Improved Surface Quality and Productivity in Ti Additive Manufacturing using EBM MultiBeam™

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Outline

• Introduction to Electron Beam Melting
  • Arcam AB
  • EBM process
  • EBM materials
  • EBM applications
• New MultiBeam™ functionality
  • Principles
  • Surface finish and resolution
  • Productivity
  • MultiBeam™ video
• Summary and conclusion
What is Arcam?

• Develops technology for additive manufacturing with EBM
• Swedish innovation, early 1990’s
• Arcam AB founded 1997
• Located in Gothenburg, Sweden
• First EBM machine delivered in 2003
• More than 60 systems installed worldwide
• Main focus (so far): Medical implants and aerospace parts made from titanium alloys
• Some well-known EBM users: Boeing, NASA, Airbus
The EBM process

- Typical powder size: 45-105 μm (-140/+325 mesh)
- Layer thickness: 0.05-0.2 mm
- 3kW electron beam
- Elevated build temperature, e.g. Ti-6Al-4V, ~700°C, γ-TiAl, >1000°C
- High vacuum: 10^{-5} mbar
- Build rate: 3-20 mm height/hour
- Build envelope: up to 350×200×200 mm (14×8×8 in.)
EBM Metal Powders

- Pre-alloyed
- Supplied by selected powder manufacturers
- No binders or additives
- Size fraction selected for safety and production economy
- Provided with optimized EBM machine parameters
EBM Materials

• "Commercial" processes developed for:
  • Ti-6Al-4V (Grade 5)
  • Ti-6Al-4V-ELI (Grade 23)
  • Titanium CP (Grade 2)
  • Gamma-TiAl, Ti-48Al-2Cr-2Nb
  • CoCr alloy F75

• Full compliance with ISO and ASTM standards

• Any metal with a melting point up to tungsten (3400°C) can be melted with a 3kW e-beam.
Other materials with proven EBM potential

- Ni-based superalloys (e.g. Alloy 625 & 718)
- Stainless steel (e.g. 17-4)
- Tool steel (e.g. H13)
- Aluminium (e.g. 6061)
- Hard metals (e.g. Ni-WC)
- Copper
- Beryllium
- Amorphous metals
- Niobium
- Invar
EBM Applications

- Aerospace
- Medical Implants
- Automotive
- Other
Lattice Structures

• Fully dense Ti parts combined with lattice structures, fabricated simultaneously.

• Applications:
  • Biomedical implants with trabecular structures enabling bone ingrowth
  • Light-weight parts
  • Components with tailored stiffness and strength
  • Filters, heat exchangers, catalyst carriers, …
CE-certified implant production since 2007

- Acetabular cups with engineered trabecular structures
- Ti-6Al-4V ELI, 12 cups in 13 hours, stackable 82 cups in 80 h
- > 35000 cups manufactured
- Approx. 7000 cups implanted
Turbine blades in $\gamma$-TiAl

- TiAl collaboration project with Avio SpA in Italy
- Demo turbine blades for the LP stage in GEnx engine
- 325 mm build height
- Dimensional tolerance $\pm 0.1$ mm
- Net build time 7 h / blade
MultiBeam™

- Dividing one beam into several beams by rapidly moving the electron spot, keeping several melt pools alive.

- With single beam, the current and scanning speed are limited by melt pool viscosity
- With MultiBeam™, viscosity is no longer a limitation
- MultiBeam™ allows lower beam power per melt pool → improved precision
- MultiBeam™ allows higher total beam power → shorter melting time
MultiBeam™

Two separate MultiBeam™ strategies:

• Continuous MultiBeam™ = all melt pools in liquid phase all the time
  • Up to 8 melt pools simultaneously
  • Higher speed
  • More energy efficient
  • Suitable for hatching

• Discrete MultiBeam™ = melt pools solidify before the beam is back
  • Up to 50 melt pools
  • Comparably lower speed
  • No geometric dependence
  • Higher resolution
  • Ideal for contours and fine details
MultiBeam™ melt line on a Ti-6Al-4V plate

1 of 8 continuous melt pools

1 of 8 intermediate melt pools

1 of 8 discrete melt pools
MultiBeam™ – Ti-6Al-4V surface finish and resolution

- Five Ti-6Al-4V specimens of identical geometry
- Plane vertical surface investigated with optical interference profilometry
- 3 x 1,5 mm surface area

<table>
<thead>
<tr>
<th>Sample #</th>
<th>Mode</th>
<th>Surface status</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 &amp; 2</td>
<td>Discrete MultiBeam</td>
<td>As-built</td>
</tr>
<tr>
<td>3</td>
<td>Continuous MultiBeam</td>
<td>As-built</td>
</tr>
<tr>
<td>4</td>
<td>Single beam</td>
<td>As-built</td>
</tr>
<tr>
<td>5</td>
<td>Discrete MultiBeam</td>
<td>Sand blasting for 20 sec.</td>
</tr>
</tbody>
</table>

- Five Ti-6Al-4V specimens of identical geometry
- Plane vertical surface investigated with optical interference profilometry
- 3 x 1,5 mm surface area
MultiBeam™ – Ti-6Al-4V surface finish and resolution

#1 & #2
Discrete MB

#3
Continuous MB

#4
Single Beam

#5
Discrete MB Sand-blasted
## MultiBeam™ – 3D Surface Texture Parameters (ISO 25178)

<table>
<thead>
<tr>
<th>Ti-6Al-4V Specimen #</th>
<th>Sa [μm]</th>
<th>Sq [μm]</th>
<th>Sz [μm]</th>
<th>Str</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Discrete MB</td>
<td>23</td>
<td>29</td>
<td>167</td>
<td>0.74</td>
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<tr>
<td>2 Discrete MB</td>
<td>22</td>
<td>28</td>
<td>157</td>
<td>0.82</td>
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<tr>
<td>3 Continuous MB</td>
<td>25</td>
<td>32</td>
<td>166</td>
<td>0.29</td>
</tr>
<tr>
<td>4 Single Beam</td>
<td>41</td>
<td>52</td>
<td>302</td>
<td>0.24</td>
</tr>
<tr>
<td>5 Discrete MB, sand-blasted</td>
<td>17</td>
<td>23</td>
<td>140</td>
<td>0.23</td>
</tr>
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*Sa, Sq, Sz = traditional height parameters
*Str = spatial parameter (close to 1 for smooth surfaces)*

- MultiBeam improves *Sa, Sq, Sz*
- Discrete MultiBeam improves *Str*
- Abrasive blasting smoothens but reveals underlying pattern of the surface
MultiBeam\textsuperscript{TM} improves productivity – Why?

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<th>Process step</th>
<th>Single Beam current</th>
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<tr>
<td>2 Raking powder</td>
<td>-</td>
</tr>
<tr>
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</tr>
<tr>
<td>4 Support melting</td>
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</tr>
<tr>
<td>5 Contour melting</td>
<td>low</td>
</tr>
<tr>
<td>6 Hatch melting</td>
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<td>7 Net structure melting</td>
<td>low</td>
</tr>
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Time consuming steps!
MultiBeam™ improves productivity – Why?

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<th>MultiBeam™ current</th>
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MultiBeam™ reduces the net build time with ~ 30%!
What does MultiBeam™ look like?
Summary and conclusions

EBM in general:
- Freedom in design and low material waste
- Ti material properties compliant with standards
- Integrated lattice structures
- Proven Ti productivity – in continuous serial production since 2007
- Large potential for other Ti alloys

With MultiBeam™:
- Improved Ti productivity
- Improved Ti surface quality

New prospects with MultiBeam™:
- New materials, e.g. intermetallic Ti
- MultiBeam™ on hatching → even higher build rate
- Reducing currents to μA → ultrafine lattice structures
Thank you!

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