Rapid Manufacturing with Electron Beam Melting (EBM) – A manufacturing revolution?

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ABSTRACT

The Electron Beam Melting technology is the result of intensive research and development and has a wide array of applications within areas such as Rapid Prototyping, Rapid Manufacturing, Tooling and Biomedical Engineering. The technology combines first-class material properties with high build speeds. The presentation will provide a basic understanding of the technology, technical status, applications and ongoing R&D.

Basic process & background

Arcam, founded 1997, has developed a unique Free Form Fabrication (FFF®) technology for Direct Manufacturing of fully dense parts from metal powder. The technology is based on Electron Beam Melting (EBM) and the parts are built up by melting the metal powder layer-by-layer.

The founders were prompted by a vision to revolutionize the art of manufacturing of complex parts. The technology is the result of intensive research and development and has a wide array of applications within areas such as Rapid Prototyping, Direct Manufacturing, Tools for Injection Molding and Die-Casting as well as Biomedical Engineering.

The technology offers a high level of geometric freedom together with first-class material properties. The CAD to Metal® technology provide fully dense metal with material properties identical with or close to the target metals used. Most conductive materials can be used although steel and titanium alloys the only materials available as per today. The strategy in the development is to combine excellent material properties with high build speeds.

With its ability to directly process complex geometries, the Electron Beam Melting process is ideal for direct manufacturing of complex parts in low volumes. The process enables customization of parts and parts optimized for the CAD to Metal process can feature geometries that cannot be achieved in other manufacturing technologies, thus providing superior performance in the part and value to the customer. The process works directly from CAD data and is fast. The designer can have a fully functional detail within 24 hours from completion of the design. The process often requires significantly less lead-time than sand casting or investment casting.

The combination of Electron Beam Melting and vacuum provide high power and good environment for the process resulting in excellent material properties.

The major difference between the Electron Beam Melting process and methods such as Laser Sintering/Laser Melting is efficiency of the Electron Beam gun compared with a laser. The electron beam technology is several times more energy efficient than laser technology resulting in less power consumption and lower maintenance and manufacturing costs. Arcam is currently using a 4 kW EB gun on its standard machine. Reflection in the pool of melted metal is also a non-issue with electron beam technology.

The availability of sufficient power in the heat source in any fully melting freeform fabrication system is of key importance to achieve good material properties and high build speeds.

Electron Beam Melting (EBM)

The fundamental idea behind the CAD to Metal® technology is to build up metal details in layers of metal powder, each of which is melted by an electron beam to exactly the geometry defined by the computer model.

The part is first designed in a 3D CAD program. The file is transferred to pre-processing software where the model is sliced into thin layers. The parts are built up layer-by-layer by the Electron Beam Melting (EBM) process in a vacuum chamber. On completion of the CAD to Metal Process the net-shape part is cleaned and can be finished as necessary by conventional methods.

The electron beam is generated in an Electron Beam Gun situated on the top of a vacuum chamber. The Electron Beam Gun is fixed and the beam is deflected to reach the entire building area.

The electrons are emitted from a filament, which is heated to high temperature. The electrons are then accelerated to half the speed of light in an electric field. The beam of electrons is controlled with two magnetic fields. The first acts as a magnetic lens and is responsible for focusing the beam to the desired diameter. The second magnetic field deflects the focused beam to the desired point on the building table.

Advantages and disadvantages

Electron Beam Welding has become a vital technology in many industries. Some of its benefits include:

Ability to achieve a high energy level in a narrow beam.
Vacuum melt quality can yield high strength properties of the material.
Vacuum environment eliminates impurities such as oxides and nitrides.
Permits welding in refractory metals and combinations of dissimilar metals

Electron Beam Melting benefits from all of these factors in the same way. Compared with laser sintering/melting additional benefits include:

Higher efficiency in generating the beam of energy resulting in lower power consumption as well as lower maintenance and installation costs
High actual overall power resulting in high build speeds
Deflection of the beam can achieved without moving parts resulting in high scanning speed and low maintenance.

Some apparent disadvantages of electron beam technology are:

Requires vacuum which adds another system on the machine which cost money and must be maintained [Added benefit: Vacuum eliminates impurities and provide and good thermal environment for freeform fabrication]
Electron beam technology produces X-rays while in operation [Solution: The vacuum tank shields the rays perfectly if properly designed.]

Process availability and current use status

As per June 30th, 2003, 8 units have been built with a 9th system in production. Four of the systems are situated at Arcam while two beta-systems where installed at companies in Sweden during 2002. The present model was launched in December 2002 and during 2003 two of these systems have been installed. One system is in operation in Italy and one system at NC State University in Raleigh, North Carolina, USA.

The best applications, now and in the future

Present R & D is focusing on parts for high performance applications within automotive and aerospace industry as well as biomedical applications such as implants. Typical applications are complex parts manufactured in low volumes where casting and machining would require too much of lead-time, machine time or scrapping of material.

The technology can also be used to manufacture parts featuring geometries that cannot be achieved in other manufacturing technologies, thus providing superior performance in the part and value to the customer. Examples of such applications are:

Complex lattice/framework structures for lightweight design
Internal cavities for lightweight design, weight distribution optimization and flow control
Optimization of material and stress distribution
Conformal cooling channels

The technology is used by teams within the car racing industry for fabrication of high performance parts and prototypes.

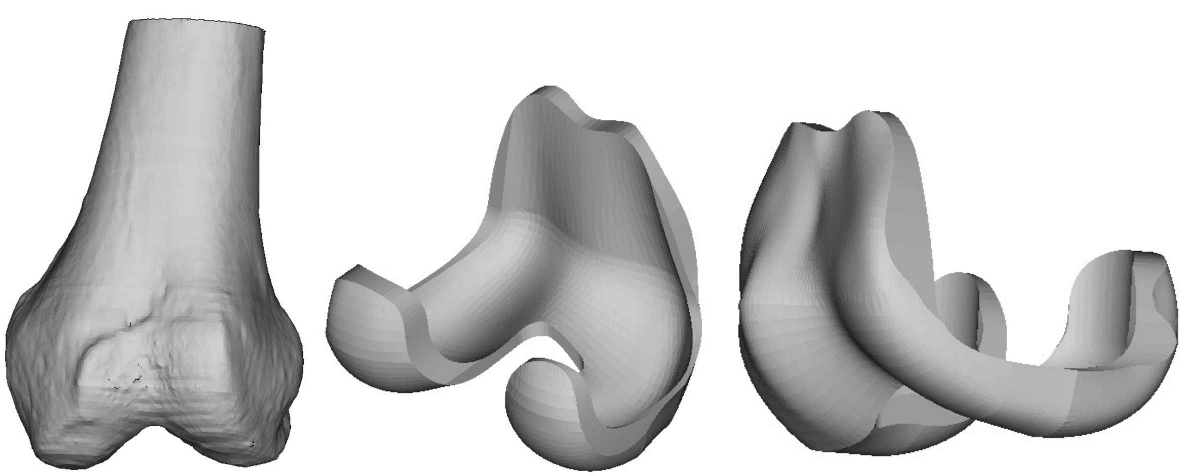
Fabrication of custom designed orthopedic implants can benefit from efficient freeform fabrication in metals such as commercially pure and alloyed titanium. There is a future for customized Knee- and Hip-implants that will provide better fitting and longer lasting prostheses and most areas of orthopedic implant surgery can benefit from customized implants.

North Carolina State University has several research projects related to customize implant technology. Areas of research include

Optimize the bone-implant interface for better performance
Reduce bone remodeling due to better stress distribution
Customize implant due to size and shape of Tibia and Femur.
Fabrication of implant components in titanium using the EBM-machine

Custom Implants

Each year over 500,000 Americans go through a hip or knee implant surgery to restore the function of a worn out joint. One of the main problems is that we are all different and the generic implants don't fit perfectly on most people, decreasing the longevity and the function of the implant. To improve the current generic implants, an effort has been made at North Carolina State University to design custom implants based on a Computed Tomography (CT) scan of the particular patient. The CT-scan is converted into a CAD-model of the patient's joint and a custom implant can be designed with optimal fit, shape and geometry.



The custom designed implant component could be fabricated through investment casting using an RP-pattern as a master, but would take a considerable amount of time and would be labor intensive, making the implant prohibitively expensive. Using the EBM-technology and the newly developed titanium alloy, the implant component could be fabricated in a matter of hours with very little labor involved using the same manual finishing as with conventional implant fabrication.

Plates for repair of severe bone fractures

Titanium and stainless steel plates are often used to repair and secure severe bone fractures on both humans and animals. The standard bone plates come in different sizes and are normally flat with evenly distributed holes. The surgeon spends a considerable amount of time in surgery to shape the bone plate to conform to the patient's specific anatomy using hand tools. This is an iterative process that prolongs the surgery, increasing the risk of trauma and infection. In many cases it is difficult to align the evenly distributed holes with the bone to attach the screws. In a new project at NCSU, custom designed bone plates are being developed using patient specific CT-scans and the EBM-technology. The surgeon will decide where to place the holes for the screws to achieve the optimal result and the plate is designed to perfectly conform to the curvature of the bone.

Materials

In theory, most conductive metals can be used in the process. To convert theory into reality Arcam is devoting significant resources to R&D in materials sciences in order to constantly develop and refine the CAD to Metal process for an increasing number of metals and alloys. Partners in materials R&D include companies and organizations such as

Chalmers University of Technology, Göteborg, Sweden
Max Planck Institute, Düsseldorf, Germany
North Carolina State University, Raleigh, NC, USA
Volvo Aero Corporation, Sweden

The CAD to Metal® process fully melts the metal powder in order to provide fully-dense metal with material properties identical with or close to the target metals used. Parts are built up in vacuum under strict temperature control.

Initial development of the technology was carried out with iron-based metals and the process has been verified for the following materials:

Tool Steel
Low Alloy Steel
Alloyed Titanium
Commercially Pure Titanium

Nickel Alloys

The current build volume that has been achieved is within a 200x200x160 mm envelope with massive parts in steel having a maximum size limitation of some 150x150x160 mm. The accuracy is within +/- 0.3 mm and is comparable to castings.

Mechanical Properties

	Ti6Al4V	**H13**
Hardness	30-35 HRc	48-52 HRc
Tensile Strength (Rm)	930 Mpa / 135 ksi	1300 Mpa / 190 ksi abt 1500 Mpa/ 220 ksi after heat treatment
Yield Strength (Rp0.2)	880 Mpa / 125 ksi	1000 Mpa /144 ksi
Modulus of elasticity	128 000 MPa	210 000 MPa
Elongation	> 10 %	N.A.
Microstructure	Lamellar alpha-phase with larger beta-grains. The material has a naturally aged condition directly from the process	Martensitic structure with a typical grain size between 10-30 mm due to fine uniform vanadium carbide dispersion.