Rapidly solidified microstructure of 3D parts fabricated by selective laser melting (SLM)
Examples of stainless steel 316L and titanium Ti-6Al-4V

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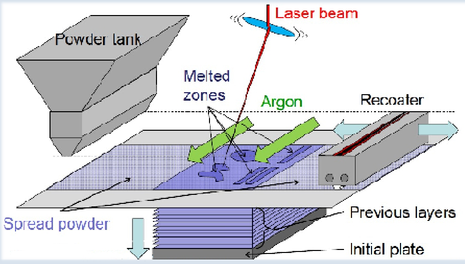
Laser additive manufacturing process capable of producing fully dense metallic parts direct from 3D CAD know a fast development. Major concerns are made to achieve the best accuracy of the final geometry and the reduction of the residual stresses but metallurgical aspects are also essential. The process can be described as a succession of very small welds. A key in the optimization of the mechanical properties is the understanding of the specific solidification mechanisms. Microstructures of two alloys were studied by metallographic examination and EBSD analysis.

Principle of selective laser melting (SLM)

Production of fully dense metal parts direct from a 3D CAD using a fibre laser (200-400W).

MTT SLM 250



Fine metal powders are fully melted layer by layer in thicknesses from 20 to 100 µm to achieve 3D structures.

TipTopLam project **ERDF** (European Regional Development Fund)

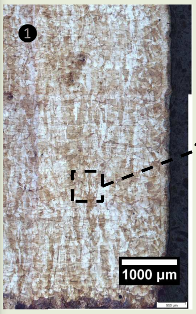
Partners: Sirris, ULg, CRM, CSL and Cewac.

Goal: development of rapid manufacturing facilities for metallic parts : Facilities: selective laser melting *MTT SLM 250*, laser cladding *Irepa Laser* and electron beam melting *Arcam*.

Applications: **Functional prototypes, Medical implants, Internal cooling systems, Smart structures...**

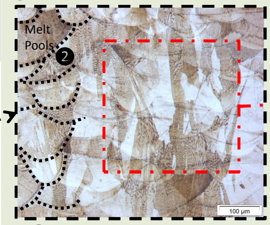
SLM smart structures made by Sirris (TipTopLam and Compolight projects)

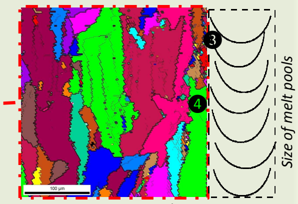
Stainless steel AISI 316L



Bulk part made by laser melting

❶→Density > 99%





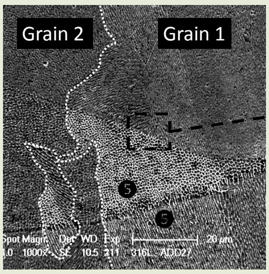
Step size = 6 µm, Grain colour representation

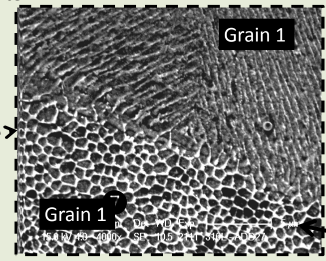
EBSD map showing crystallographic grains whose size is compared with schematic melt pools.

❷→Melt pools are 100x100 µm² size.

❸→Evidence of epitaxial nucleation along several melt pools

❹→100% austenite.



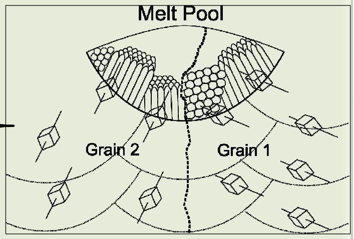


*Melt pool boundaries inside **one** grain showing epitaxial nucleation with different directions of S/L cellular interface growth.*

❺→Evidence of cellular Solid/Liquid (S/L) interface during solidification.

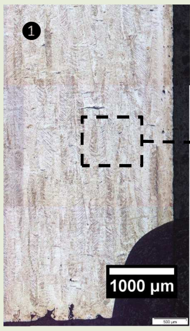
❻→Evidence of non conservation of the direction of S/L interface despite epitaxial nucleation.

❼→Very fine cellular microstructure = high temperature gradient and growth rate.



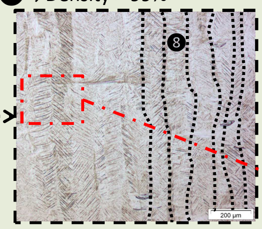
Schematic epitaxial nucleation in a melt pool

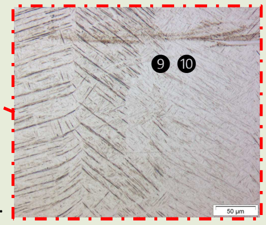
Titanium Ti-6Al-4V



Bulk part made by laser melting

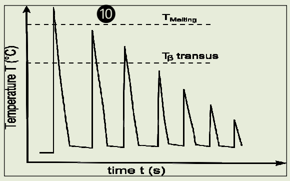
❶→Density > 99%





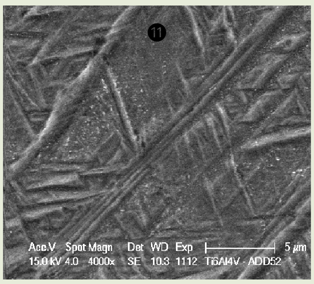
❽→Long primary β-grains.

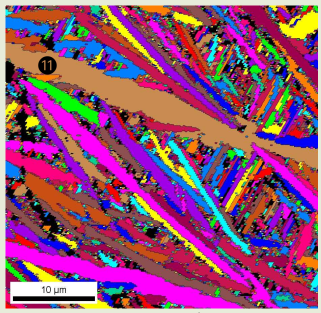
❾→Melt pools traces erased.



Schematic thermal cycle during SLM

❿→High temperature β phase is transformed in α laths during subsequent rapid heating/cooling as shown in the schematic thermal cycle.
(phase transf. β→ α is about 995°C)





Step size = 0.15 µm , Grain colour representation

SEM micrograph and EBSD map showing α laths whose width is close to the micron.

⓫→Evidence of very fine α+β acicular or basket-wave microstructure.

Conclusions

Solidification during SLM is characterized by small melt pools (≈100 µm) and high energy input → High temperature gradient + High growth rate.

Microstructural observations reveal :

- Parts are fully dense (>99%).
- Epitaxial nucleation along several melt pools resulting in elongated grains in the direction of fabrication (anisotropy of mechanical behaviour?).
- Direction of growth of Solid/Liquid interface can vary from one melt pool to another inside a same grain (*i.e.* with the same crystallographic orientation).
- Microstructures very fine :
  - Cellular in 316L resulting from micro-segregation at the solid/liquid interface ; size of cellules ≈ 1 µm
  - α+β acicular in Ti-6Al-4V resulting from several β→ α → β→ α transformations ; width of lath ≈ few µm and less
- Good mechanical properties are expected.

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