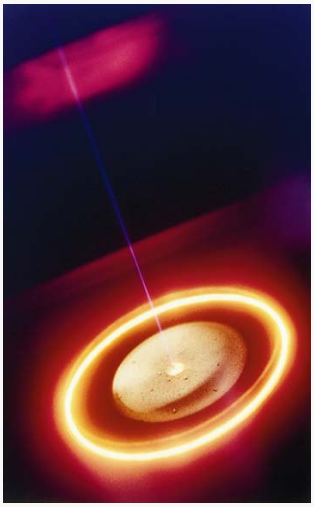
Rapid Manufacturing with Electron Beam Melting (EBM®)

Outline

- Overview
- EBM S12 System
- Applications
- Materials



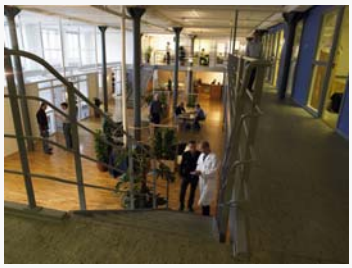
CAD to Metal®

Layer-based Direct Manufacturing of complex parts by melting metal powder with Electron Beam Melting (EBM)

A revolution in the Art of Manufacturing!

Arcam in short

- Swedish innovation from the beginning of 1990's
- Arcam AB incorporated 1997
- Listed on Nordic Growth Market, Stockholm Stock Exchange
- Solid Owners - Industrial Development Trust + large private investors
- Beta machines to the market in 2002
- First EBM S12 machine delivered March 2003
- >25 installations worldwide
- 26 employees, 2 in the US
- Agents in Europe, Asia and the US



Arcam Products & Services

- Machines and Equipment for Electron Beam Melting
- Service and Application Support
- Powder Metals and Consumables

Applications

- Aerospace
  - Functional Parts
  - Prototypes
- Medical
  - Implants
  - Prosthesis
  - Instruments
  - Prototypes
- Automotive
  - Functional Parts
  - Prototypes

Clients

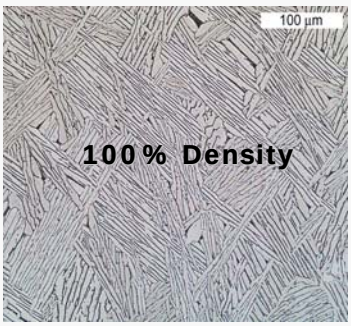
Examples of clients include

End Users
- Boeing Phantom Works, St Louis, USA
- NASA, Marshall Space Flight Center, USA
- Airbus, Bristol, UK
- Unnamed Implant Manufacturers, Asia / Europe / USA

Service Bureaus
- CalRAM, USA
- Synergeering Group, USA, 2 systems
- Protocast, Italy
- Fruth Innovative Technologien, Germany

Research Institutes
- North Carolina State University, USA
- Erlangen University, Germany
- Royal College of Art, London, UK

Materials

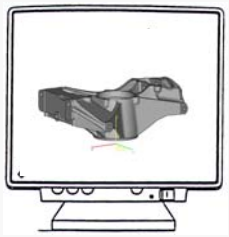


"Normal" properties for:
- Strength & Elasticity
- Hardness
- Chemical composition
- Thermal properties

Qualified
- Ti6Al4V
- Ti6Al4V ELI
- Commercially Pure, Grade 2
- CoCr, ASTM F75

R&D
- Inconell – 718, 625
- Beryllium/AlBeMet
- GRCop-84
- Stainless Steels - 316L, 17-4PH
- Aluminium Alloys

Process overview



1. CAD-model

The part is designed in a 3D CAD program or created from a CT-scan of a patient. The CAD-file is saved as an STL file which is used to prepare the job.

The STL-file is sliced into an SLC-file and transferred to the Arcam EBM system

2. EBM

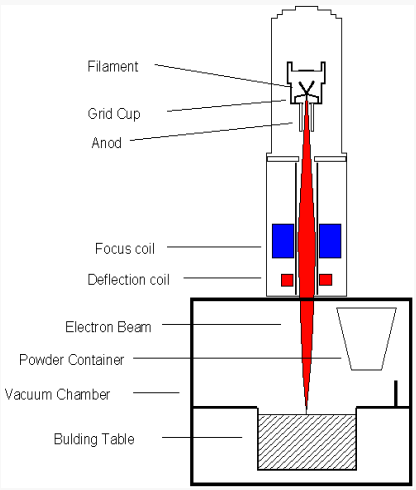
The part is built up by melting metal powder layer-by-layer with the Arcam Electron Beam Melting (EBM) process.

3. Metal Part

The result is a functional metal part, ready to be put into operation!

Electron Beam Melting (EBM®)

- **Electrons** are emitted from a filament which is heated to > 2500° C
- The electrons are **accelerated** through the anode
- A magnetic field lens brings the beam into **focus**
- Another magnetic field **controls the deflection** of the beam
- When the electrons hit the powder **kinetic energy** is transformed to **heat**.
- The heat **melts** the metal powder
- Power is controlled by altering the current in the beam.



No moving parts!

EBM® Characteristics

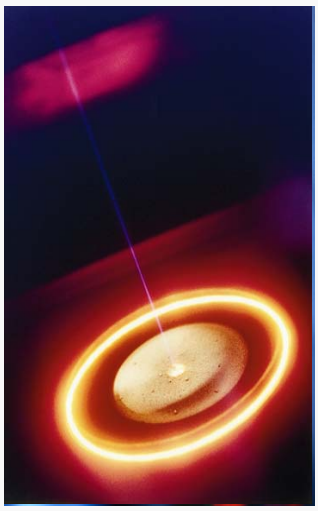
- Ability to achieve **high power** (4 kW available) in a narrow beam.
- **High power utilization**
- **High build temperature**
- Beam Deflection with **no moving parts**
- Vacuum melt quality **eliminates impurities** and yields high strength properties of the material.
- Good thermal environment, leading to **good form stability** and **low residual stress** in the part
- Permits melting of **refractory metals** and combinations of dissimilar metals
- **Low operating costs**

Core benefits

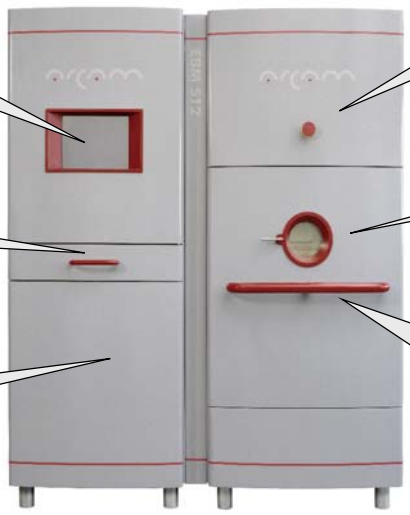
- **Full functionality of parts**
  - Fully melted material - 100% density
  - Better than cast
  - Controlled grain size
  - High strength
- **Fast & Economical Fabrication**
  - High Build Rate
  - Power Efficiency
  - Material Recycling

Outline

- Overview
- **EBM S12 System**
- Applications
- Materials



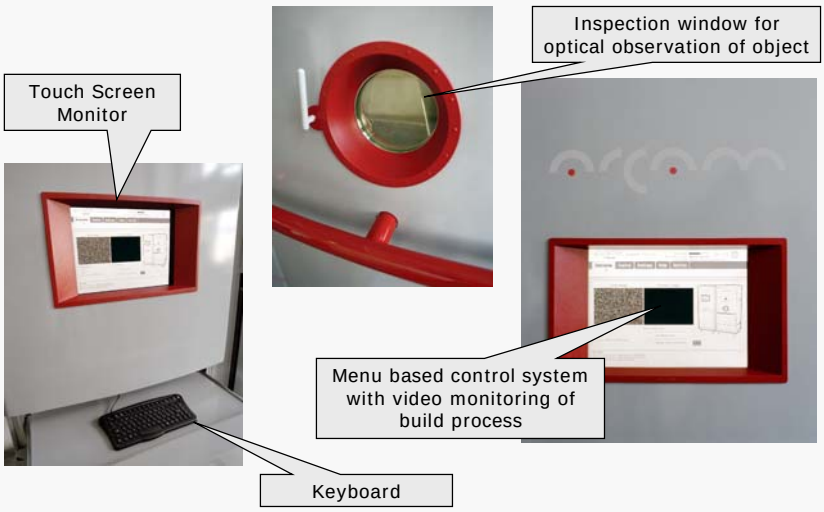
Arcam EBM® S12



Arcam EBM® S12 Technical Data

Building tank volume	250 x 250 x 200 mm
Maximum build size	200 x 200 x 180 mm
Accuracy	+/- 0.4 mm
Melting speed	0.3-0.5 m/s
Layer thickness	0.050- 0.200 mm
EB scan speed	> 1000 m/s
EB positioning accuracy	+/- 0.05 mm
Max EB output	4 kW
Power supply	3 x 400 V, 32 A, 7 kW
Machine size	Approx. 1800 x 900 x 2200 mm
Weight	1350 kg
Process computer	PC / XP Professional
CAD interface	Standard: STL
Network	Ethernet 10/100
Certification	CE

User interface



Powder Recycling System

- > 95% powder recycling
- Minimal dust generation for safe operation
- Closed circuit until powder recycling is completed
- Good accessability and efficient sideloading

Invisible Supports

- "Soft" supports developed for easy removal after build
- Partially sintered, 100% re-usable powder
- Easily removed by hand
- Enables "stacked" builds

Outline

- Overview
- EBM S12 System
- **Applications**
  - **Aerospace**
  - Medical
  - Automotive
  - Miscellaneous
- Materials

Landing Gear Component

Material: Ti6Al4V
Weight: 4,5 kg

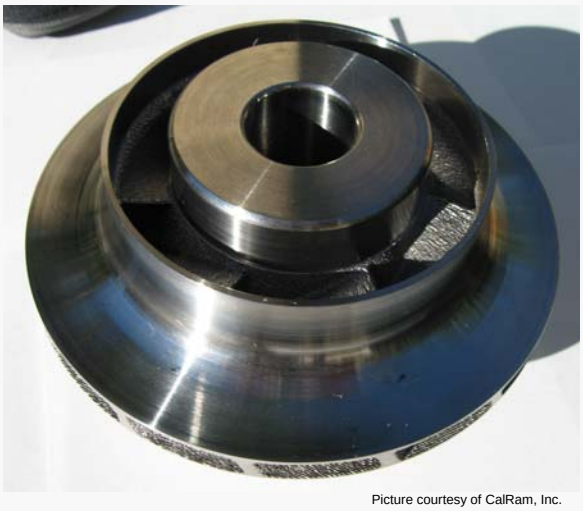
Arcam EBM system

Aerospace Prototype

Material: Ti6Al4V
Weight: 5,5 kg

Arcam EBM system

Rocket Engine Impeller



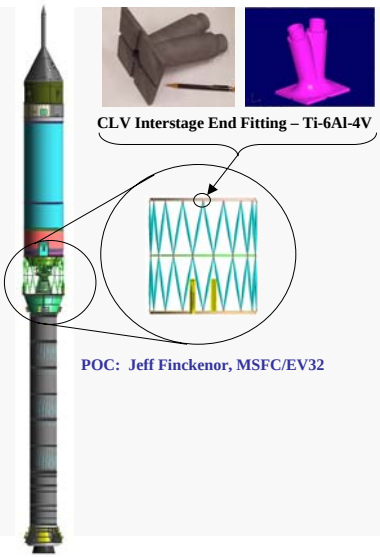
Material: Ti6Al4V ELI
Size: Ø 140 x 80 mm
Weight: 2,5 kg

Picture courtesy of CalRam, Inc.

Arcam EBM system

CLV Interstage End Fitting

Manufactured by Synergeering for NASA Marshall Space Flight Center



POC: Jeff Finckenor, MSFC/EV32

Arcam EBM system

Outline

- Overview
- EBM S12 System
- **Applications**
  - Aerospace
  - **Medical**
  - Automotive
  - Miscellaneous
- Materials

Direct Implant Manufacturing

Specific **benefits** for **Implants and Prosthetics**

- Short and easy transition from CT or MRI data
  - to CAD model – to part!
- No tools, part design can be individualized
- Moderate production lots without setting times
- Possibility for engineered materials, porosity, scaffolds
- CAD to Metal is often quicker and less costly than conventional methods

Customized Tri-flange Implant

Arcam EBM system

Parts direct from CT-scan

Material:	Ti6Al4V
Size:	225 x 160 x 170 mm
Weight:	ca 2,5 kg
Build time:	24 hours

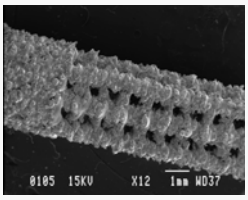
Arcam EBM system

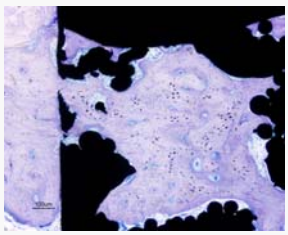
Customized Bone Plate

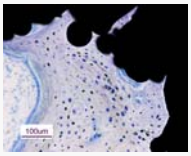
Material:	Ti6Al4V
Size:	5 x 20 x 55 mm
Weight:	-
Build time:	3 hours / 6 pieces

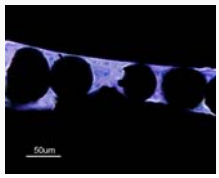
Controlled Porosity

- The material can incorporate Controlled Porosity and scaffolds.
- This enables design for bone ingrowth and reduces the number of process steps in manufacturing.









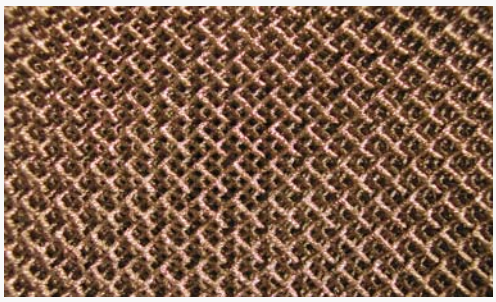
Pictures of bone growing into titanium implants with controlled porosity, manufactured in the EBM process.

(courtesy of Professor Peter Thomsen, MD, Dept. of Biomaterials, University of Gothenburg).

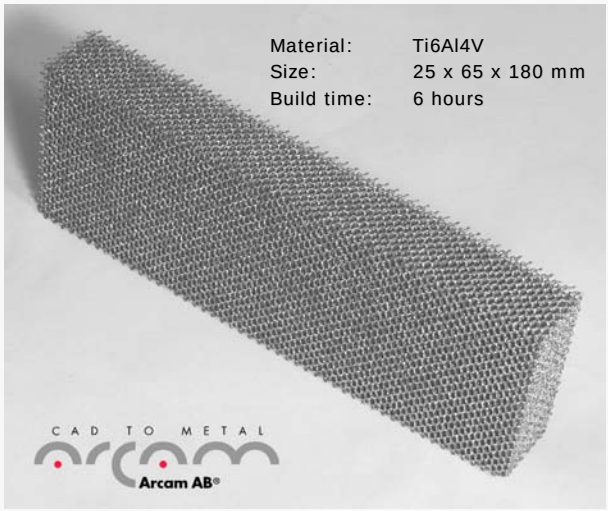
Advanced Gratings

The process supports production of Advanced Gratings and Engineered Materials. Possibilities include:

- Scaffolds
- Light weight design
- Mass production of tiny structures, e.g. Spine tubes
- Bone ingrowth



Lattice Structures



Acetabular Cups

Material: Ti6Al4V

With fully dense core.

Outer surface either fully dense, with low porosity or with high porosity

← Low porosity

← High porosity

Direct Implant Manufacturing, costs

- Competitive manufacturing cost, typical cost 110 EUR per machine hour, including operator, powder and financial costs.

- One typical build overnight gives, for example;
  - 6 hip implants @ 200 EUR per part
  - 9 acetabular cups @ 120 EUR per part
  - 4 tri-flange @ 300 EUR per part
  - 50 moderate size bone plates @ 30 EUR per part
  - 4 complex bone plates @ 400 EUR per part

Outline

- Overview
- EBM S12 System
- **Applications**
  - Aerospace
  - Medical
  - **Automotive**
  - Miscellaneous
- Materials

Arcam EBM system

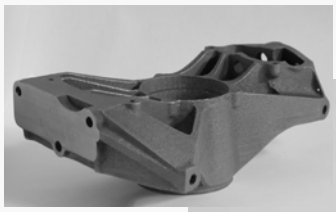
Race Car Gearbox Casing

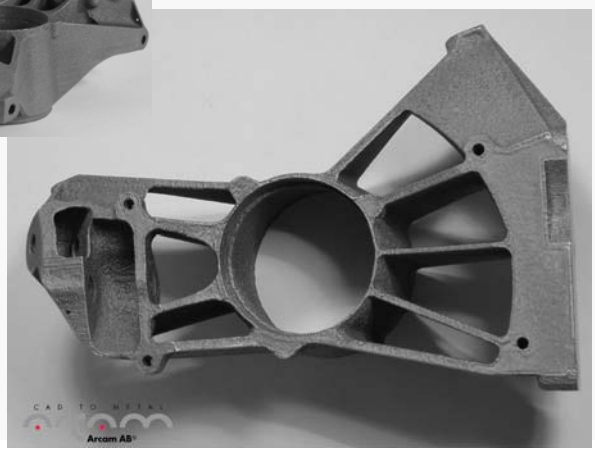
Material: Ti6Al4V
Weight: 2,5 kg

Arcam EBM system

Race Car Suspension Parts

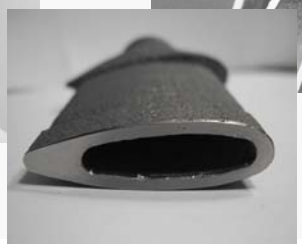
Material: Ti6Al4V
Size: 160 x 210 x 105 mm
Weight: 1130 grams





Arcam EBM system

Race Car Suspension Parts



Material:	Ti6Al4V
Size:	60 x 20 x 80 mm
Weight:	90 grams
Build time:	4.5 hours / 6 pieces

Arcam EBM system

Spine Model for Crash Tests

Material: Ti6Al4V

All components packed into one build.

Outline

- Overview
- EBM S12 System
- **Applications**
  - Aerospace
  - Medical
  - Automotive
  - **Miscellaneous**
- Materials

Sports Technology

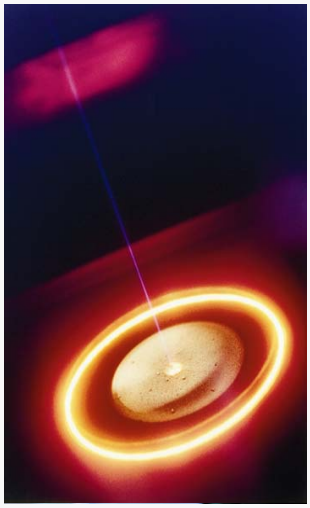
Direct Manufacturing of Ice Axe Blade in CoCr alloy.

Impeller Prototype

Material:	Ti6Al4V
Size:	Ø 120 x 30 mm
Build time:	8 hours

Outline

- Overview
- EBM S12 System
- Applications
- **Materials**



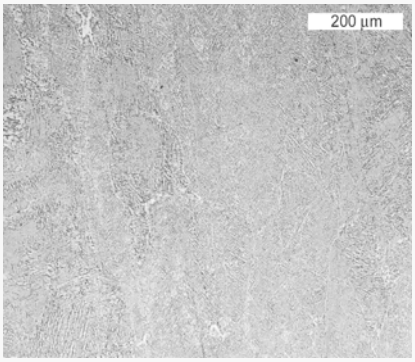
Material Development

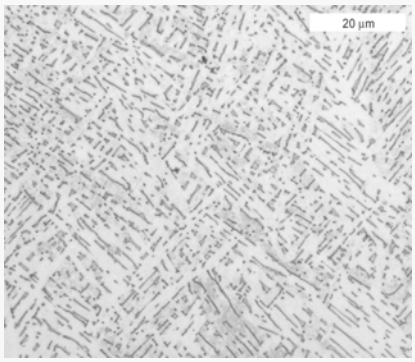
- Material Properties are essential for demanding applications.
- Arcam R&D is committed to ensure first-class mechanical properties on all qualified materials.
- All qualified materials are extensively tested before release to customers.

Chemical Composition

- Pre-alloyed metal powder
- No additives or binders
- Retained chemical composition due to:
  - Good vacuum $<10^{-4}$ mbar
  - Very small melt volume
  - Rapid cooling from liquid to solid state

Arcam Ti6Al4V





Arcam Ti6Al4V Titanium Alloy has a homogenous fine-grain microstructure better than cast Ti6Al4V containing a lamellar alpha-phase with larger beta-grains. The material comes out of the Electron Beam Melting process in a naturally aged condition.

Arcam Ti6Al4V

- The most widely used Titanium Alloy
- Mechanical properties:

Yield strength (Rp 0,2)	910-960 MPa
Ultimate tensile strength (Rm)	970-1030 MPa
Rockwell hardness	30-35 HRC
Elongation	12-16%
Fatigue strength*) @ 6-600 MPa	>10 million cycles
Modulus of Elasticity	120 GPa

*) After Hot Isostatic Pressing

- Applications:
  - High performance parts
  - Aerospace
  - Racing
  - Implants
  - Marine

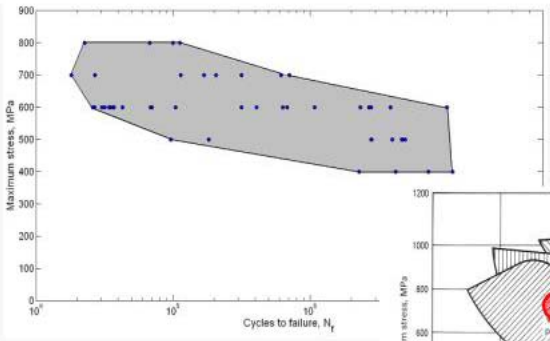
Arcam Ti6Al4V ELI

- Extra Low Interstitials (ELI)
- Mechanical properties:
  - Yield strength (Rp 0,2) — 910-940 MPa
  - Ultimate tensile strength (Rm) — 950-990 MPa
  - Rockwell hardness — 30-35 HRC
  - Elongation — 14-16%
  - Fatigue strength*) @ 6-600 MPa — >10 million cycles
  - Modulus of Elasticity — 120 GPa

*) After Hot Isostatic Pressing

- Applications:
  - Implants
  - Aerospace
  - Cryogenic applications

Fatigue / Endurance



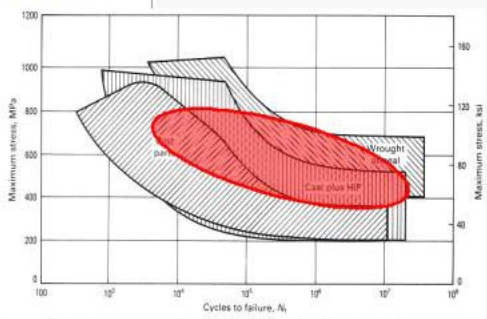


Fig. 10 Comparison of smooth axial room-temperature fatigue rate in cast and wrought Ti-6Al-4V at room temperature with $R = +0,1$

Arcam ASTM F75 Cobalt Chrome Alloy

- Medium strength and stiffness
- High Corrosion Resistance

- Mechanical properties:
  - Yield strength (Rp 0,2) 600 MPa
  - Ultimate tensile strength (Rm) 900 MPa
  - Rockwell hardness 34 HRC
  - Elongation 10%

- Applications:
  - Orthopaedic Implants
  - Prosthesis
  - Aerospace

Specialty materials – GRCop-84

- High Temperature Copper Alloy, Cu-8at.%Cr-4at.%Nb
- Originally developed by NASA for rocket engines
- GRCop-84 is rapidly finding applications within aerospace, motor sports and industrial applications.

Material features:
- high relative strength
- potential for high heat flux applications up to 700 ºC
- excellent elevated temperature strength
- excellent thermal conductivity
- good creep resistance

Contact

Thank you for your attention!

Arcam AB
Krokslätts Fabriker 30
SE-431 37 Mölndal, Sweden
Phone: +46 31 710 32 00
Web site: http://www.arcam.com
E-mail: info@arcam.com

Use Arcam to manufacture your future!