A study on the chemical and microstructural optimization of the Ti-48-2-2 alloy processed by Electron Beam Melting

Manuela Galati[1, 4], Cristian Ghibaudo[2, 4], Giovanni Rizza[1], Reinhold Wartbichler[3], Svea Mayer[3], Luca Iuliano[1,4], Helmut Clemens[3], Daniele Ugues[2, 4], Sara Biamino[2, 4]

[1] Department of Management and Production Engineering, Integrated Additive Manufacturing (IAM) Centre, Politecnico di Torino, Italy
[2] Department of Applied Science and Technology, Integrated Additive Manufacturing (IAM) Centre, Politecnico di Torino, Italy
[3] Department of Materials Science, Montanuniversität Leoben, Austria
[4] INSTM, Italy

NEWTEAM

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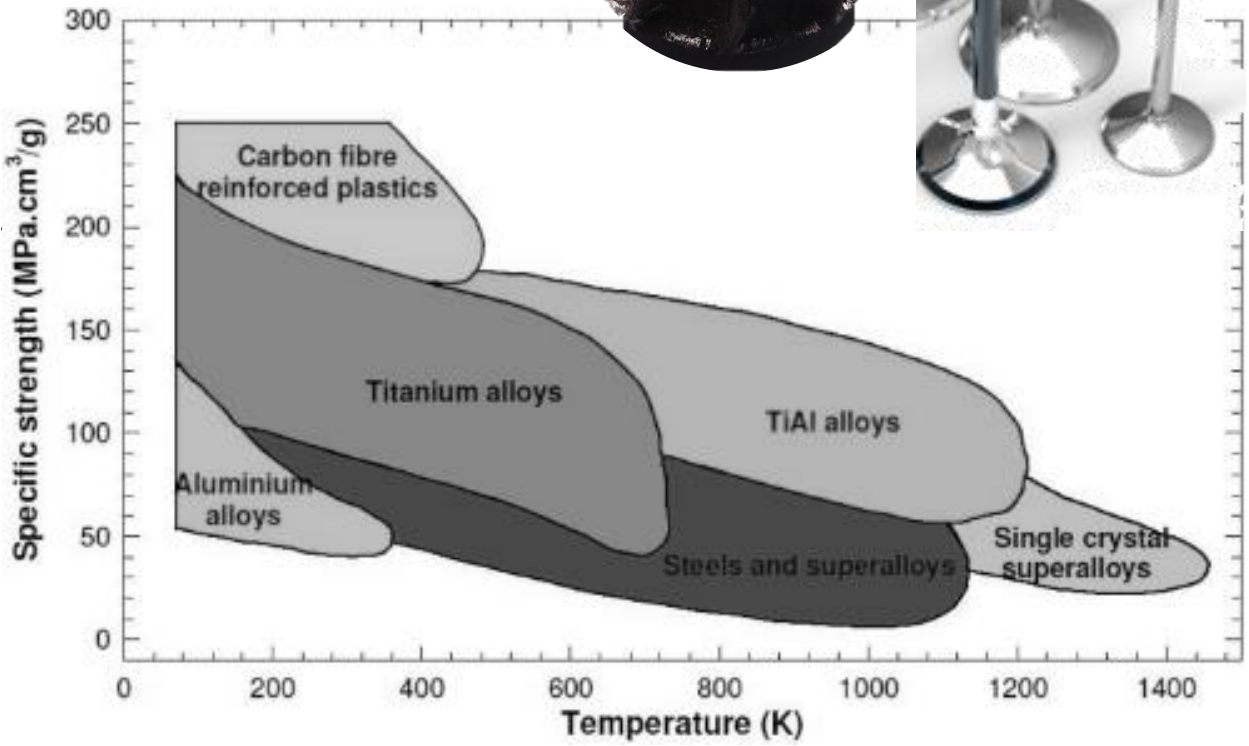
Context

TiAl alloys are attractive materials for structural aerospace applications at high T in particular low pressure turbine blades:

- Specific strength comparable to Ni base superalloys
- γ-TiAl 4 g/cm3 vs 8 g/cm3 Ni-base superalloys
- Good oxidation and corrosion resistance up to 750-800 °C

[1]

[1]



[2]

[1] Loria, Intermetallics-2001, “Quo vadis gamma titanium aluminide”
[2] Bewlay, Material at high temperature-2016, “TiAl alloys in commercial aircrafts engines”

AIM:

- Develop new **TiAl alloys** for EBM process for the production of the next generation of low pressure turbine (LPT) blades

- Modifications of the chemical composition with respect to the reference Ti-48Al-2Cr-2-Nb were investigated;
- Optimization of the EBM process parameters were done coupling experimental trials with the development of simulation tool;
- Full mechanical characterization of the new alloys and comparison with the reference Ti-48Al-2Cr-2-Nb alloy

BUDGET 800.000 €

Designing TiAl alloys for Electron Beam Melting

Ti-(42-48)Al-(0-4)Cr/Mn/V-(0-10)Nb/Ta/W/Mo-(0-2)Si/C/B

Less Al: more α_2-phase, higher strength, lower RT ductility, lower oxidation resistance

RT ductility

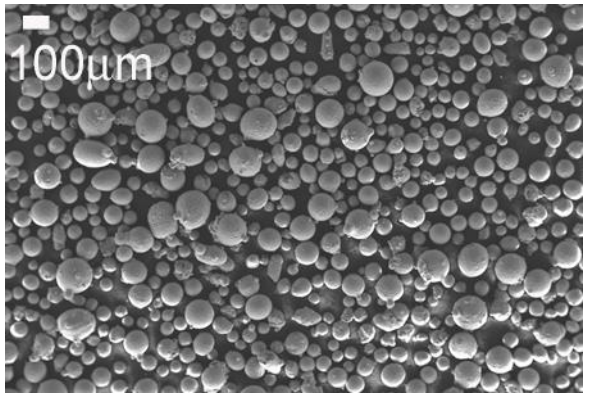
Oxidation resistance, hot-workability, refinement of microstructure, creep strength

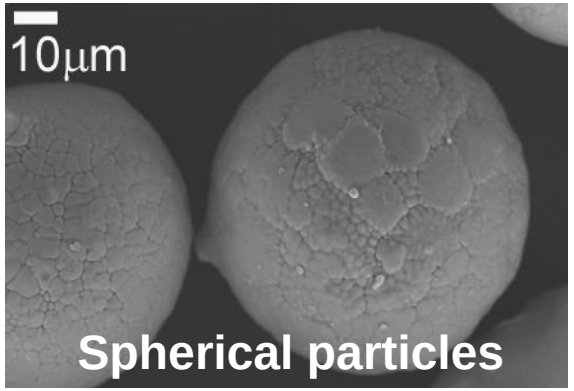
Oxidation resistance, refinement of microstructure, creep strength

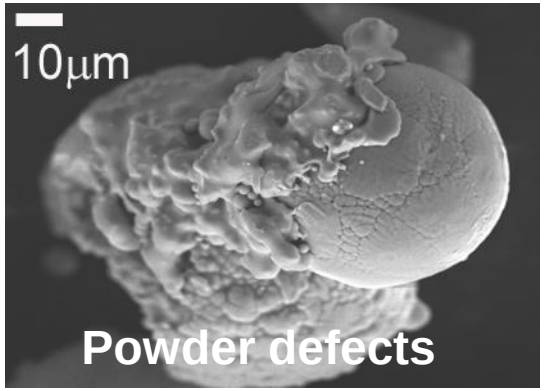
Powder characteristics are a key parameter

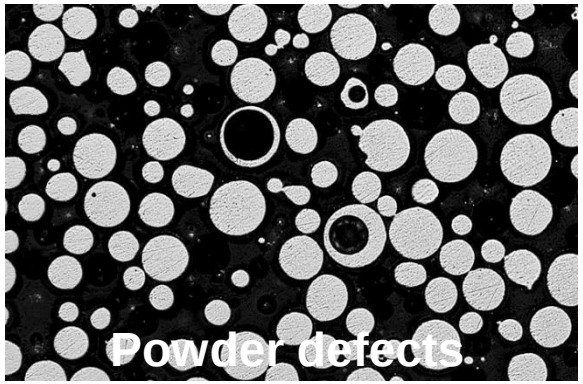
Gas-atomized powder with specifications:

- Chemical composition (to be balanced the loss of evaporating elements)
- Mesh size
- Powder flowability
- Powder apparent density

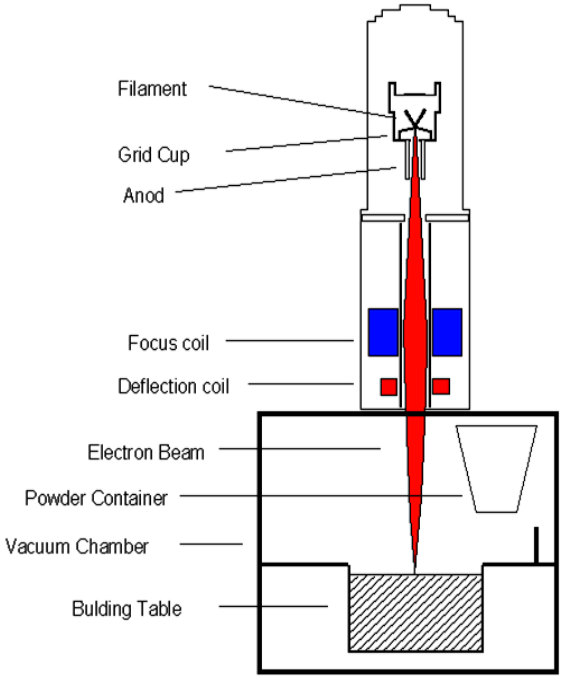


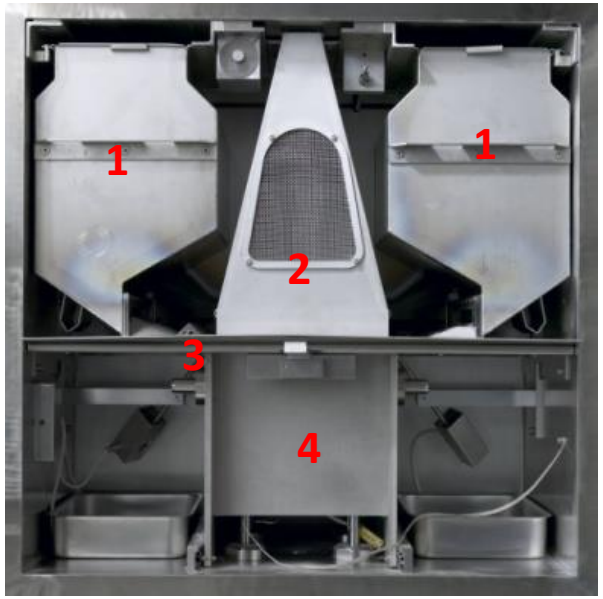






The EBM process:





1) Powder tanks
2) Electron Beam path
3) Rake for powder distribution on the building plate
4) Building plate which move down layer by layer

Advantages:

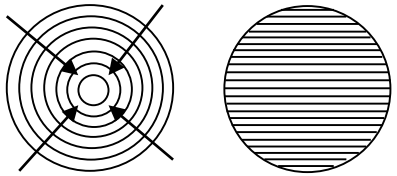
- freedom of design
- dense material with good material properties
- low material waste
- good productivity
- Possibility of preheating powder
- Vacuum melting process (no contaminations)

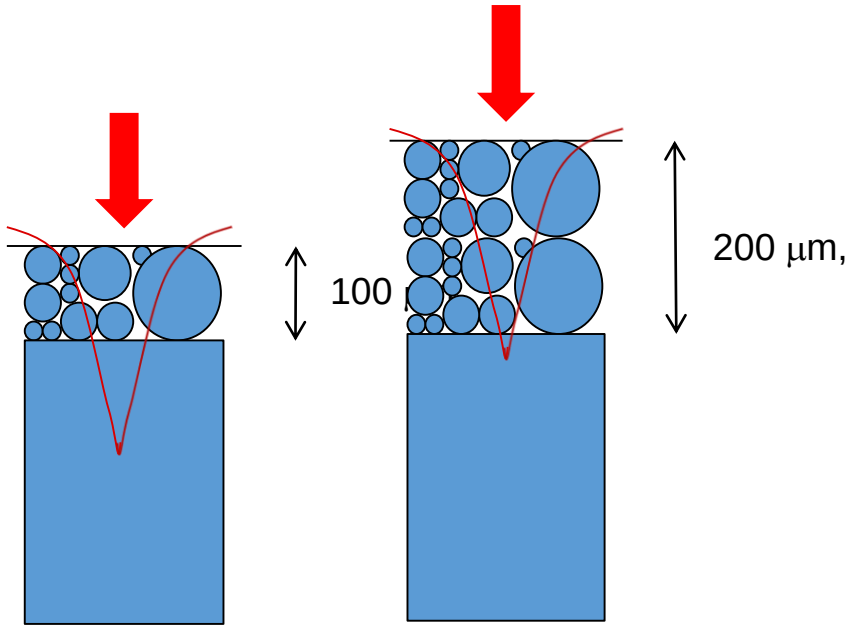
Technical features:

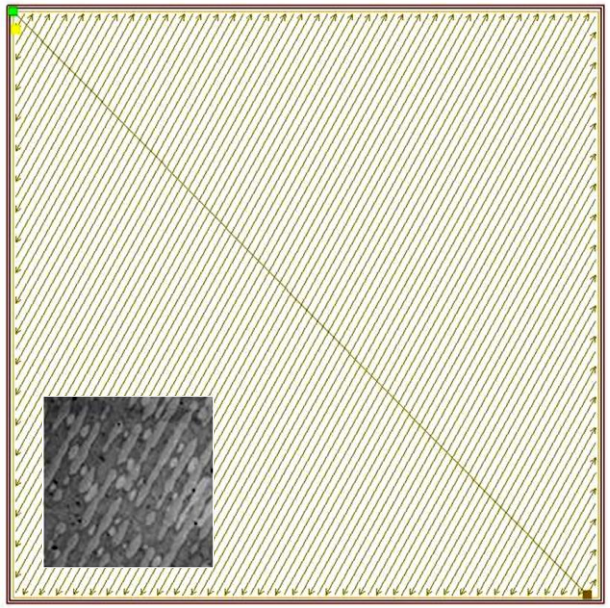
- 6 kW electron beam
- High preheating: up to 1000-1100 °C
- Vacuum chamber: 10^{-3} -10^{-5} mbar
- Approximate chamber dimension: 350x350x350 mm
- E-Beam rate: up to 8000 m/s
- Layer thickness: 70-200 micron
- Approximate build rate: 60 cm^3/h

There are aloto of EBM parameters that have to be optimized in oreder to produce defects free materials:

- Process power
- Powder layer thickness
- Scanning velocity
- Line offset
- Scanning strategy
- Preheating temperature

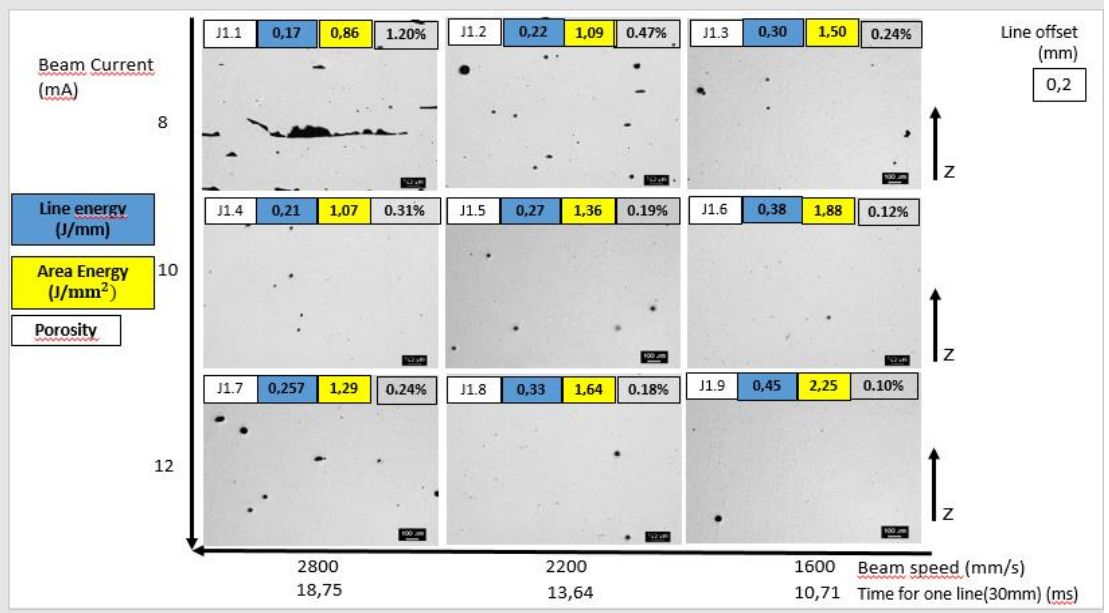






They affect: process productivity, residual defects, obtained microstructure

Optimization of the process parameter for the reduction of the residual defects



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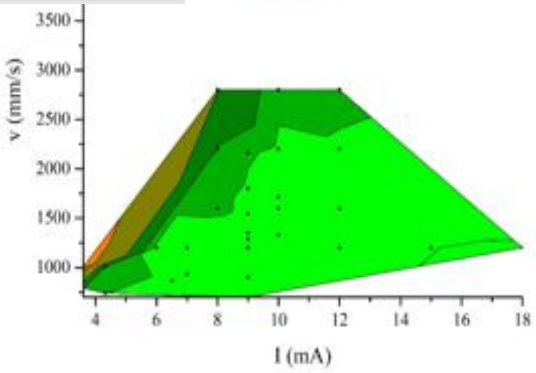
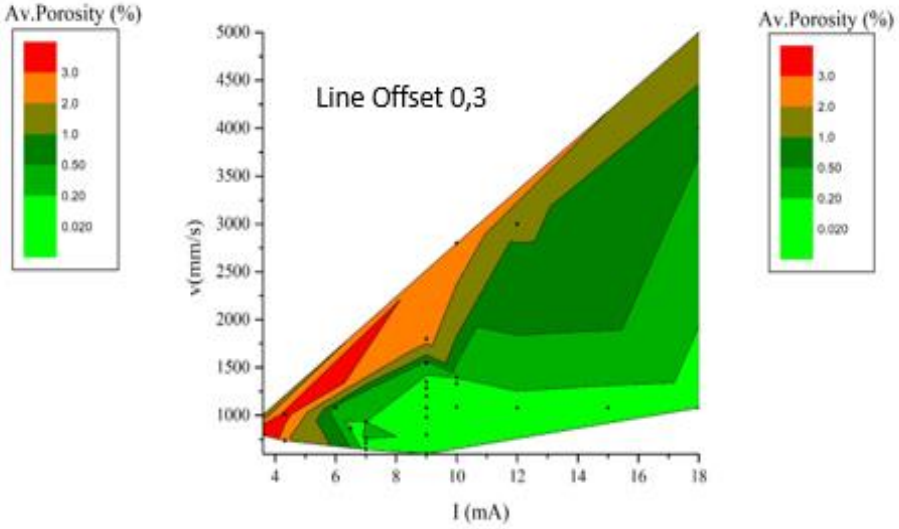
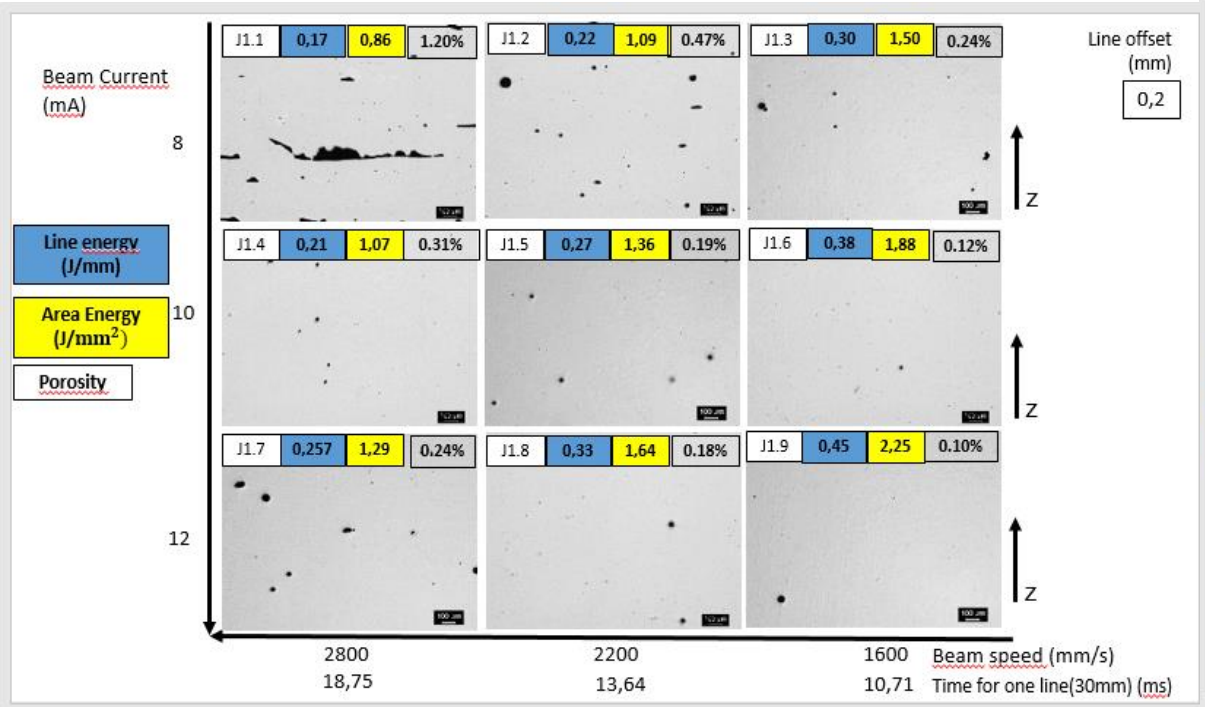
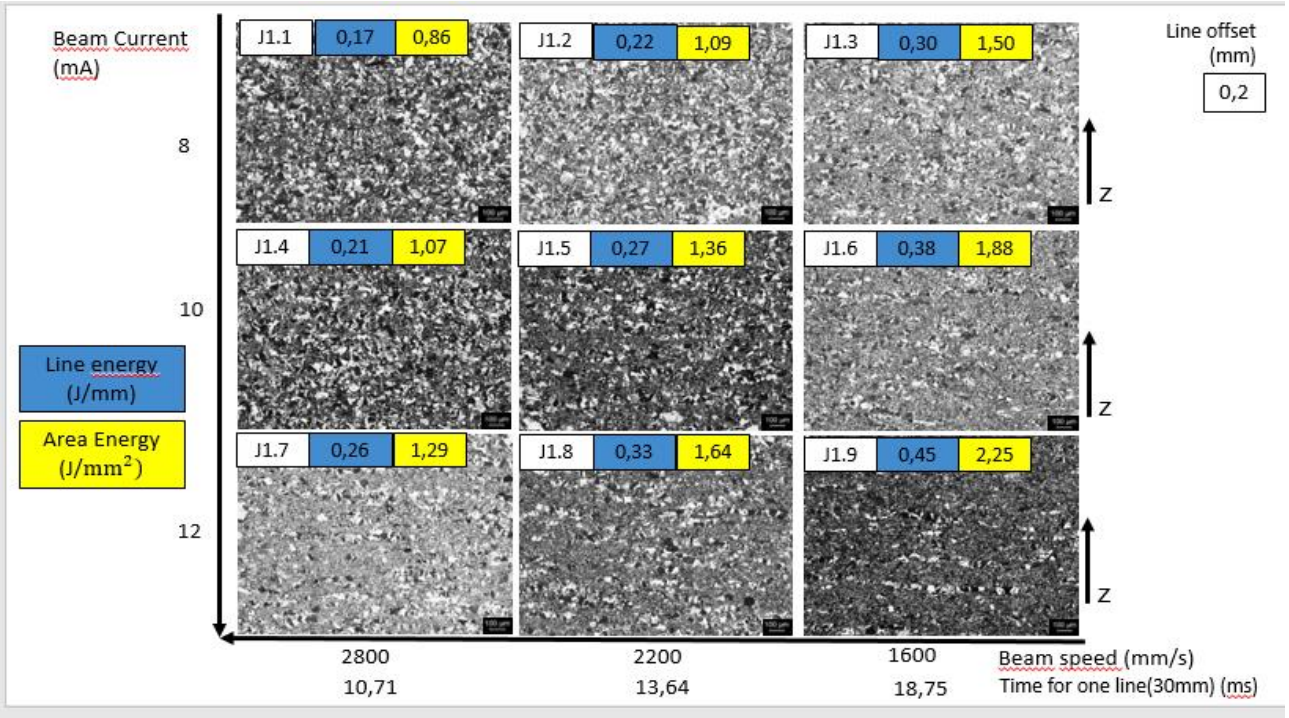


Porosity chart

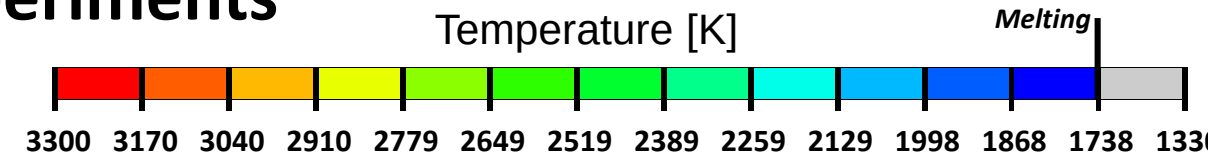


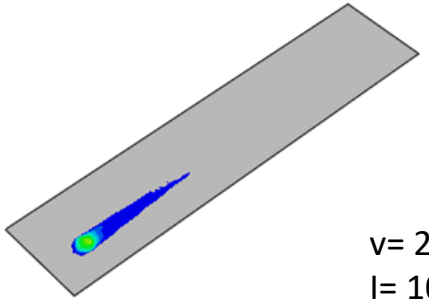
Optimization of the process parameter for the improvement of the microstructure homogeneization



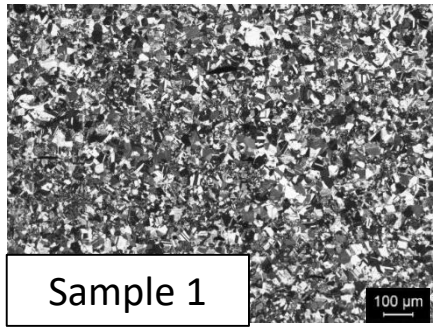


Simulation and Experiments

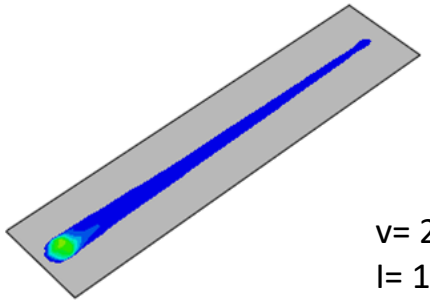




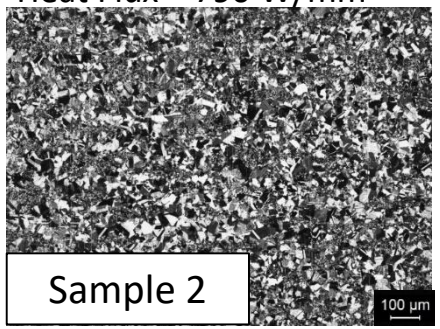
v= 2800 mm/s
I= 8 mA
Heat Flux = 828 W/mm^2



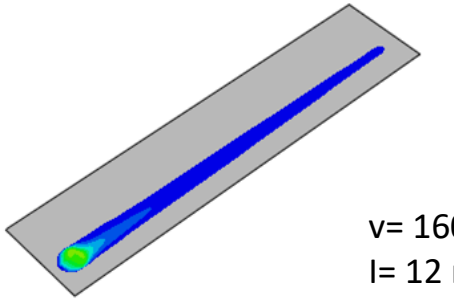
Line Energy = 0.171 J/mm
Area Energy = 0.86 J/mm^2



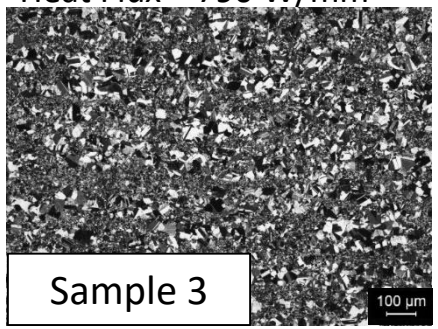
v= 2800 mm/s
I= 10 mA
Heat Flux = 790 W/mm^2



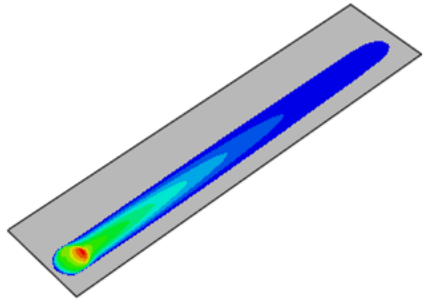
Line Energy = 0.214 J/mm
Area Energy = 1.07 J/mm^2



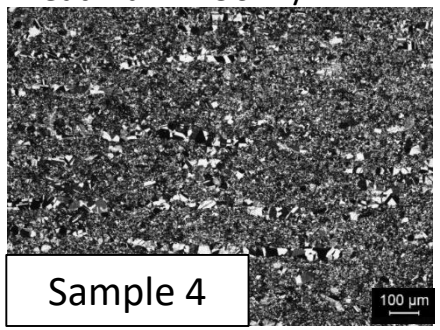
v= 2200 mm/s
I= 10 mA
Heat Flux = 790 W/mm^2



Line Energy = 0.27 J/mm
Area Energy = 1.36 J/mm^2

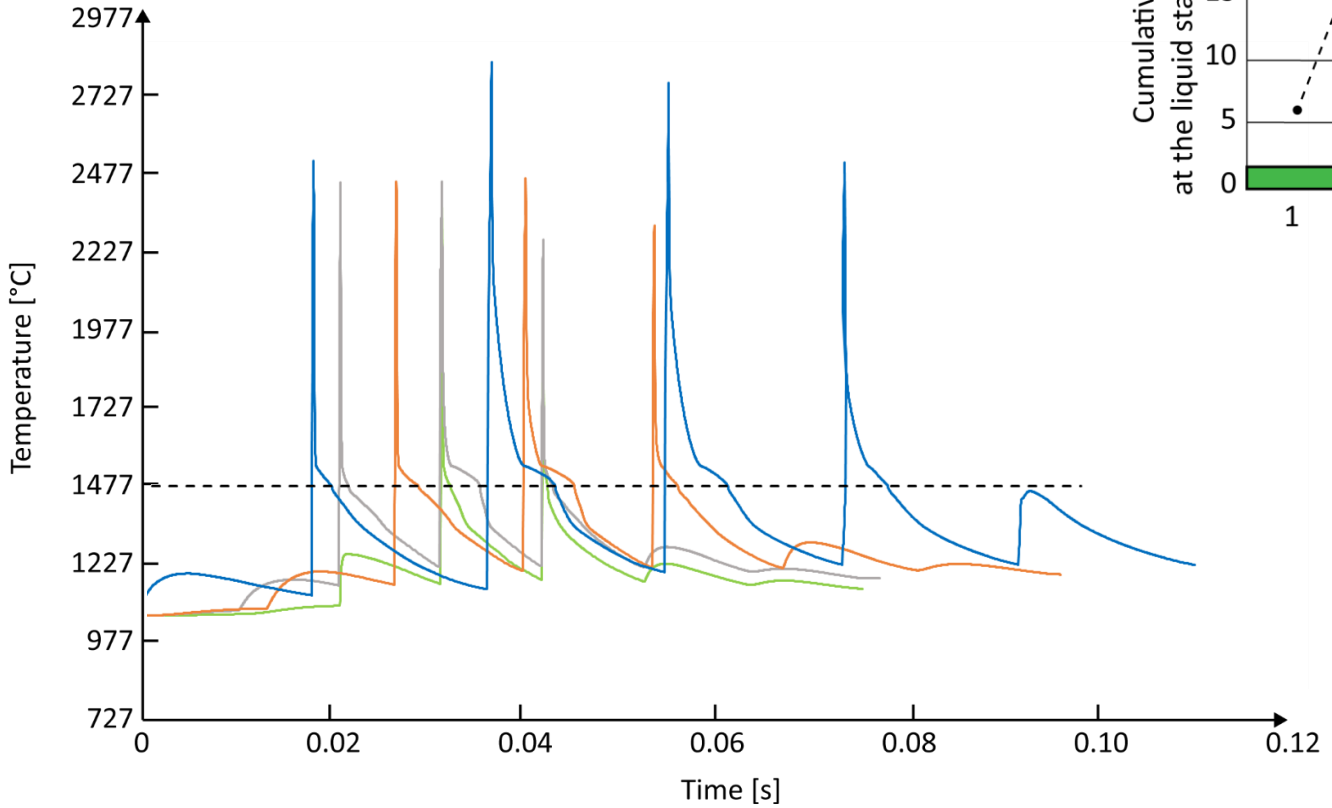


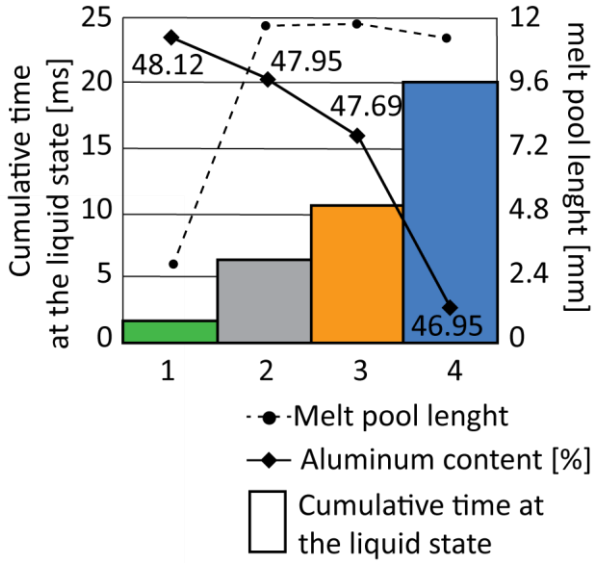
v= 1600 mm/s
I= 12 mA
Heat Flux = 796 W/mm^2

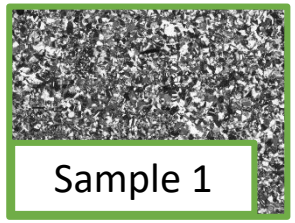


Line Energy = 0.450 J/mm
Area Energy = 2.25 J/mm^2

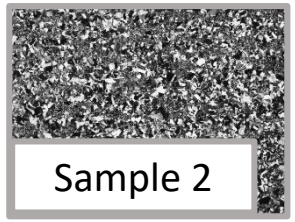
Simulation and Experiments



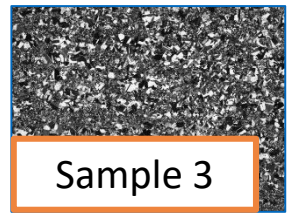




v= 2800 mm/s
I= 8 mA
Heat Flux = 828 W/mm^2



v= 2800 mm/s
I= 10 mA
Heat Flux = 790 W/mm^2



v= 2200 mm/s
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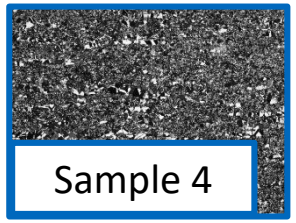
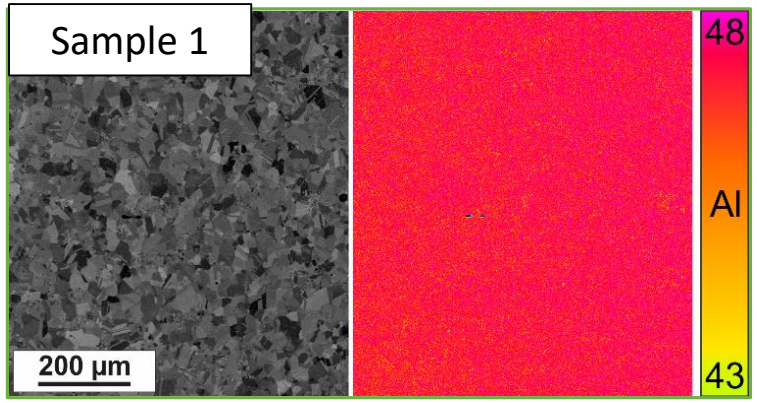
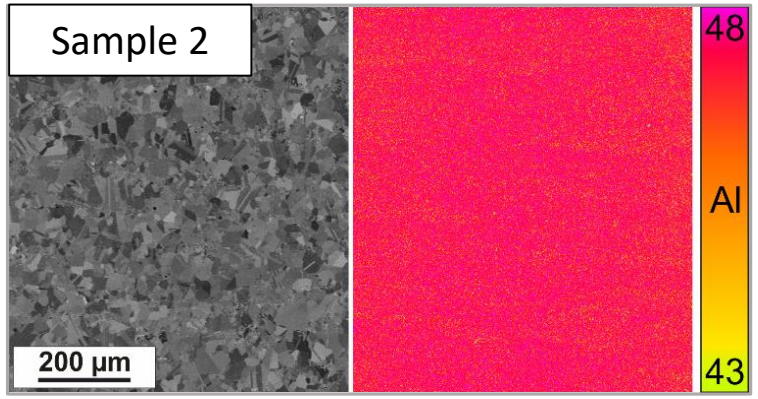
Heat Flux = 790 W/mm^2

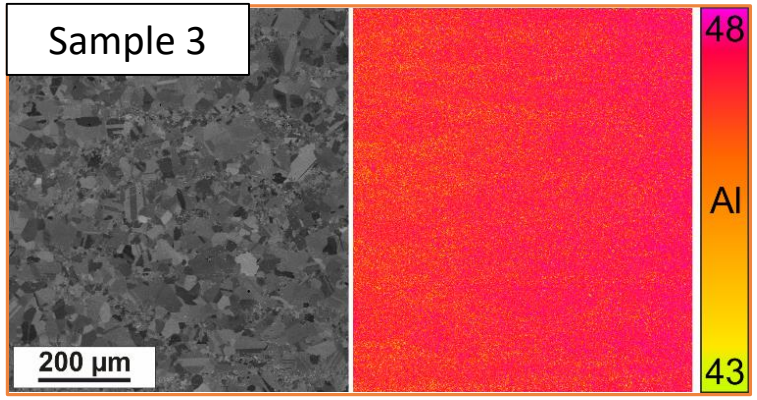


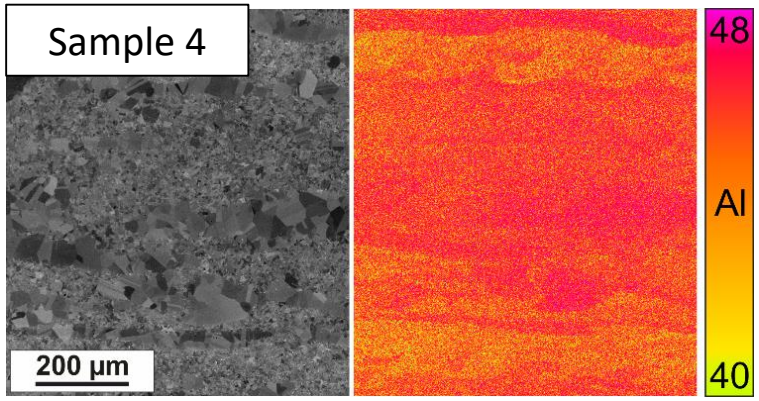
v= 1600 mm/s
I= 12 mA
Heat Flux = 796 W/mm^2

Chemical homogeneity by electron probe micro analysis









- Chemical homogeneity and overall chemistry are a function of processing parameters due to evaporation.
- Inhomogeneous Al distributions might lead to banded microstructures after heat treatment.

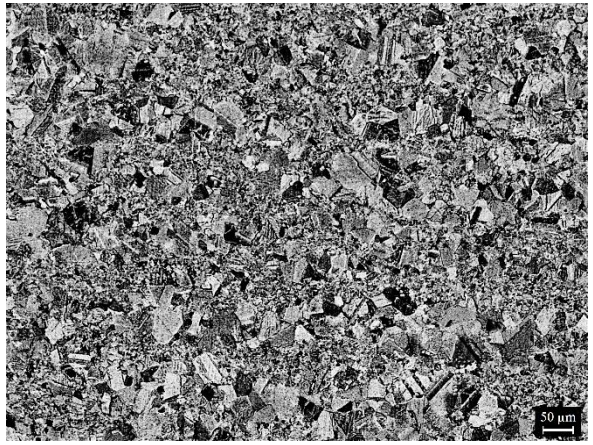
Effects of the heat treatment on the microstructure

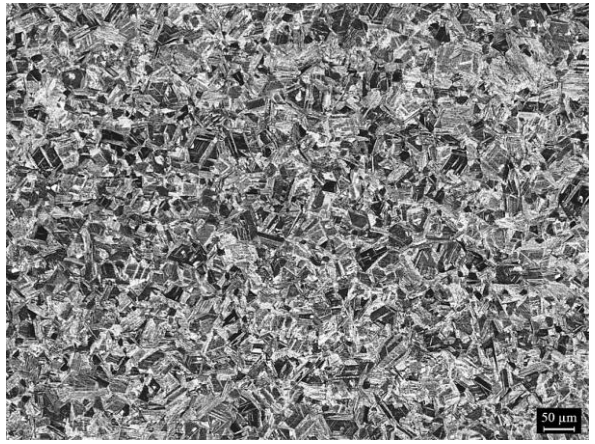
Sample 2

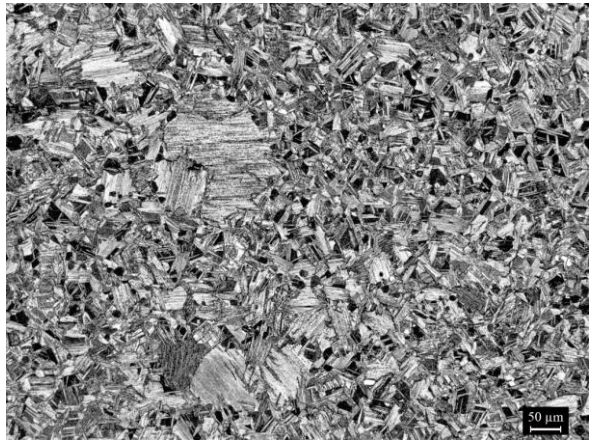
v=2800mm/s
I=10 mA
Heat Flux= 790 W/mm²

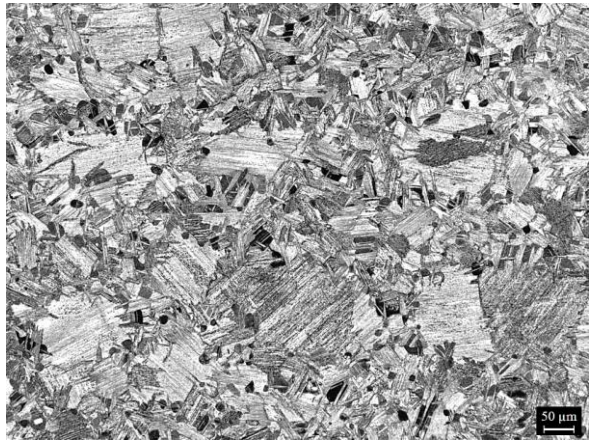
Increased set point temperature during heat treatment

As-built

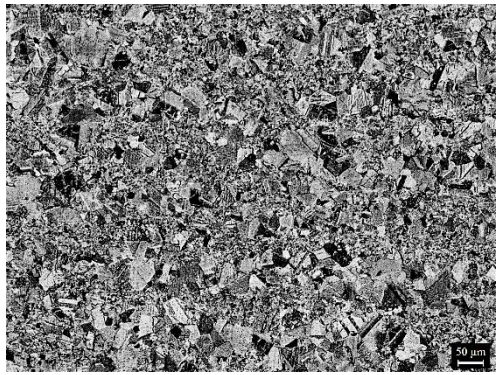
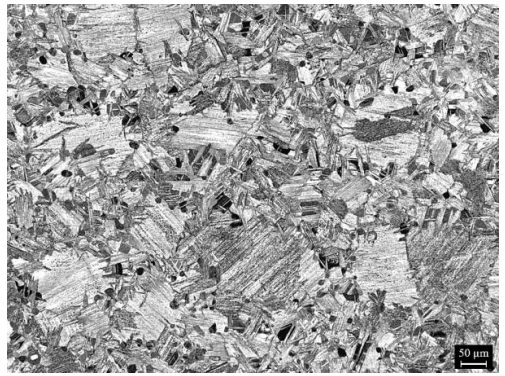
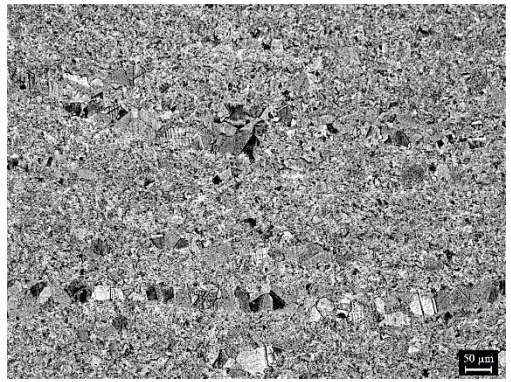
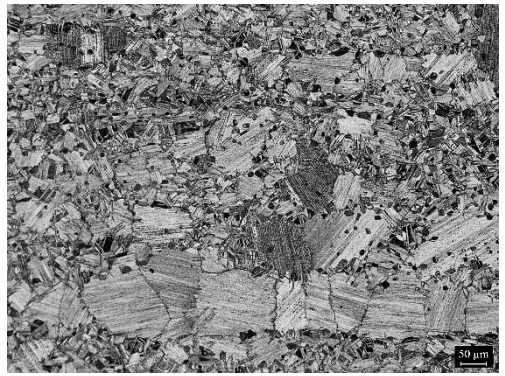




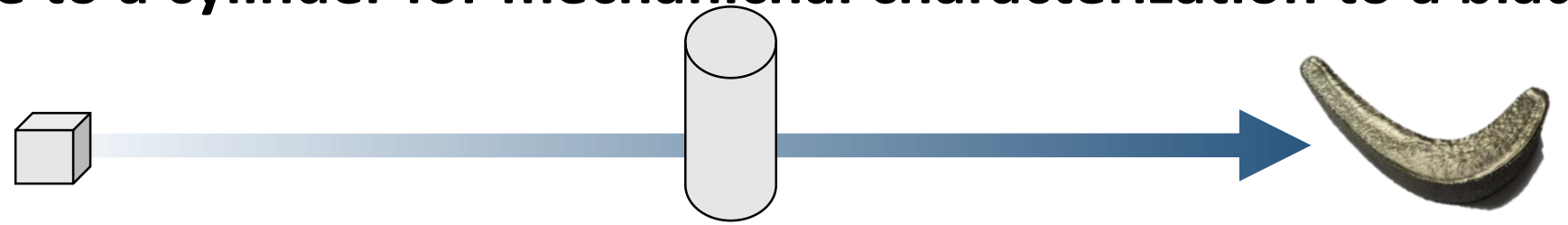


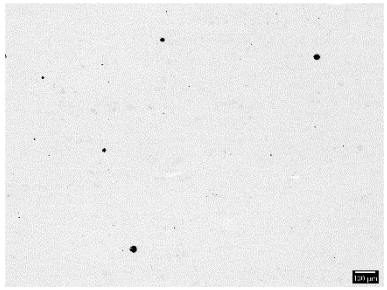


Effects of the heat treatment on the microstructure

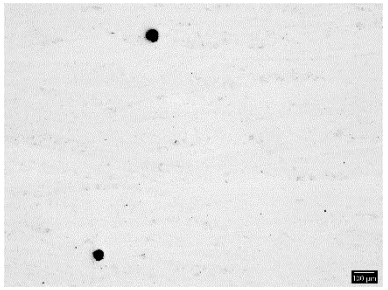
	As-built	After HT
Sample 2 v=2800mm/s I=10 mA Heat Flux= 790 W/mm² **33,7 wt% Al**		
Sample 4 v=1600mm/s I=12 mA Heat Flux= 796 W/mm² **32,6 wt% Al**		

From a cube to a cylinder for mechanichal characterization to a blade

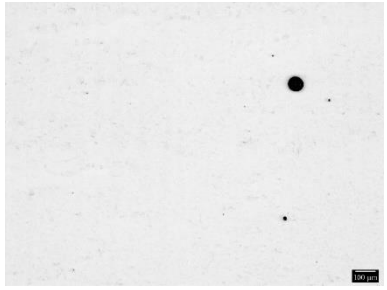




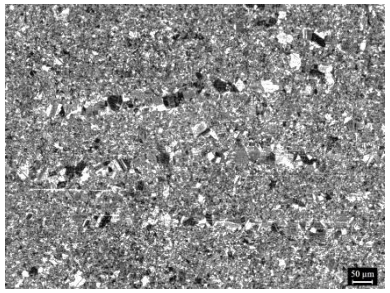
Av.P: 0,12% Dmax: 100 µm

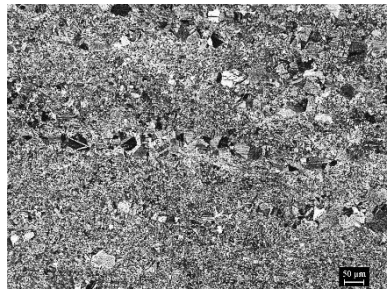


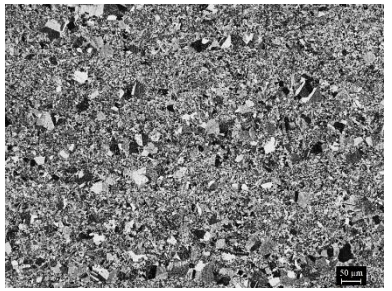
Av.P: 0,14% Dmax:120 µm



Av.P: 0,12% Dmax:120 µm







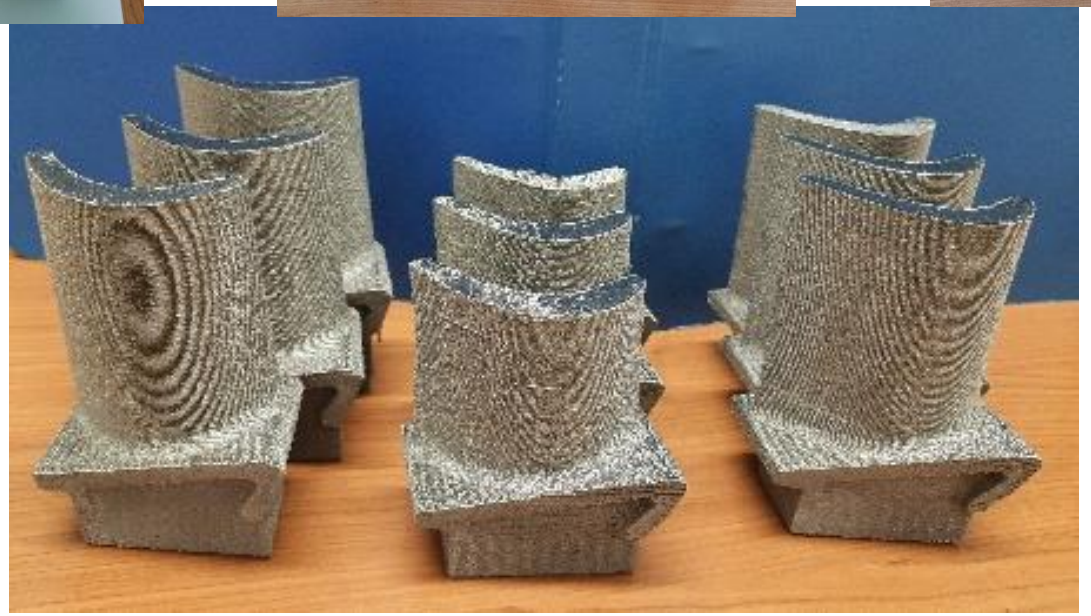
Per each alloy:

- ❖ **Production of cylinders for tensile, creep and HCF;**
- ❖ **Production of representative protion of dem blades**

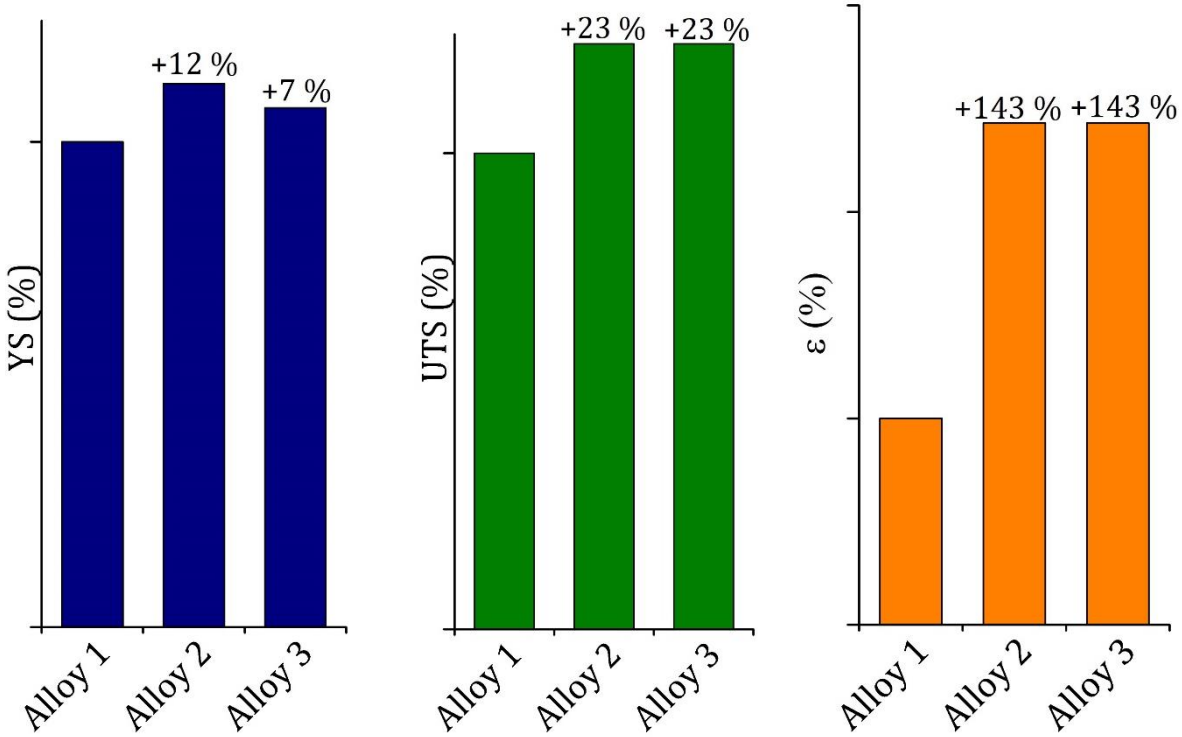
Alloy 1: ref material

Alloy 2

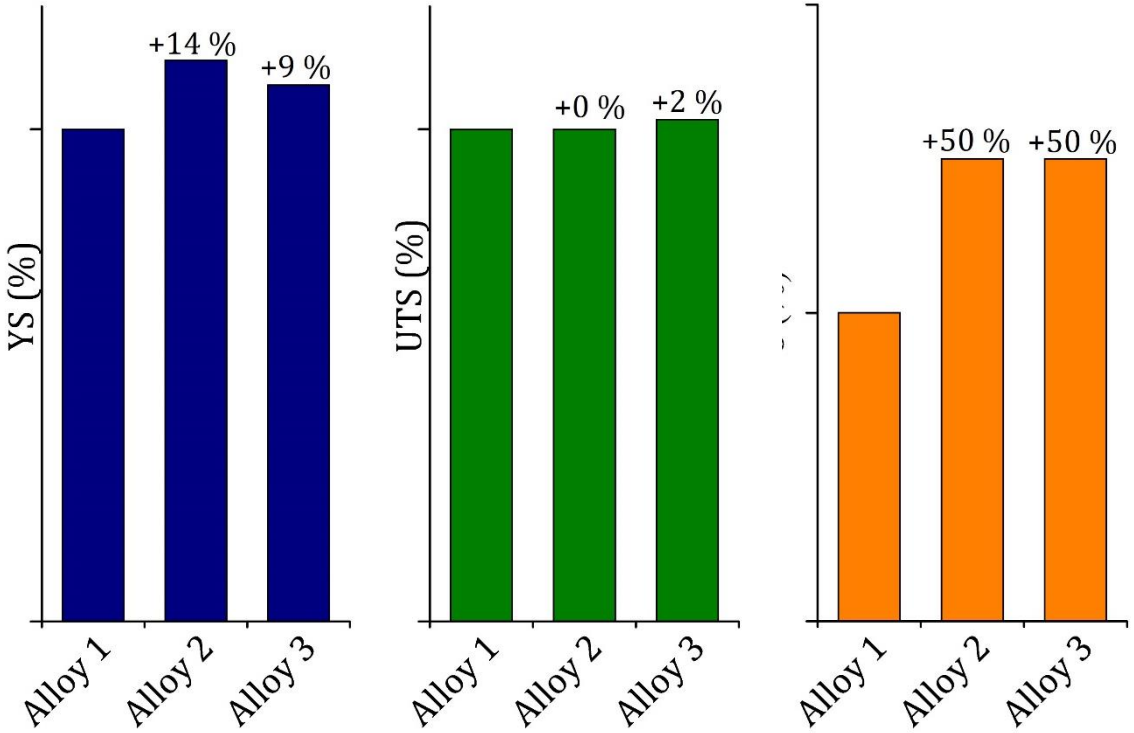
Alloy 3



Tensile at room temperature

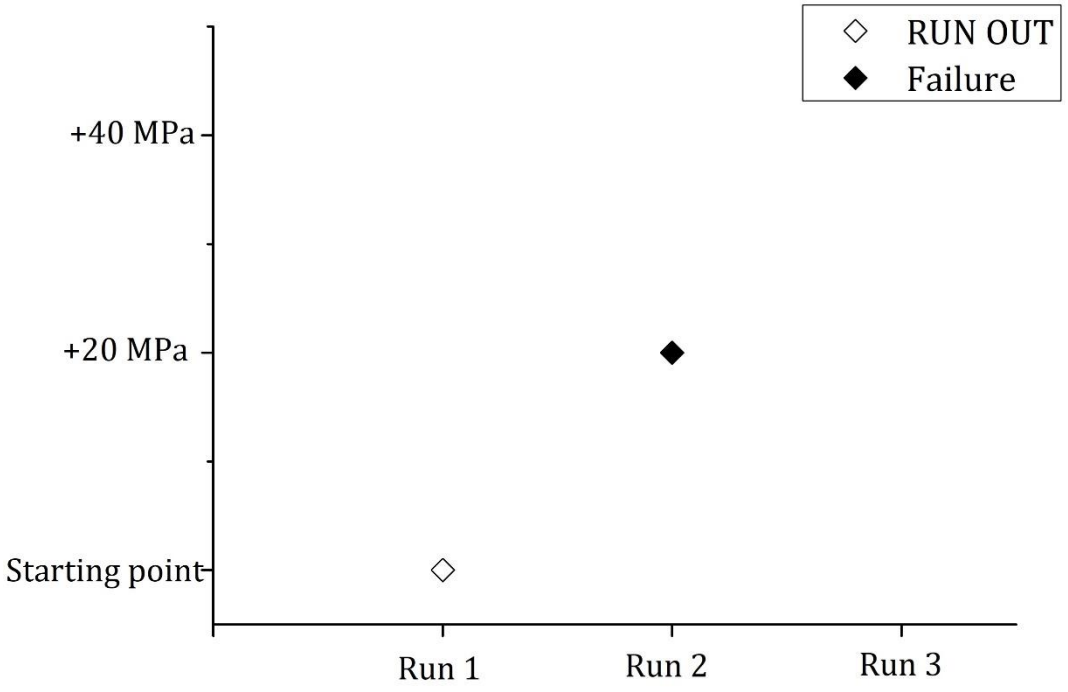


Tensile at 760°C

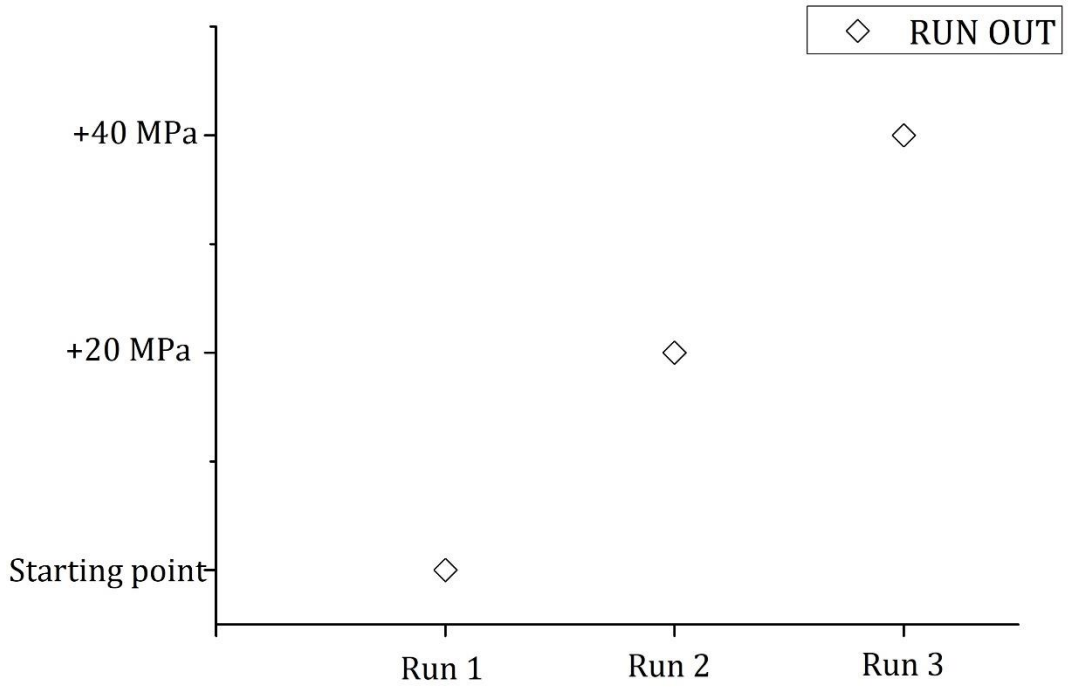


High Cycle Fatigue at 760 °C with a R=0

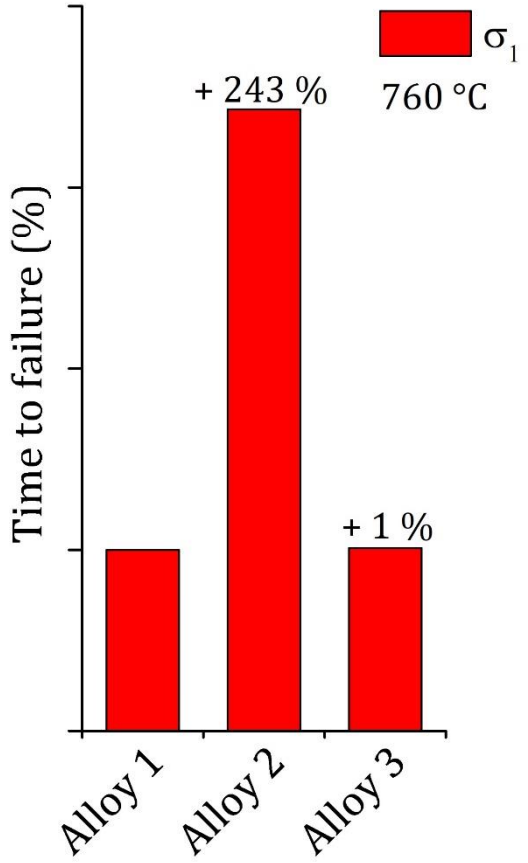
Alloy 1

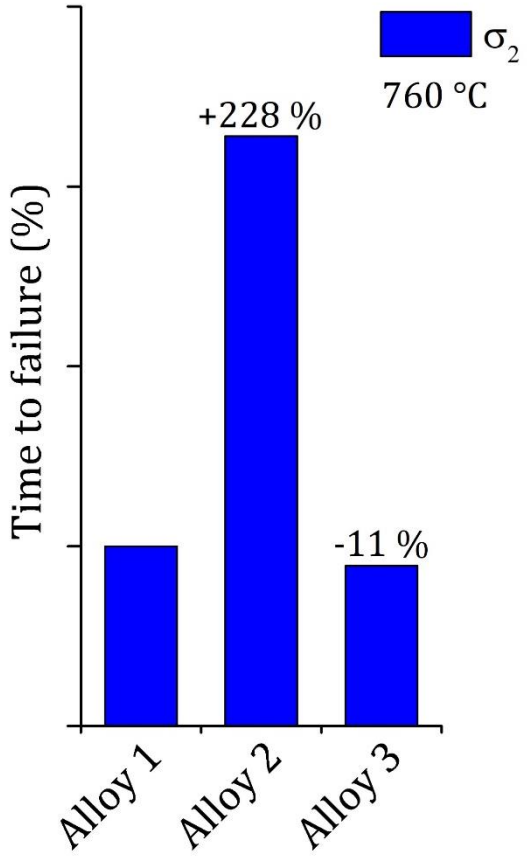


Alloy 2 and Alloy 3



Time to failure during creep test





$\sigma_1 < \sigma_2$

Conclusion

- The characteristics of the EBM process have to be taken into account when **designing TiAl alloys for EBM**.
- The **simulation of the process** helped in understanding the effect of the process parameters on the final microstructure and aluminium content
- Thanks to the **process simulation** the optimisation of the process parameters from a simple cube to a complex shape has been speeded up.
- The process parameters influence the heat treatment and can be optimized for **reducing the inhomogeneity in Al distribution**.
- The two new chemical compositions exhibited **improved performances with respect to the reference alloy**.

A study on the chemical and microstructural optimization of the Ti-48-2-2 alloy processed by Electron Beam Melting

Manuela Galati[1, 4], Cristian Ghibaudo[2, 4], Giovanni Rizza[1], Reinhold Wartbichler[3], Svea Mayer[3], Luca Iuliano[1,4], Helmut Clemens[3], Daniele Ugues[2, 4], Sara Biamino[2, 4]

[1] Department of Management and Production Engineering, Integrated Additive Manufacturing (IAM) Centre, Politecnico di Torino, Italy
[2] Department of Applied Science and Technology, Integrated Additive Manufacturing (IAM) Centre, Politecnico di Torino, Italy
[3] Department of Materials Science, Montanuniversität Leoben, Austria
[4] INSTM, Italy

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cristian.ghibaudo@polito.it