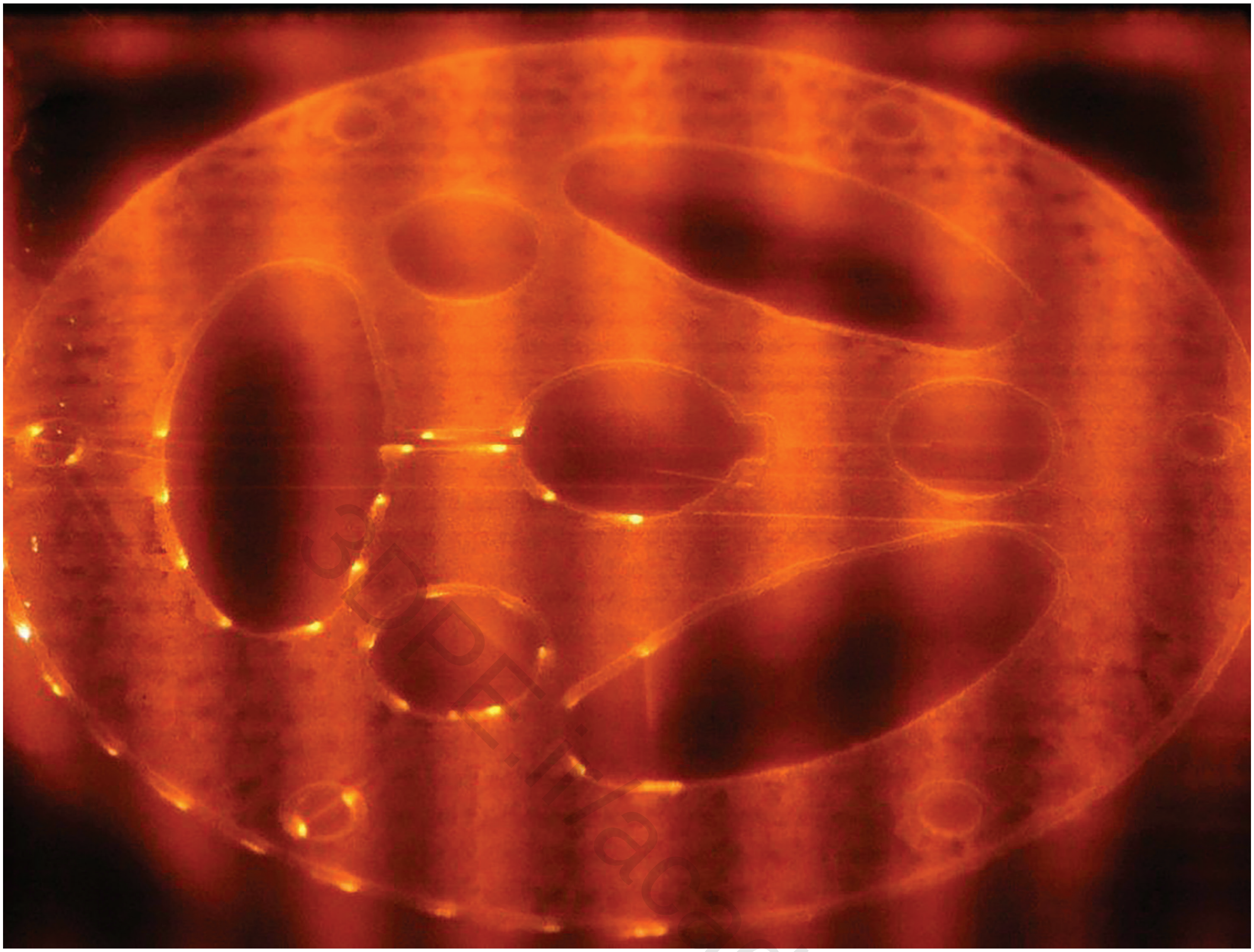
INSIDE

ELECTRON BEAM MELTING

GE Additive



Production of Alloy 718

INTRODUCTION

Electron Beam Melting (EBM) technology offers high productivity by utilizing a high-power electron beam that allows for high melting capacity of metal powder. The electron beam unit is built on state-of-the art electronics with no moving parts, which enables extremely fast and accurate beam control—allowing melting at multiple points simultaneously without compromising surface finish, precision or build speed.

During the EBM build process a thin layer of powder is distributed, heated and selectively melted. After melting the layer, the build table is lowered, and the sequence is repeated until the build is complete. The EBM process takes place in a vacuum, providing a clean and controlled environment and excellent thermal insulation. It is a high temperature process, resulting in stress-relieved components with material properties better than cast and comparable to wrought.

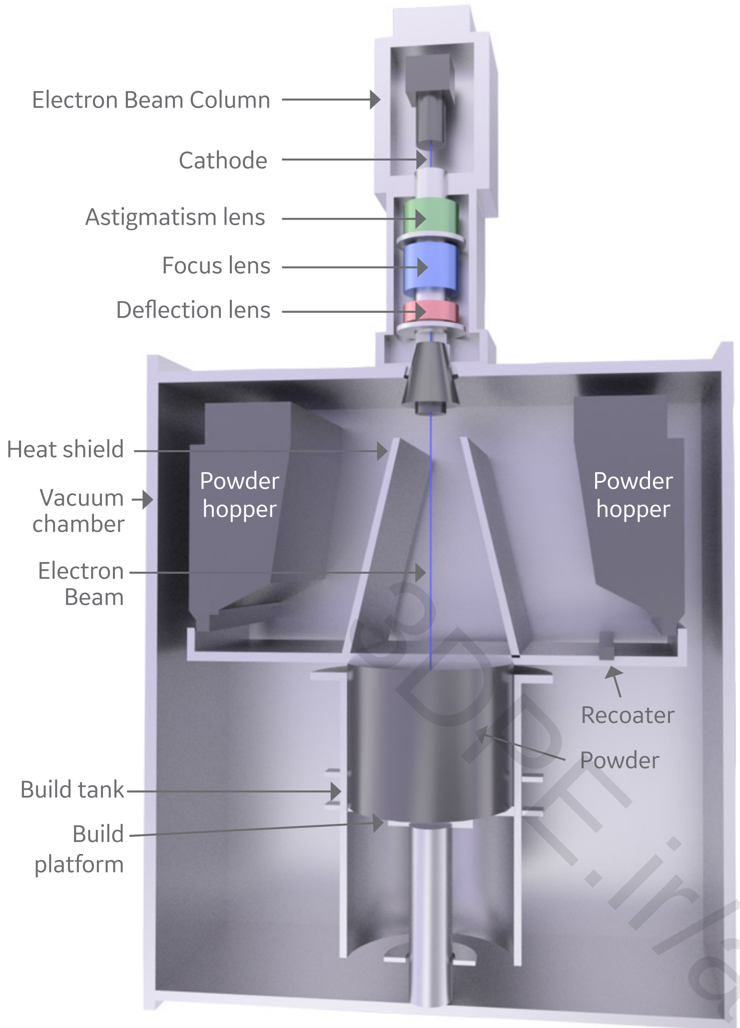


FIGURE 1

The EBM Difference

Electrons as energy carriers - provides deep penetration and low reflection in the powder. It also allows for the electromagnetic beam control to function extremely fast.

Hot process - provides low internal stress which enables production of crack prone materials, bulky parts or thin, free-floating beams to be produced.

Vacuum process - enables extreme cleanliness and energy efficiency.

Parts produced free floating in sintered powder – allows tight stacking of parts for high productivity and the possibility to build with no or limited support.

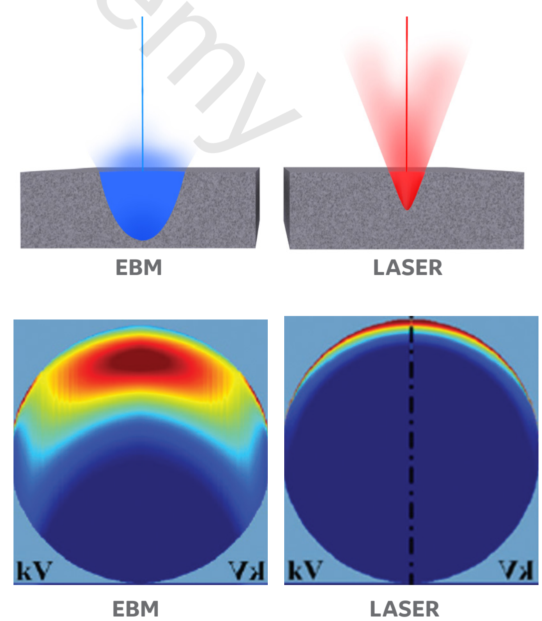
Figure 1: Schematic sketch of an EBM system, showing the electron beam column with the cathode or filament where the electrons are generated. The beam is controlled with electromagnetic lenses (coils) further down in the column.

The vacuum chamber contains the powder hoppers used as powder storage that feeds powder to the build table by gravity. The recoater fetches powder from each side to distribute an even layer on the build table. The electron beam selectively melts each layer and the build platform is lowered before applying and melting the next layer.

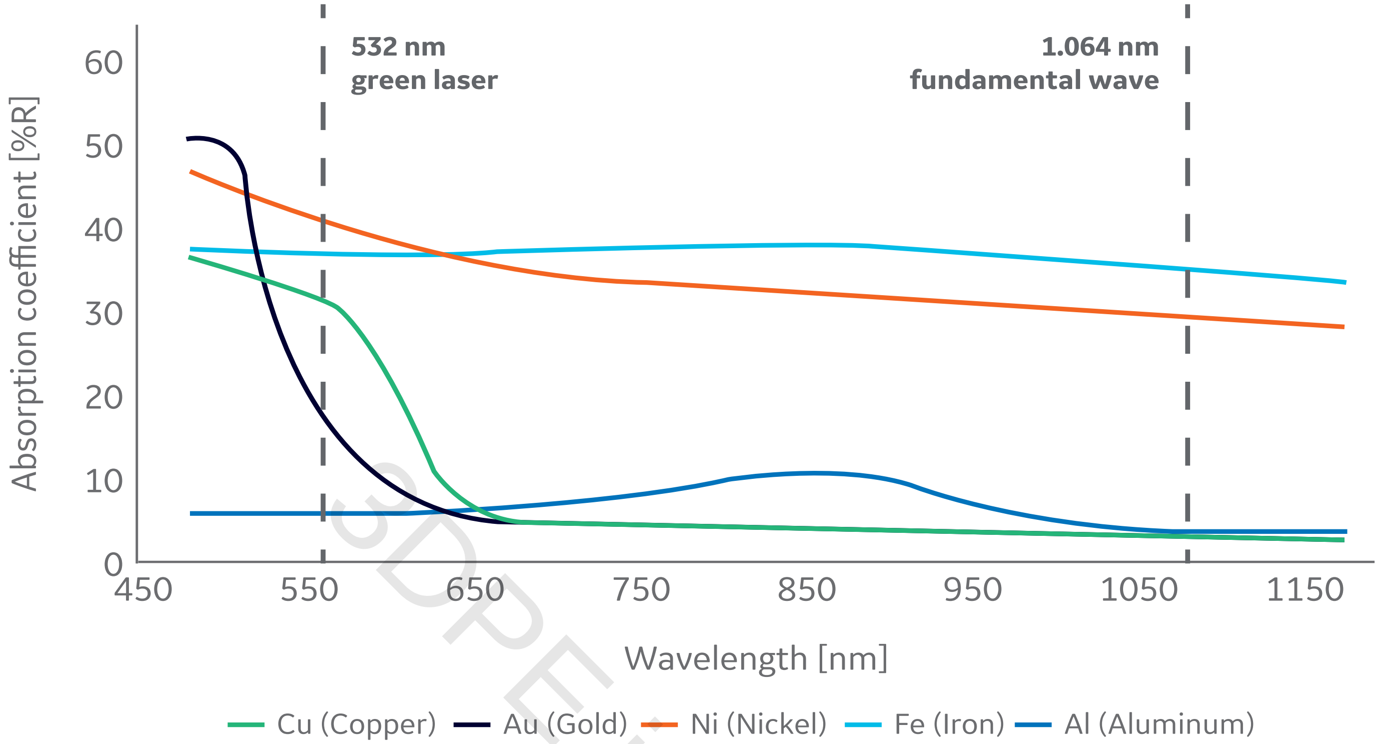
ELECTRONS AS ENERGY CARRIERS

Using an electron beam as an energy source to melt metal powder, offers positive advantages compared to a laser.

A notable advantage is the electron's ability to reach far into the material and homogenously melt the powder particles. This facilitates melting of highly reflective metals without the risk of vaporizing the surface of the particle before melting the core.



Energy transfer in Ti64 powder using EBM (left) and laser (right) technology.



The absorption efficiency for laser is dependent on the reflectivity of the material and the wavelength of the laser. Typical reflectivity ranges are between 2–60%. For Copper, laser has an absorption efficiency of 2-10%, for Titanium it is about 60% and for Aluminum about 20%. For EBM, the absorption is only slightly dependent on density of the material and is in the range of 65-85% for most materials.

The high absorption efficiency for EBM means a high energy efficiency for the complete process. It results in a low power consumption, reducing the production cost in volume production.

Additionally, the EBM process allows for larger powder particles to be used and a thicker layer to be built, resulting in an easier and safer powder handling and a more productive process. The price of powder with larger powder particles has up to a 50% lower price, which has a significant impact of part cost in volume production.

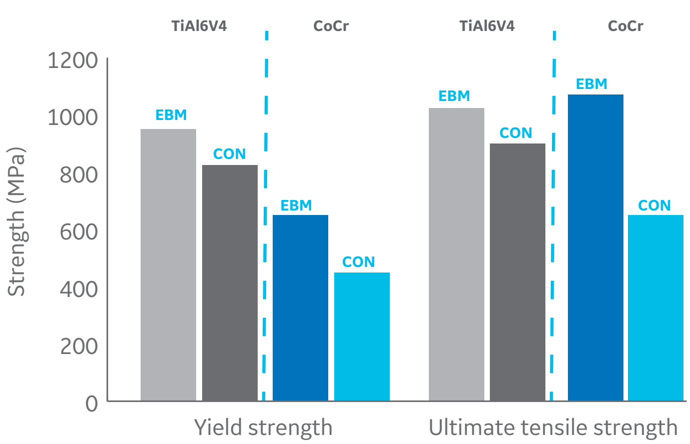
EBM technology allows for extremely fast electromagnetic beam control. Different electronic coils are controlling the beams position, size and astigmatism. With no mechanically moving parts in the beam control, the beam can be changed extremely fast. The beam position can be changed at a speed of 8000 m/s at the build area. The beam can be moved from one meltpool to another, allowing up to 70 simultaneous meltpools to be “alive” in a sequence. This function is called Arcam EBM MultiBeam. No moving parts in the EBU also requires less maintenance.

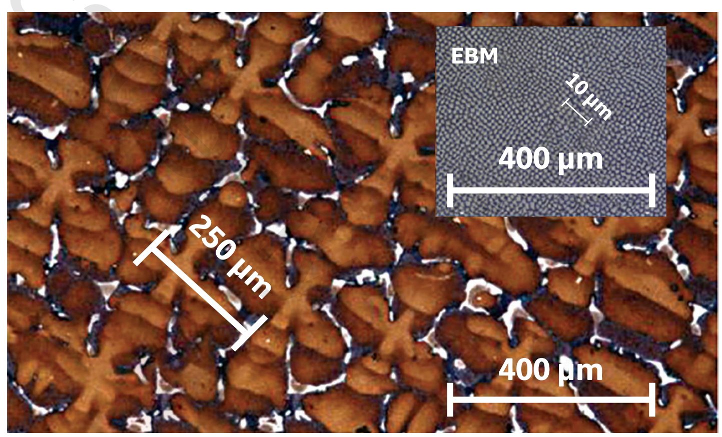
Maintain temperature elevation
Another unique characteristic of EBM is the ability to keep the entire build at an elevated temperature, if needed—above 1,000 °C. For each layer in the build, the electron beam heats the entire powder bed to an optimal process temperature, specific to the material used. This ensures a correct microstructure and parts free from residual stresses. It also eliminates the need for post process heat treatment, which has a significant impact on the total production cost.

Manufacture brittle and crack prone alloys
The hot process also allows for extremely brittle and crack prone alloys to be additively manufactured. For example, jet engine turbine blades can now be additively produced in Titanium Aluminide (TiAl), using EBM. As of 2019, EBM is the only commercially available additive manufacturing method for TiAl production.

Increased design capabilities
The hot process enables users to create unique designs, large bulky parts without swelling and thin, free-floating beams in sintered powder.

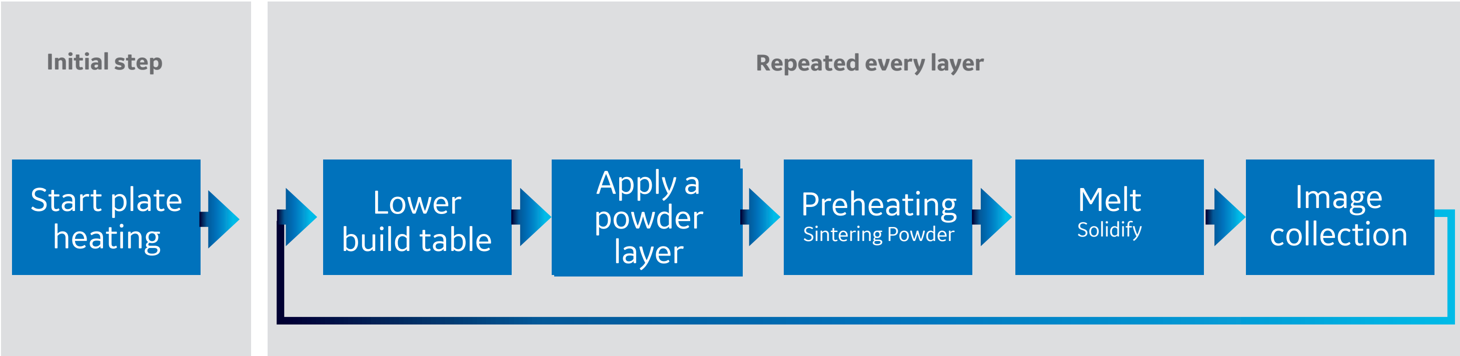
Increased productivity
Given that the entire build is kept at an elevated temperature, the time to reach the melting temperature is shorter, compared to a cold process. In addition, less energy is needed to melt the metal and the melting time is faster, resulting in increased productivity.





Conventional cast

The material produced In EBM has a finer structure and higher strength



Process steps

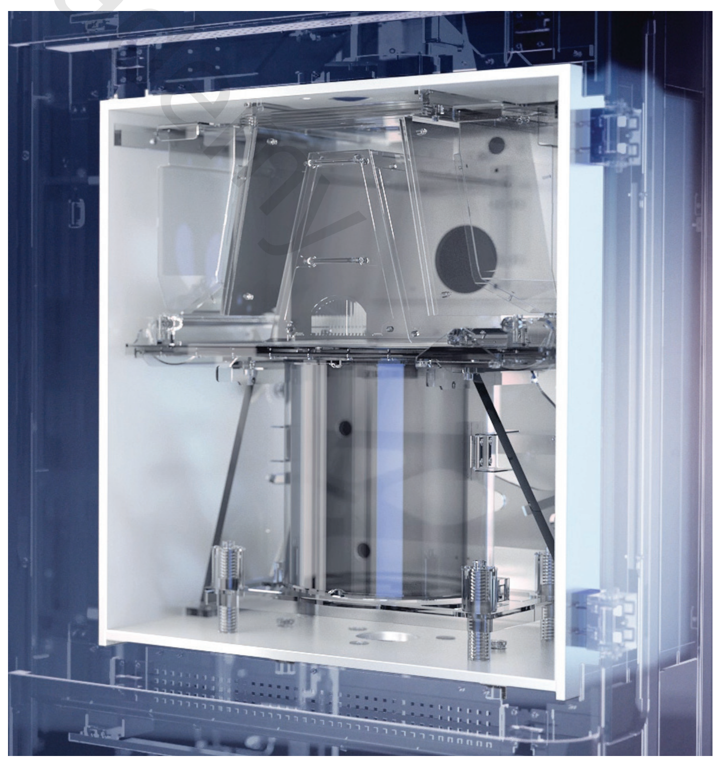
Start plate heating: Before the first metal powder layer is distributed, the start plate temperature is increased.
Lower build table: The build table is lowered, preparing for the next powder layer.
Apply a powder layer: The recoater distributes an even layer of powder over the build table.
Preheat: The powder is loosely sintered to enable tight stacking of parts. This further increases the productivity.

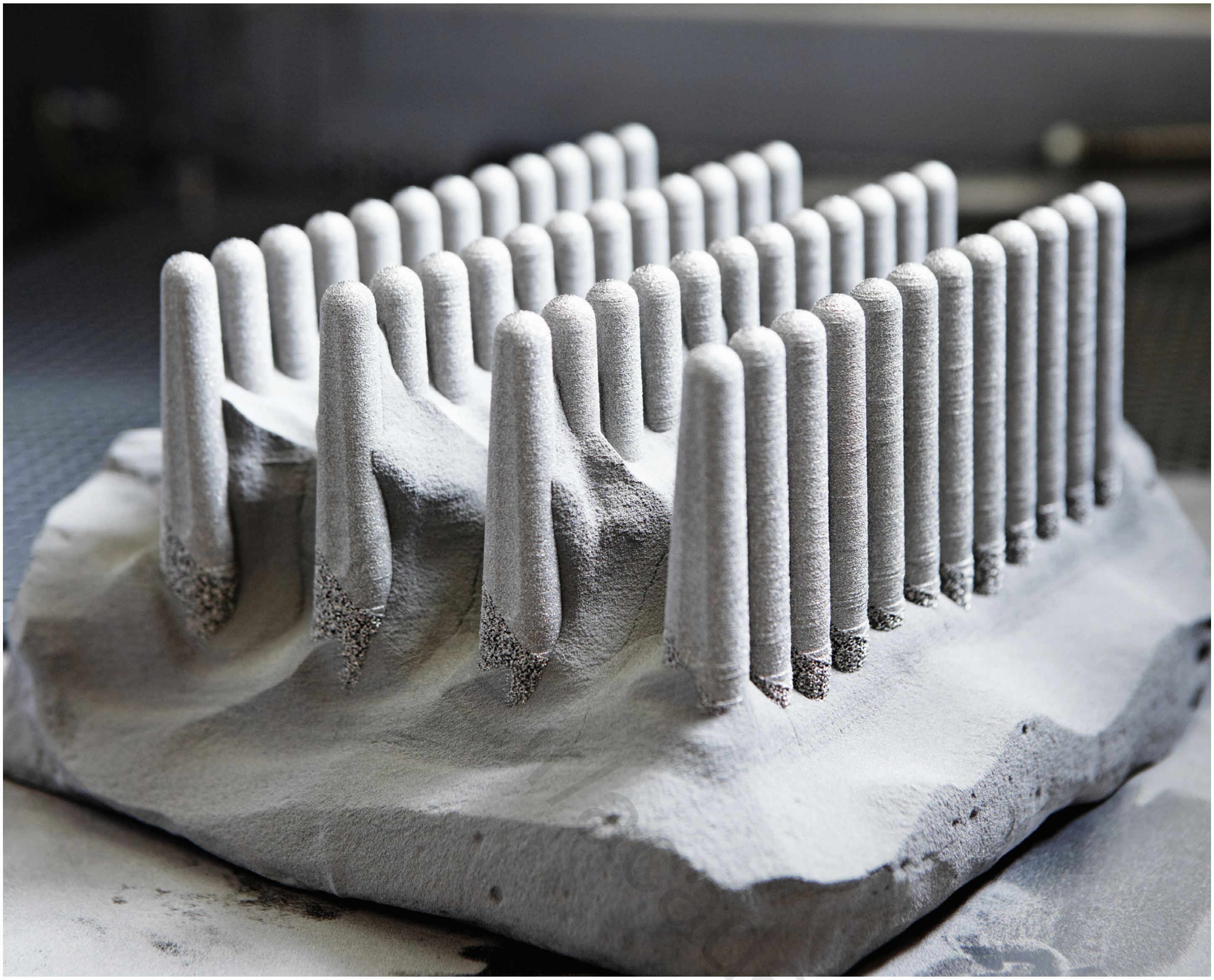
Melt: The powder is solidified. Two different types are available: contour and hatch melting. Hatching creates the bulk melt while contours are the barrier between the sintered powder cake and the hatch, thus providing the part its surface finish.
Image collection: A high-resolution camera captures one picture of each layer. This quality verification system is called LayerQam™. Each picture captures a full build area with 100 µm resolution and each layer is captured and stored.

VACUUM PROCESS

The vacuum system provides a base pressure of 5 x10^{-5} mbar or better throughout the entire build cycle. During the process a partial pressure of Helium is introduced to 4 x10^{-3} mbar. This ensures a clean and controlled build environment, which is important to maintain the chemical specification of the build material. The very low oxygen level of the vacuum in the build chamber allows processing of reactive material and eliminates the need for a laminar flow of inert gas.

The vacuum process ensures excellent susceptibility to Hot Isostatic Pressing (HIP), eliminating pores in the material. This means if pores are created in the EBM process, the pores contains a vacuum. Vacuum pores are easily removed by HIP compared to gas-filled pores.

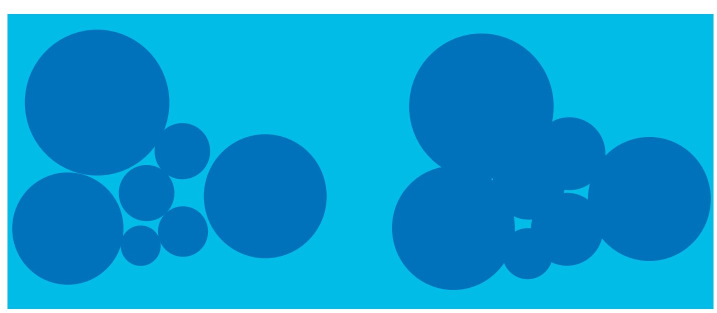




Build parts in sintered powder

SINTERED POWDER

Parts produced free floating in sintered powder
In the EBM process, the metal powder around the build part is sintered. This means the metal powder particles are heated and slightly attached to each other, without reaching the melt temperature. This provides a stable environment for the part being built. The sintered powder surrounding the build part provides several benefits:



Schematic picture of sintered powder particles

- The sintered powder acts as a support structure for the part being built. In most cases, no additional mechanical support structures are needed. This allows for increased freedom when designing parts for increased product performance.

- The supports used in EBM are primarily used as a cooling element—ensuring an even build temperature. Fewer supports also means less waste and more powder to be reused for the next build.

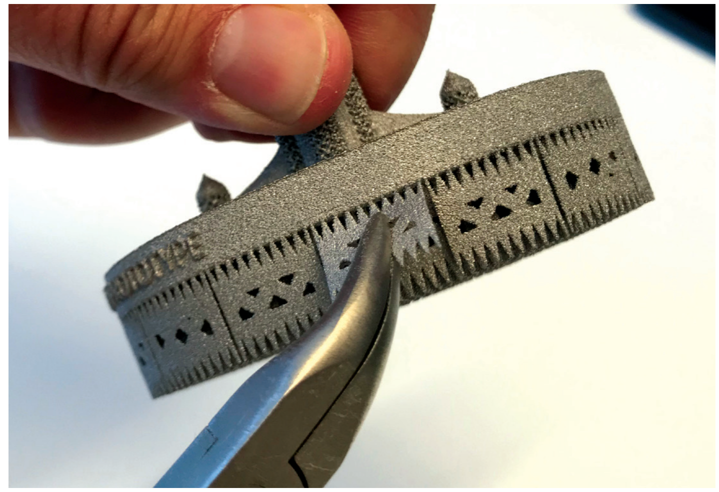
- A major benefit of building with sintered powder is the ability to tightly stack parts. Allowing you to build more parts each time, leading to high productivity and lower cost per part.

- With a minimum support in each build, less material has to be melted. This positively impacts the build time and productivity.

- In EBM the parts produced in Titanium and Cobalt Chrome do not need to be anchored in the build plate, to avoid swelling. The parts can easily be removed from the start plate. The production step of wire EDM cutting is eliminated which further increases productivity.

Powder Removal

The sintered powder is removed in a Powder Removal Station (PRS). The PRS has a similar concept as a blasting cabinet, however the manufacturing powder is used as blasting media. The main purpose of the PRS is to remove the excess powder (powder cake) that has agglomerated or around the parts during the hot manufacturing process. Our Arcam EBM equipment enables reuse of in-process powder extracted from the PRS, the powder in the vacuum chamber left after a build, and the powder cake of previous builds. Excess powder left in the EBM machine can be removed using the auxiliary vacuum cleaner. This excess powder, and powder from the PRS, can be sifted to remove agglomerated particles, and then reused in following builds.



The supports are easily removed from the part.

Hip cups tightly stacked with sintered powder between each part

LOWER COST PER PART

If you look at the entire production process, EBM has several productivity benefits, compared to laser technology. In addition, depending on the characteristics of the part you are building, the cost per part can be up to 50% lower for EBM.

PRODUCTION COST WITH EBM

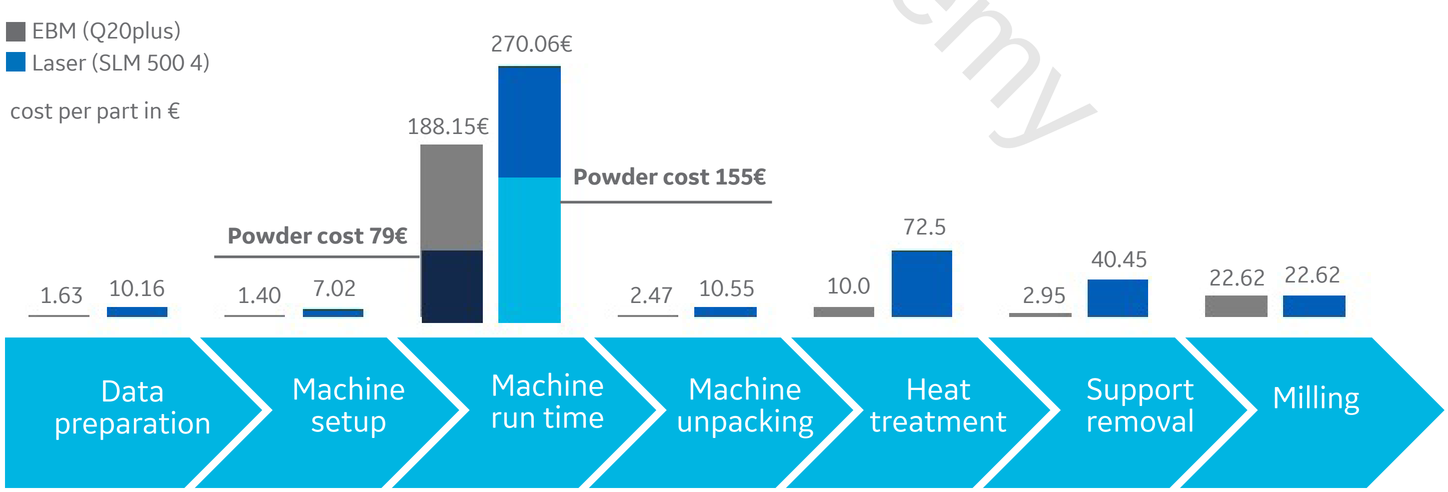
We worked with an independent consultant, to evaluate the production costs with EBM compared to several laser machines. Two applications where selected a bracket for the Aerospace industry and a hip cup for the orthopedic industry. Both applications were produced in Titanium (Ti64).

The production process was divided into seven steps: data preparation, machine setup, machine run time, machine unpacking, heat treatment, support removal and milling.

The Results:
EBM had a significant cost advantage, during all steps except milling. The steps with the most notable and largest advantages are:

1. **Machine Run Time:** The machine run time process cost was primarily affected with the lower powder price. In this case the powder price for EBM was 49% lower than for laser. This is the part of the cost comparison that has the largest impact in terms of money of all. The tight stacking possibilities and EBM's higher melt rate also helps to lower the production cost in this step.
2. **Heat Treatment**: As EBM is a hot process, the Heat treatment is not needed for stress relieving of the components.
3. **Support Removal:** Supports on EBM produced parts are easily removed; therefore, the cost during the support removal process very low for EBM.

The production cost comparison, bracket example



Source: AM power study