Image](image2.png)

![Process Image](image3.png)
Powder relevance for AM
Powder assessment: non-standard methods

**Characterization Method**
- Raking step
  - Raking test station
- Powder rheometry
  - Freeman FT4
- Dynamic avalanching test
  - Revolution Powder Analyser

**Parameters**
- Density of the raked layer
- Roughness parameters
- Irregularities (pores, inhomogeneities)
- Torque
- Axial force
- Avalanche angle
- Fractal dimension of the powder surface

**Relevance**
- Rake type
- Raking velocity
- Powder design
- Part: density, internal build flaws
- Flow behavior
- Powder feeding
- Influence on layer quality
- Flow behavior
- Powder feeding
- Influence on layer quality
Powder
Case study EBM – standard method

- 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

<table>
<thead>
<tr>
<th></th>
<th>Batch 1 (45 – 120 µm)</th>
<th>Batch 2 (45 – 150 µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hall Flow Test</td>
<td>28±2 s</td>
<td>22.5±0.2 s</td>
</tr>
<tr>
<td>Apparent Density</td>
<td>2.18 g/cm³</td>
<td>2.23 g/cm³</td>
</tr>
</tbody>
</table>
Powder
Case study EBM – non-standard method (rheometer)

<table>
<thead>
<tr>
<th>Pulver</th>
<th>BFE</th>
<th>SE</th>
<th>Processability</th>
</tr>
</thead>
<tbody>
<tr>
<td>TiAl-Pulver 45-125 µm</td>
<td>high</td>
<td>high</td>
<td>Not qualified</td>
</tr>
<tr>
<td>TiAl-Pulver 45-150 µm</td>
<td>low</td>
<td>low</td>
<td>applicable</td>
</tr>
</tbody>
</table>
Powder
Case study EBM – non-standard method (RPA)

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

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>Rotation Rate</th>
<th>Avalanche Energy</th>
<th>Energy Std Dev</th>
<th>Avalanche Time</th>
<th>Avalanche Angle</th>
<th>Rest Angle</th>
<th>Surface Fractel</th>
</tr>
</thead>
<tbody>
<tr>
<td>TLS-TIA-45-150</td>
<td>0.5 rpm</td>
<td>10.15 kJ/kg</td>
<td>4.90 kJ/kg</td>
<td>21 sec</td>
<td>31.4 deg</td>
<td>26.9 deg</td>
<td>2.36</td>
</tr>
<tr>
<td>TLS-TIA-45-125</td>
<td>0.5 rpm</td>
<td>12.76 kJ/kg</td>
<td>6.38 kJ/kg</td>
<td>21 sec</td>
<td>31.5 deg</td>
<td>26.5 deg</td>
<td>2.14</td>
</tr>
<tr>
<td>TLS-TIA-60-125</td>
<td>0.5 rpm</td>
<td>12.31 kJ/kg</td>
<td>4.90 kJ/kg</td>
<td>21 sec</td>
<td>31.0 deg</td>
<td>26.7 deg</td>
<td>2.27</td>
</tr>
<tr>
<td>TLS-TIA-45-125</td>
<td>0.5 rpm</td>
<td>12.14 kJ/kg</td>
<td>4.90 kJ/kg</td>
<td>21 sec</td>
<td>31.3 deg</td>
<td>26.4 deg</td>
<td>2.28</td>
</tr>
</tbody>
</table>

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

- Integration of parts → OK
- Mass reduction while satisfying load cases → OK (-50%)
- Consideration of assembly (e.g. rivets) → OK
Design & Process – Ti-6Al-4V
Components – Main Gear Bracket (II)

- MGB is relevant to security and fatigue stressed
  - weight 2,5 kg; dimension (180 x 170 x 150) mm³
  - build time: 29h
  - surface treatment (CNC milling, electro polishing)
  - due to its geometric complexity this component is "EBM only", since the support for LBM would be too extensive
Design & Process – Ti-6Al-4V
Components – Steering Column Mount (I)

- Conventional design consists of 18 parts
  - Two milled parts (Al)
  - Two clamping pieces (Al, water jetted)
  - 14 standard components
- Optimization goal:
  - Part integration
  - Weight reduction
  - Stiffness increase → better feedback to pilot
  - Assembly identical to conventional component
Design & Process – Ti-6Al-4V
Components – Steering Column Mount (II)

- Optimization targets achieved
- Post processing considered
  - Fixation in CNC-mill (red)
  - Allowance for mating face (green)

<table>
<thead>
<tr>
<th></th>
<th>Number of parts</th>
<th>Max. deformation</th>
<th>Weight</th>
<th>Fabrication time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>18</td>
<td>0,5 mm</td>
<td>514 g</td>
<td>1 Month</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>0,1 mm</td>
<td>334 g (65%)</td>
<td>1 Week</td>
</tr>
</tbody>
</table>
Process – TiAl
demonstrator: TC wheel (II)

- progress and problems
  - first test of multi-layer placement of TC wheels
  - build job finished successfully
  - CT scans indicate good reproducibility of parts (biggest issues for deviation: surface roughness)
Outlook - Powder

- 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
Outlook – Process
Materials

- Started projects for material qualification
  - Ni-base
  - Steel (austenitic, duplex)
- Started projects for “EBM only” material development
  - TiAl
  - Tool steel
Outlook – Process hybrid manufacturing

Project AGENT3D-IMProVe
- High wear rate due to material heterogeneity
- final machining is very material- and time-consuming
- → increase of thickness of wear-resistant material by hybrid manufacturing
- Near net shape manufacturing of top piece
Outlook – R&D and industrialization challenges

- **Productivity**
  - despite current efforts it is still too low (limited by layer thickness, beam power, no. of beam sources, pre- & post-heating)

- **Build Space**
  - build space is limited by beam power and number of beam sources

- **Quality Control**
  - current systems contain e.g. camera, but detectors known from SEMs are not implemented yet