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Arcam in short

• Arcam AB incorporated 1997
• Listed on NASDAQ OMX Stockholm
• First EBM system delivered in 2003 to NC State University
• About 150 systems installed worldwide
• About 230 people in Arcam Group, in Sweden, US, Canada, UK, Italy and China
• Arcam Group includes powder manufacturer and contract manufacturer of orthopedic implants

Electron Beam Melting (EBM®)

Same same, but different…

EBM is powder bed fusion. So where is the laser?

ASTM F2792:
There are some similarities between EBM and laser processes, but also distinct differences:

• EBM is a hot process
• EBM uses high vacuum
• EBM has high beam power and very fast scan speed
• Electrons have higher penetration depth into solid material

Electron Beam Melting (EBM®)

Same same, but different…

Hot process - the build is continuously held at 500-1000°C

• Low residual stresses
• Semi-sintered powder helps to support build
• Very few solid supports needed
• No need to anchor supports to build platform
• Advanced stacking of parts possible

High vacuum (10⁻⁵ mbar) = High purity environment

• No contamination risk from protective gas
• Very low gas consumption
• Excellent for reactive metals like Ti

High beam power and fast scan speed = Many degrees of freedom

• Layer thickness
• Particle size
• Build temperature
• Scanning algorithms, multibeam features, etc.
• Full access to beam control parameters

Motivation for developing Alloy 718 for EBM

Arcam Mission Statement:
Arcam provides a cost-efficient Additive Manufacturing solution for production of metal components, focusing on aerospace components and orthopedic implants.

Ti-6Al-4V is the workhorse of Ti industry since decades. Ti-6Al-4V has also been the #1 material for Arcam since 2004.

Similarly, Alloy 718 is the workhorse of nickel superalloys, widely used for aerospace and other applications requiring high temperature strength and oxidation resistance.

Alloy 718 is a natural choice when we expand our materials portfolio.
Process development for EBM

Iterative, experimental procedure

- Searching for a good powder quality
- Finding the right process temperature
- Developing basic process parameters
- Evaluating material properties
- Refining process parameters for complex geometries
- Testing heat treatments (if needed)
- Testing recyclability
- Etc.

Initial goal for Alloy 718:

- Develop a process that complies with the basic requirements (chemical composition, tensile properties) in well-known standards (ASTM F3055, AMS 5662, etc.)

718 EBM Process - Basic data of 1st release

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tr>
<td>Layer thickness</td>
<td>75 µm</td>
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<tr>
<td>Powder size</td>
<td>25-105 µm</td>
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<tr>
<td>Powder type</td>
<td>Plasma atomized</td>
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<tr>
<td>Build speed</td>
<td>~ 3-4 mm per hour</td>
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<tr>
<td>Process temperature</td>
<td>~ 1000°C</td>
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<td>EBM machine</td>
<td>A2X</td>
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<tr>
<td>Software version</td>
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<tr>
<td>Post heat treatment required</td>
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</table>

Video showing EBM process steps for Alloy 718

1. Powder raking – triple stroke
2. Preheating 1 – covers full build envelope
3. Preheating 2 – covers melt areas only
4. Contour melting – with Multibeam technology
5. Hatch melting – with Multibeam technology (new in EBM Control v.4)
6. Support melting – with Multibeam technology
7. Postheating – maintains the heat balance
8. Lowering build table – by one layer thickness (75 µm for Alloy 718)

Video of 718 EBM process

718 Powder Morphology

- Gas atomized
- Rotary atomized
- Plasma atomized
- Powder cross section
- EBM build cross section

Powder porosity → Build porosity
718 microstructure, "cold" build

Horizontal (XY)

No cracks, only δ-precipitation in grain boundaries

Vertical (Z)

Reduced precipitation in grain boundaries

718 microstructure, "hot" build

Horizontal (XY)

Reduced precipitation in grain boundaries

Vertical (Z)

718 Tensile Test Requirements

AMS 5662

<table>
<thead>
<tr>
<th>Description</th>
<th>Stress Relieved</th>
<th>Stress Relieved &amp; HIPed</th>
<th>Stress Relieved &amp; HIPed &amp; Solution Treated</th>
<th>Stress Relieved &amp; HIPed &amp; Solution Treated &amp; Aged</th>
<th>Stress Relieved &amp; Solution Treated</th>
<th>Stress Relieved &amp; Solution Treated &amp; Aged</th>
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<td>Long-Term Test</td>
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<td>120°C (Max)</td>
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<td>150°C (Max)</td>
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<td>1160</td>
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<td>180°C (Max)</td>
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</table>

AMS 5662 (new AM standard from the F42 committee)

Post-Treatment

Hot Isostatic Pressing (HIP) Cycle
(Bodycote standard cycle for Ni superalloys)

Temperature: 1200°C ±10°C
Pressure: 1000 bar -0/+50 bar
Dwell Time: 240 minutes ±30 minutes
Heating/Cooling: Free (not fixed)

Heat Treatment

<table>
<thead>
<tr>
<th>Applicable AMS</th>
<th>Solution Annealing</th>
<th>Precipitation/Hardening</th>
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<tbody>
<tr>
<td>AMS5597</td>
<td>1200°F (650°C) 1 hour to 1 hour maximum</td>
<td>1200°F (650°C) for 10 hours, furnace cool to 1200°F (650°C) and hold at 1200°F (650°C) for total precipitation time of 20 hours, Air Cooling.</td>
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<tr>
<td>AMS5598</td>
<td>1200°F (650°C) 1 hour max</td>
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<tr>
<td>AMS6644</td>
<td>1200°F (650°C) 1 hour max</td>
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</table>

Microstructure after Post-Treatment

HIP

HIP + Heat Treatment
718 Recyclability Study

Chemical composition of built material

- Chemistry well preserved from powder to built material. No selective evaporation. Possibly some outgassing of O and N.
- Chemistry of Build 1 and Build 6 practically the same.
- All elements comply with the 718 spec, also in Build 6.

Chemical composition of powder

- No significant changes of the elements specified for alloy 718.
- Possibly some small oxygen pickup.
**718 Recyclability Study**

**Powder morphology**
- Initial powder is very spherical and free from agglomerates.
- Some dents appear on recycled powder due to blasting process.
- After Build 6, a few agglomerates appear.
- Dents and agglomerates correlate with flowability and density results.

**Summary, 718 development for EBM**
- Stable process parameters found at a build temperature ~ 1000°C
- Plasma atomized powder gives built material free of porosity
- Chemical composition complies with standards
- Tensile properties complies with standards after HIP and heat treatment
- Precipitation dissolved after HIP and heat treatment
- Repeated recycling did not reveal any significant degradation of the powder

**Sample parts in Alloy 718**

Ongoing work:
Some final adjustments to optimize surface quality and support design

**Thank you for your attention!**