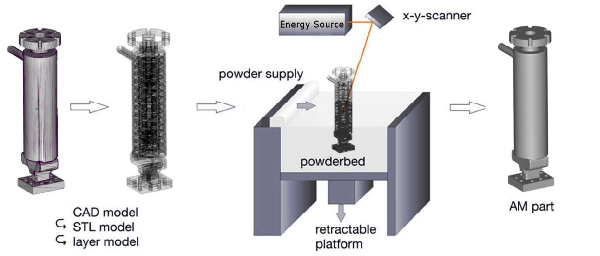
FCC WEEK 2016
ENGINEERING DEPARTMENT

# Additive Manufacturing for Accelerators Components

*R. Gerard[1], I. Aviles Santillana[2], F. Bertinelli[1], K. Eiler[1], G. Favre[1], A. Grudiev[1], T. Sahner[1]*
*[1]CERN, Geneva, Switzerland; [2]University Carlos III, Madrid, Spain*

## What is Metal Additive Manufacturing ?

Metal Additive Manufacturing (AM) by Powder Bed Fusion is a near net shape manufacturing process in which an energy source selectively melts regions of a metal powder bed, layer after layer. Electron Beam Melting (EBM) refer to AM with electron beam as energy source and Selective Laser Melting (SLM) with Laser as energy source.

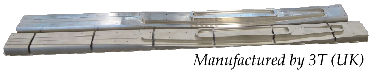



*Schematics of the Powder Bed Fusion process. After being converted into a surface model (triangle based file format STL (STereoLithography)), the part is virtually sliced to model the different layers that will successively be exposed to the laser. The part is then manufactured with layer thicknesses typically ranging from 20 μm to 70 μm. Finally, the parts are removed from the base plate.*
*In order to achieve higher quality requirements, a wide range of post-processing techniques such as heat treatment, surface treatment or machining may be used.*

## Examples of AM parts

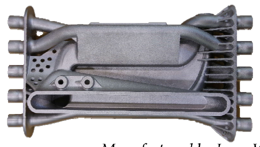
*Manufactured by INITIAL (FR)*

*In RF loads, the low electrical conductivity of titanium or stainless steel is a property of interest in order to dissipate the RF power. These parts feature complex inner shape and cooling channels – CLIC*



*Manufactured by 3T (UK)*

*High Temperature Superconductors Magnet Former. Comparison between machined and Laser AM (1.5 m long)*



*Manufactured by LayerWise (BE)*

*Heat exchanger for LIEBE (Liquid Eutectic Lead Bismuth Loop Target for Eurisol) – ISOLDE*

## Advantages of AM

- **Complexity for free:**
  - Cooling channels
  - Organic structures
  - Surface features
  - Single-part assembly
- **Short lead times**
  Manufacturing time: from a couple hours to a few tens of hours for a full platform
- **Low waste**

## Limitations of AM

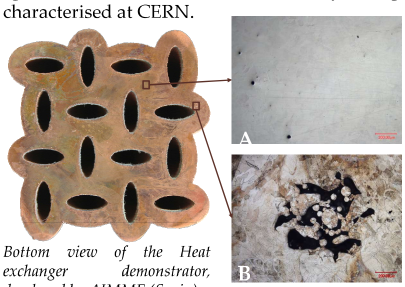
- **Limited size**
  Typically 250 × 250 × 250 mm³
- **Small list of available materials:**
  Predominantly stainless steel (SS316L), titanium alloy (Ti6Al4V), aluminium alloy (AlSi10Mg) and Inconel (IN718)
- **Require post processing due to:**
  Large Geometrical Tolerances: 0.1 to 0.2 mm.
  High surface roughness: Ra 10 – 15 μm
- **Material and metallurgical quality**
  Difficulty to reach high chemical purity

## Research and Development in collaboration with industry

### New materials development: Electron Beam Melting of pure copper

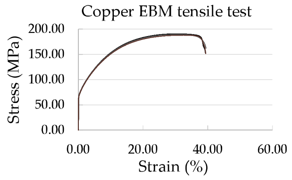
As part of the ongoing research on new materials development (pure copper and niobium, for both EBM and SLM), the development in pure Copper EBM by the Spanish institute AIMME is currently being characterised at CERN.


*Heat exchanger demonstrator made by EBM of pure copper.*




*Bottom view of the Heat exchanger demonstrator, developed by AIMME (Spain).*

*First optical microscopy results reveal mostly dense areas (micrograph A).*
*However, large defects, referred to as lack of fusion, can be identified (micrograph B). A typical characteristic of those defects are the entrapped and partially molten powder particles.*




*Mechanical behaviour close to cast pure copper (C80100) in terms of strength and elongation at break (UTS of 180MPa and elongation of 40%).*
*However, the measured Young's modulus is lower: 98 GPa against 117 GPa for Cast copper.*

### RF characterisation of Metal Additive Manufacturing for application in broad-band all-metal dry RF load

The aim of this project is the low power Radio Frequency (RF) characterisation of the powder bed additive manufacturing process. 5 waveguides in Ti6Al4V (4 SLM and 1 EBM) are compared in terms of:

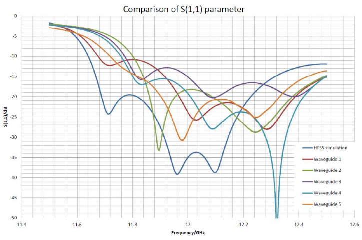
- Ultra High Vacuum Compatibility (outgassing and leak tightness)
- Shape accuracy and surface roughness
- Mechanical properties

*Additively manufactured titanium alloy waveguide for low power testing. SLM waveguide were manufactured by EOS (Germany) and Concept Laser (Germany). EBM waveguide was manufactured by Grenoble INP (France).*

#### Results and conclusion

- SLM waveguide ok for UHV. The EBM waveguide was unable to pump down due to small holes.
- A systematic deviation of the shape was observed for all waveguides (oversize of 100 μm for SLM to 300 μm for EBM)
- Mechanical properties acceptable (Higher strength but lower elongation compared to wrought alloys)

**All SLM waveguides were validated for low power RF testing.**
**EBM to be improved w.r.t. leak tightness.**
**High power testing is taking place at CERN.**




*S(1,1) parameter representing the reflection of the power to the input. The goal is the have the least reflection at the working frequency: 12GHz*
*Waveguide 2 is manufactured by EBM, waveguides 1, 3, 4 and 5 are manufactured by SLM*

## Qualification programme for Additive Manufacturing at CERN

To qualify the Additive Manufacturing process for use in accelerator environment, the following characterisations will be performed as part of a process qualification programme for the different available materials.

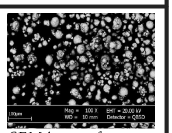
**Additive manufacturing qualification programme**

**Metallurgical and shape properties**
- Mechanical properties (ambient and cryogenic temp.)
- Microstructure
- Shape accuracy
- Surface roughness

**Physical properties**
- Electrical conductivity
- Residual Resistance Ratio
- Chemical composition

**Ultra High Vacuum compatibility**
- Leak tightness with different wall thicknesses
- Out-gassing behaviour

**Metal powder**
- Chemical composition
- Flow properties
- Size distribution
- Particle shape



*SEM image of AM Copper Powder BSE (100x)*

## Future steps

- **In-house machine late 2016 Use: R&D, prototyping and finished products**
  Build chamber size: 250 × 250 × 250 mm³
- **Development of novel materials**
  OFE Copper and Niobium both in-house and in collaboration with industry
- **Optimisation of the process for specific applications**
  Ultra High Vacuum (UHV), Radio Frequency (RF) and Cryogenic