Quality assessment of parts produced by Selective Laser Melting

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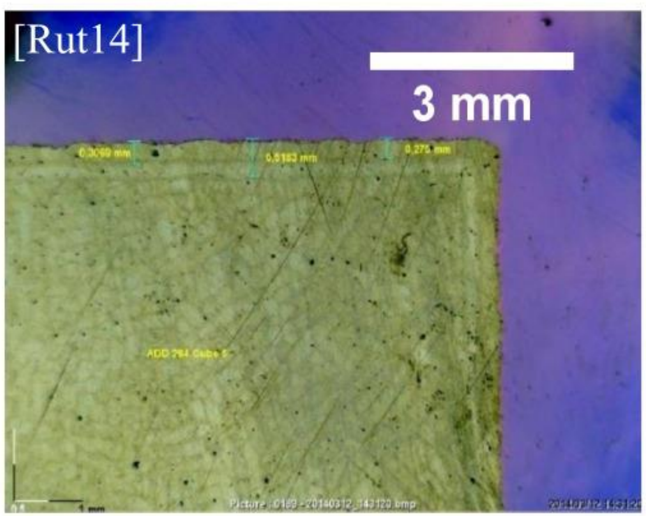
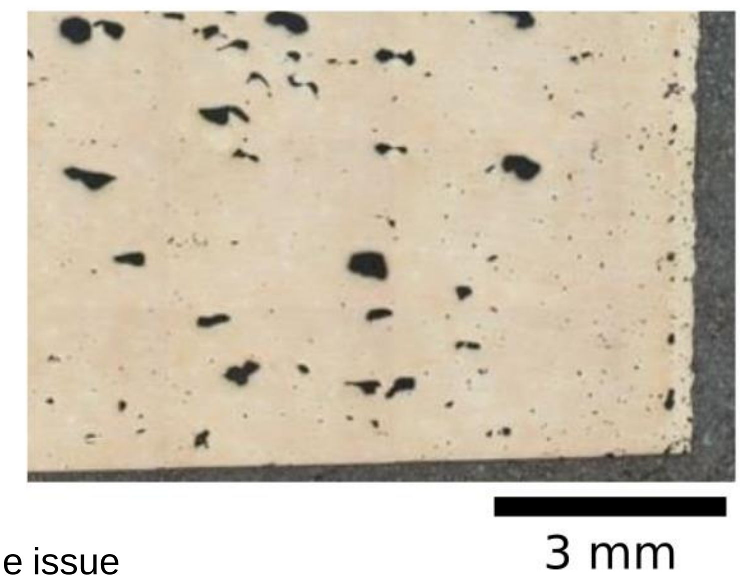
DIPARTIMENTO DI INGEGNERIA INDUSTRIALE

Motivations

Aim of the job

- Mechanical properties (static, fatigue) parts defined by its microstructure (phases, size, orientation) and defects (porosities, oxide contamination)
- Microstructure and defects related to process parameters (power, scan speed, powder …)
- **Qualified the process trough microstructural analysis guarantee good mechanical properties of parts**





Powder storage issue

[Rut14] D. Reuter, Master thesis, Université de Liège, 2014.

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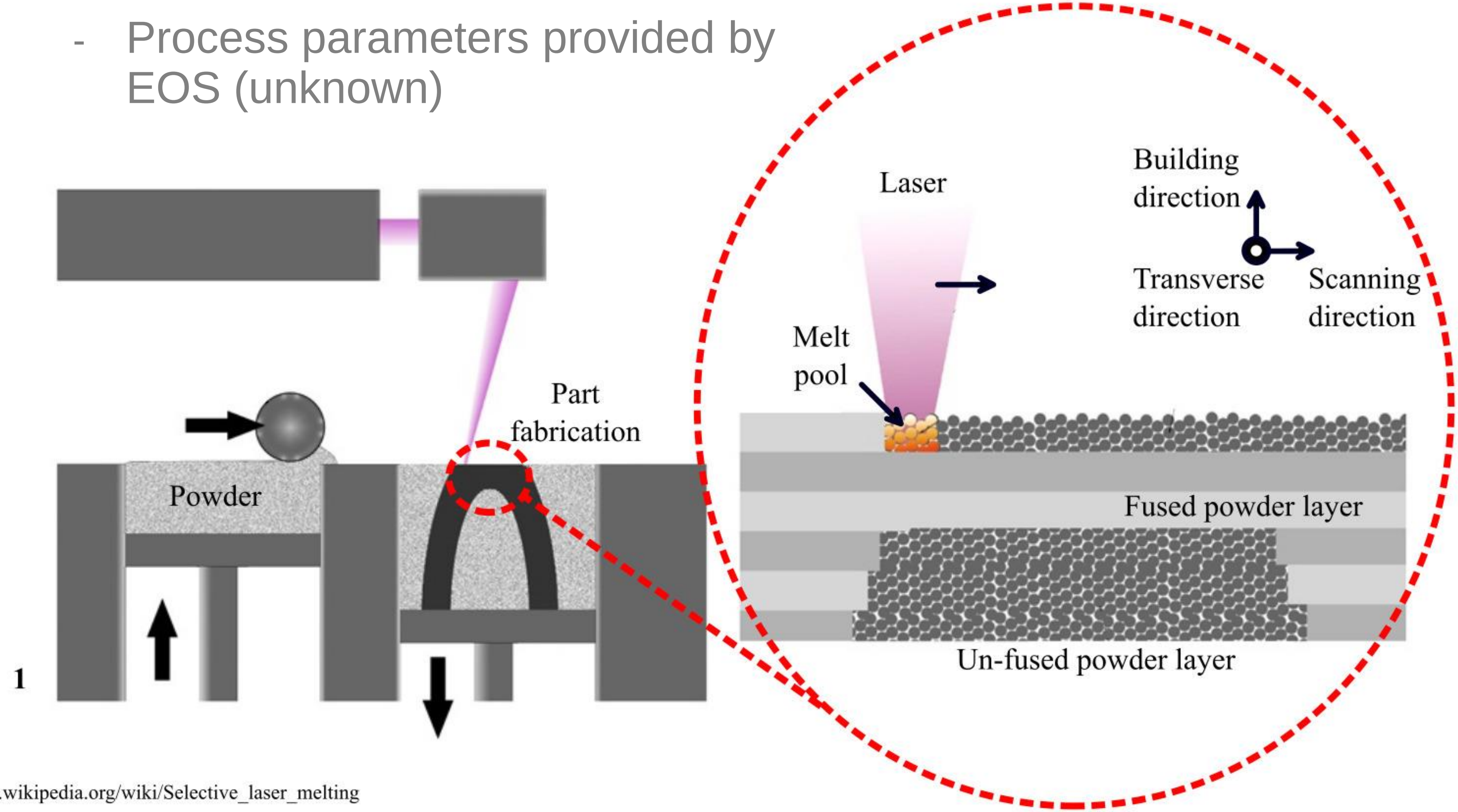
Sample fabrication

- 316L and TA6V SLM samples produce with ESO M280 machine at the university of Padova
- Process parameters provided by EOS (unknown)



[1]https://en.wikipedia.org/wiki/Selective_laser_melting

Contents

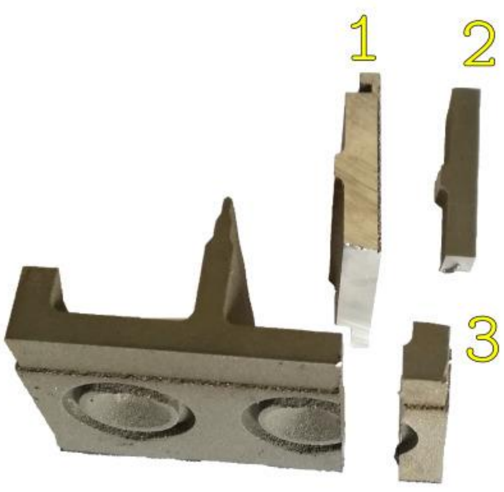
Experimental methods

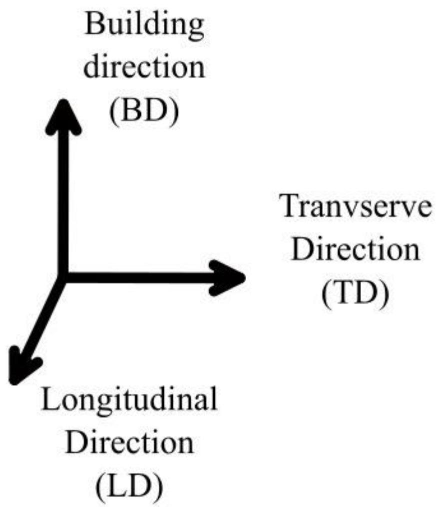
Sample preparation

- Sectioning and resin mounting
- Polishing until 0.05 alumina suspension
- Electro-etching with oxalic acid solution (10g/100 mL Water) 2 V 10-20s for microstructure analysis

Analysis

- Porosity, surface roughness, microstructure analysis with optical microscope and ImageJ software





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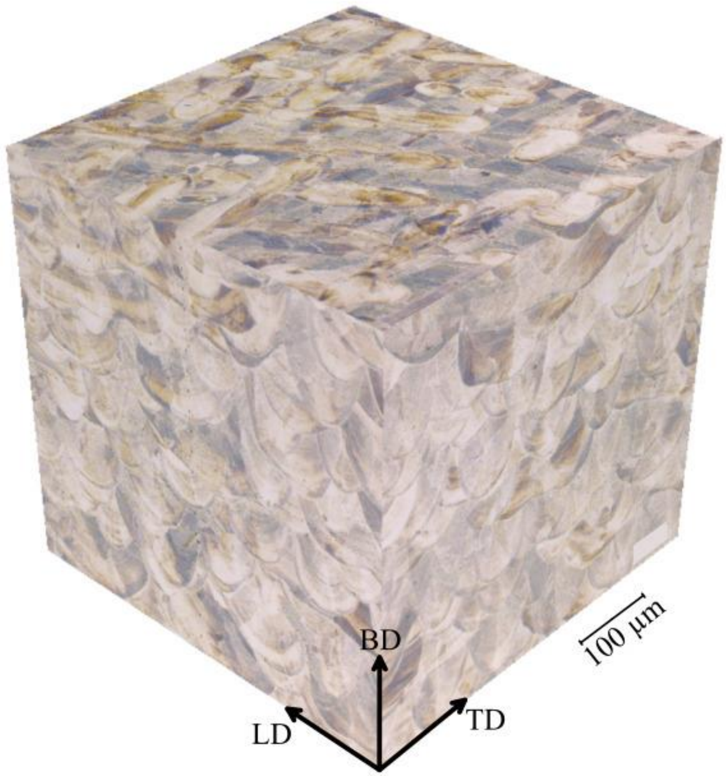
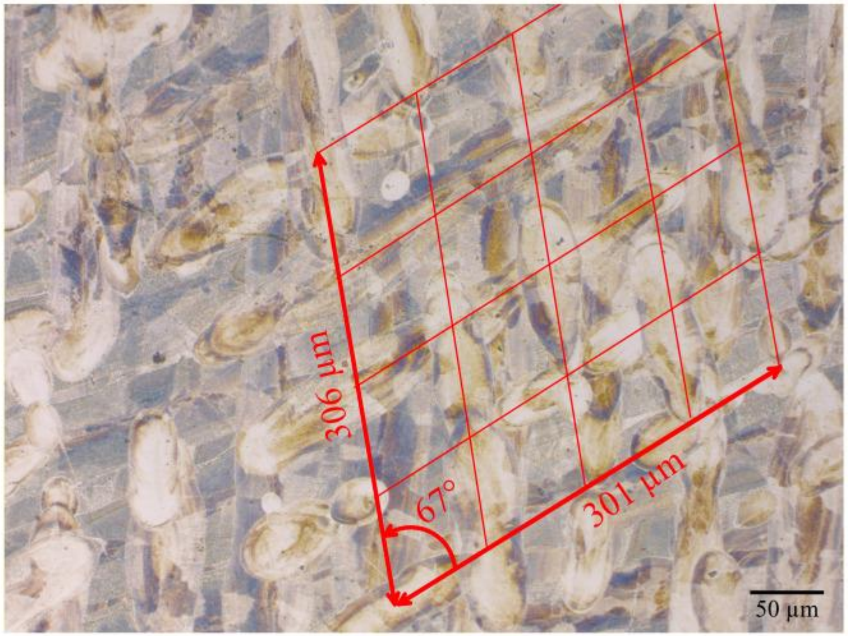
Melt pool

- Process parameters : hatching space 75 µm scan rotation 67° between layers





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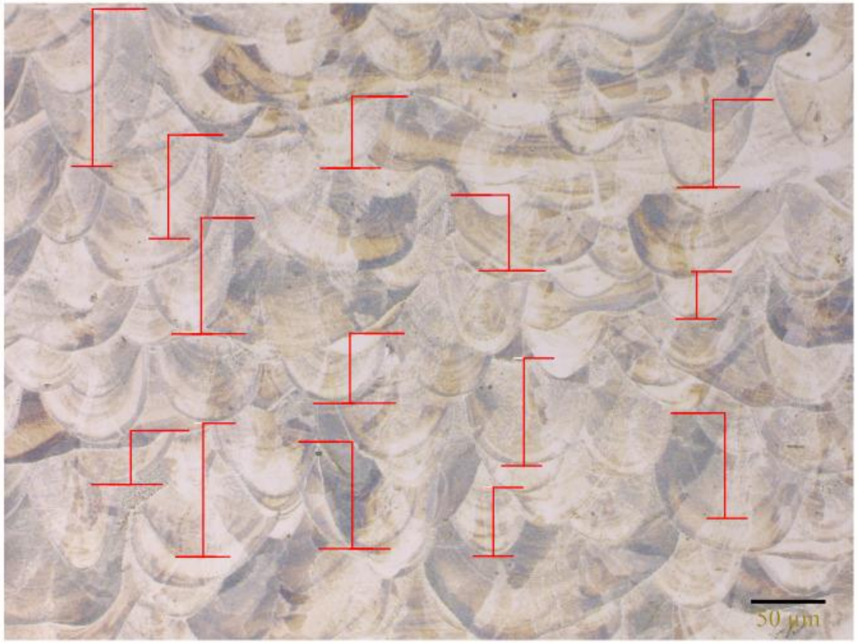
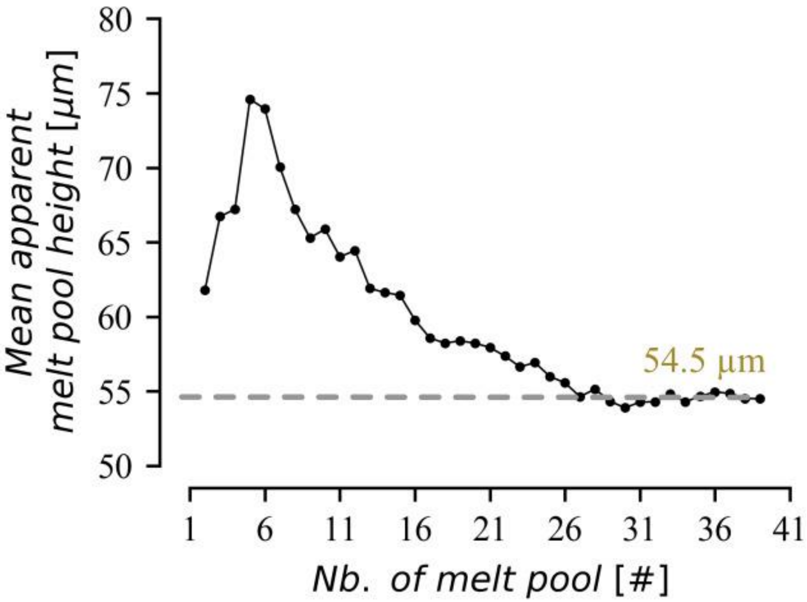
Melt pool

- Melt pool size 54.4 µm
- Melt pool size related to thermal history (super statured matrix, grain size …)





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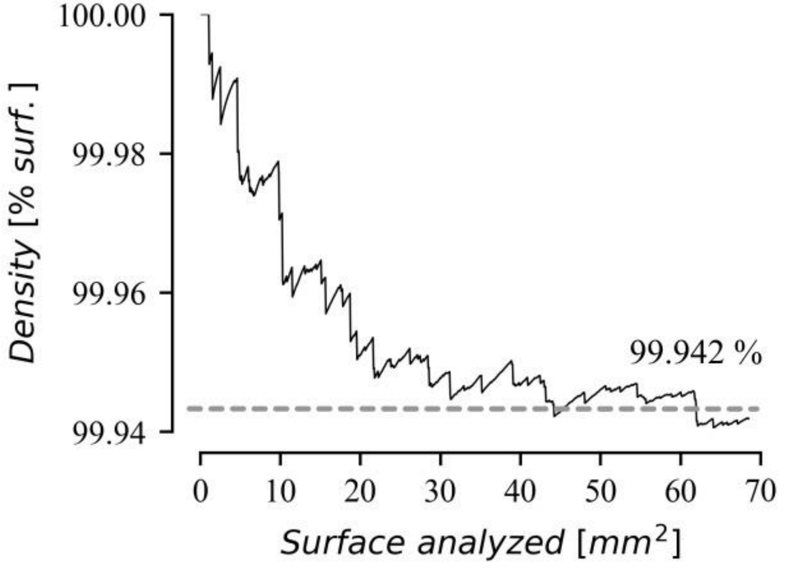
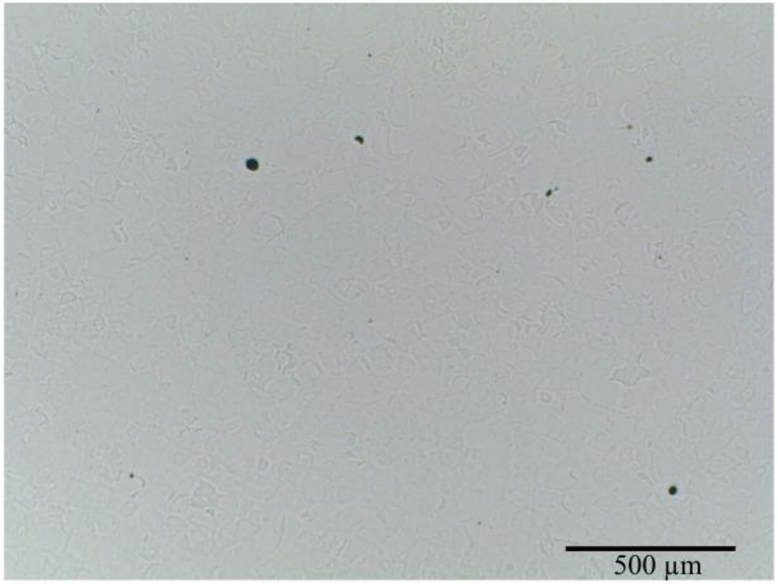
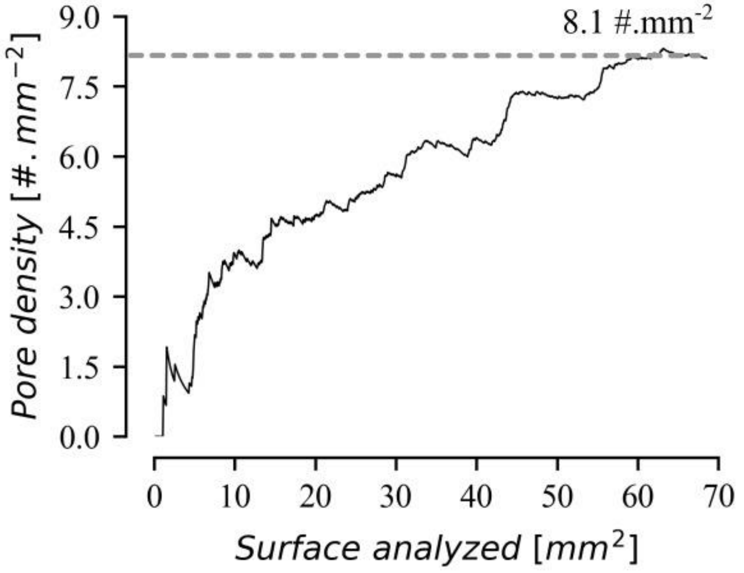
Porosity

- Full dense part
- Low pore density







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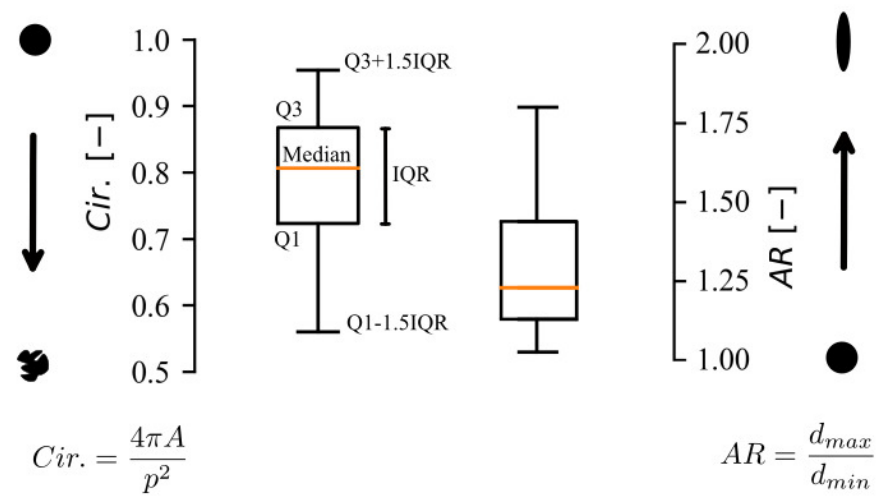
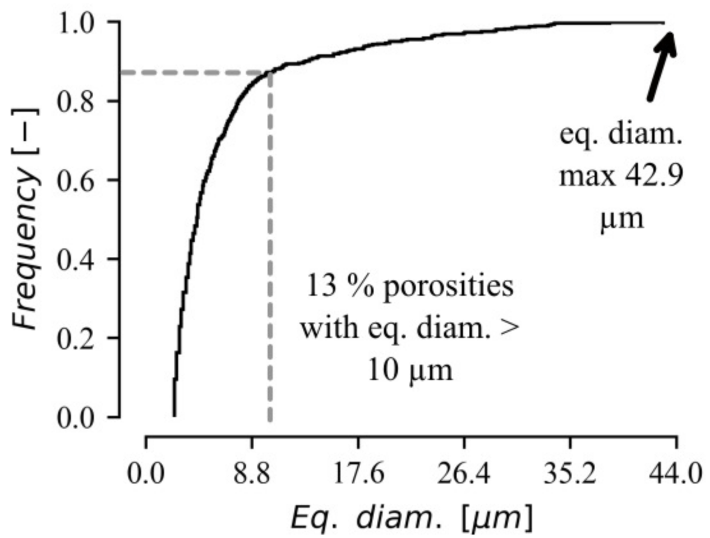
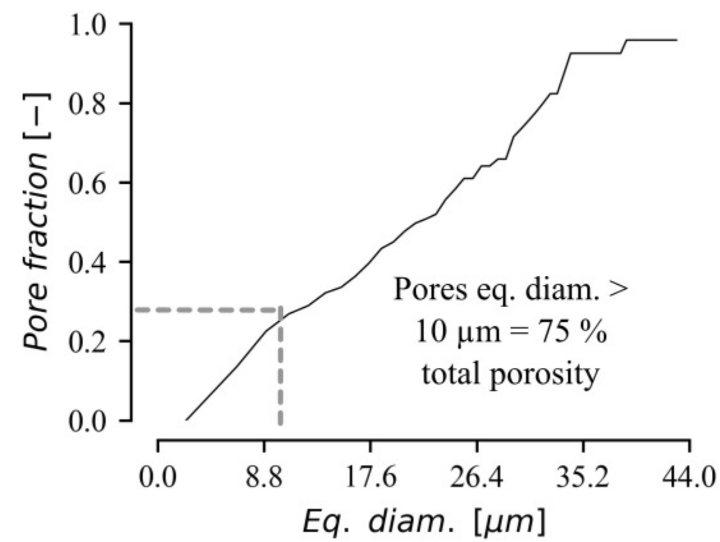
Porosity

- Mainly small pores and few big ones
- Porosity probably due to gas entrapped (Circularity and aspect ratio ~1)







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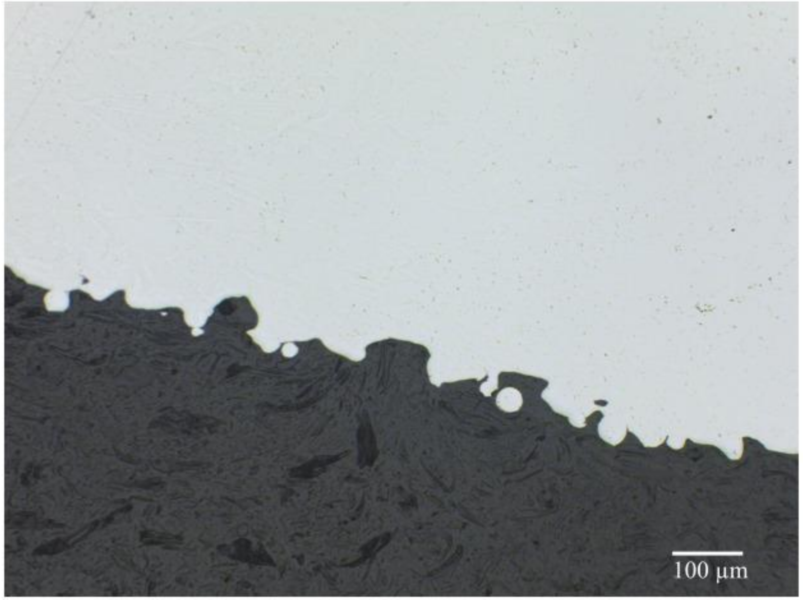
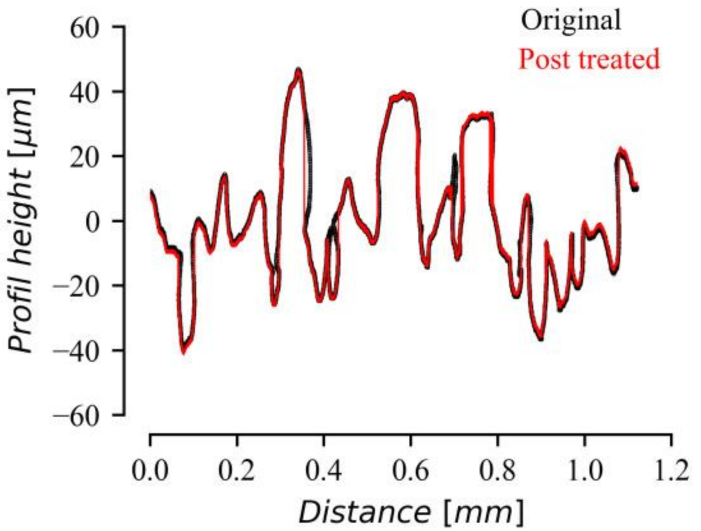
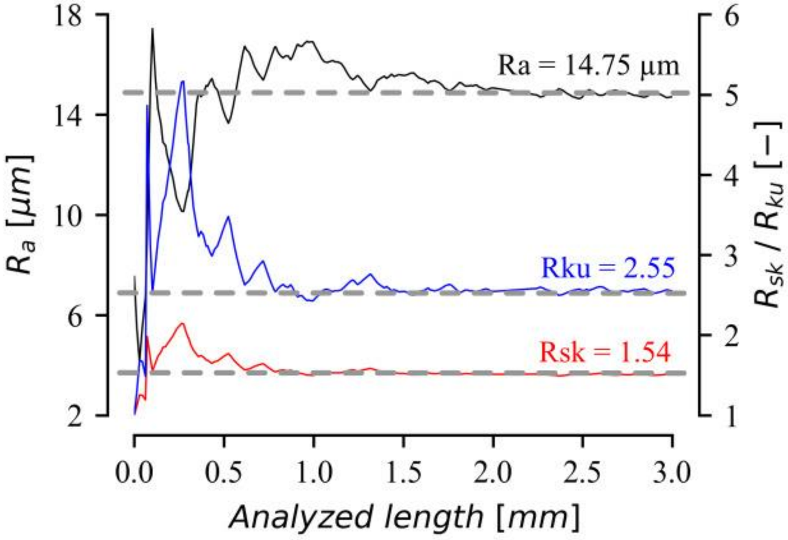
Surface roughness

- Roughness high (not good fatigue resistance)





arithmetical mean height	$R_a = \frac{1}{l}\int_0^l \lvert Z(x)\rvert dx$
Rootmean square deviation	$R_q = \sqrt{\frac{1}{l}\int_0^l Z^2(x)dx}$
Kurtosis	$R_{ku} = \frac{1}{R_q^4}\left[\frac{1}{l}\int_0^l Z^4(x)dx\right]$
Skewness	$R_{sk} = \frac{1}{R_q^3}\left[\frac{1}{l}\int_0^l Z^3(x)dx\right]$



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Summary

- Melt pool analysis gives informations about process parameters (retro-engineering) and part thermal history
- Full dense part, value in agreement with EOS's ones
- Process parameters not optimized for surface roughness

Roughness, Ra	**Density**	**Reference**
[µm]	[%]	[-]
14.75	99.94	This study
13+/-5	~100	[Eos14]

[Eos14] Material data sheet - EOS StainlessSteel 316L, (2014).

Contents

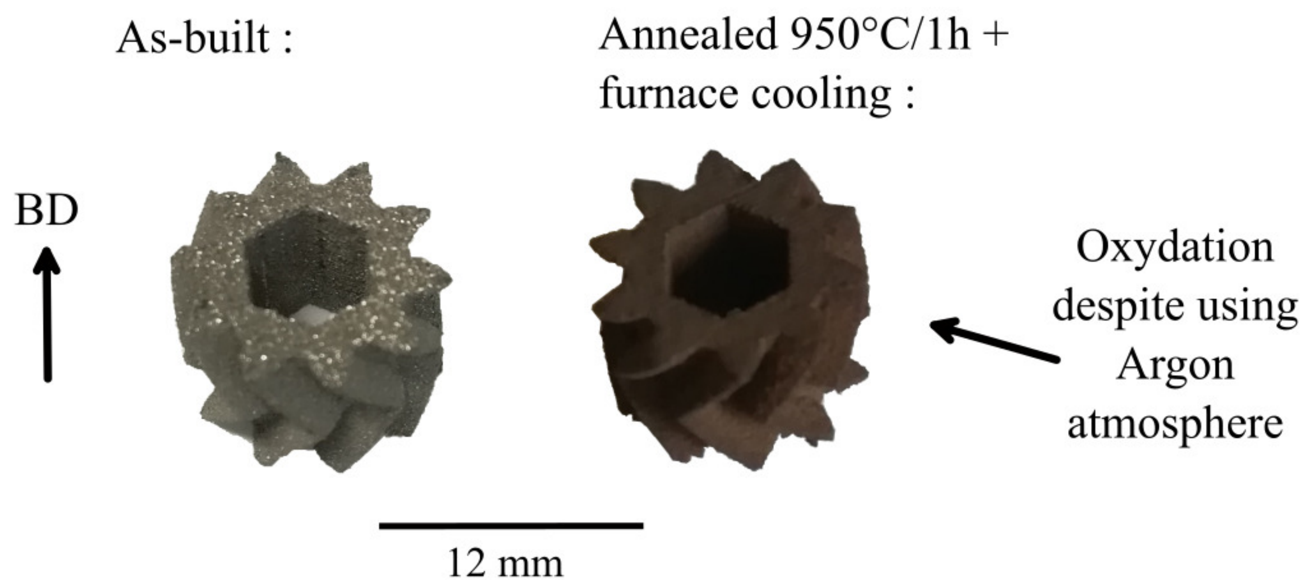
Experimental methods

Sample preparation

- Sectioning and resin mounting
- Polishing until 0.05 alumina suspension
- Etching with Kroll's Reagent
- Sample heat treated

Analysis

- Porosity, microstructure analysis with optical microscope and ImageJ software, hardness test



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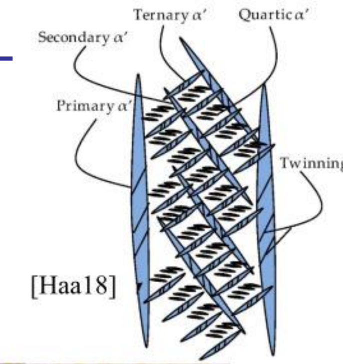
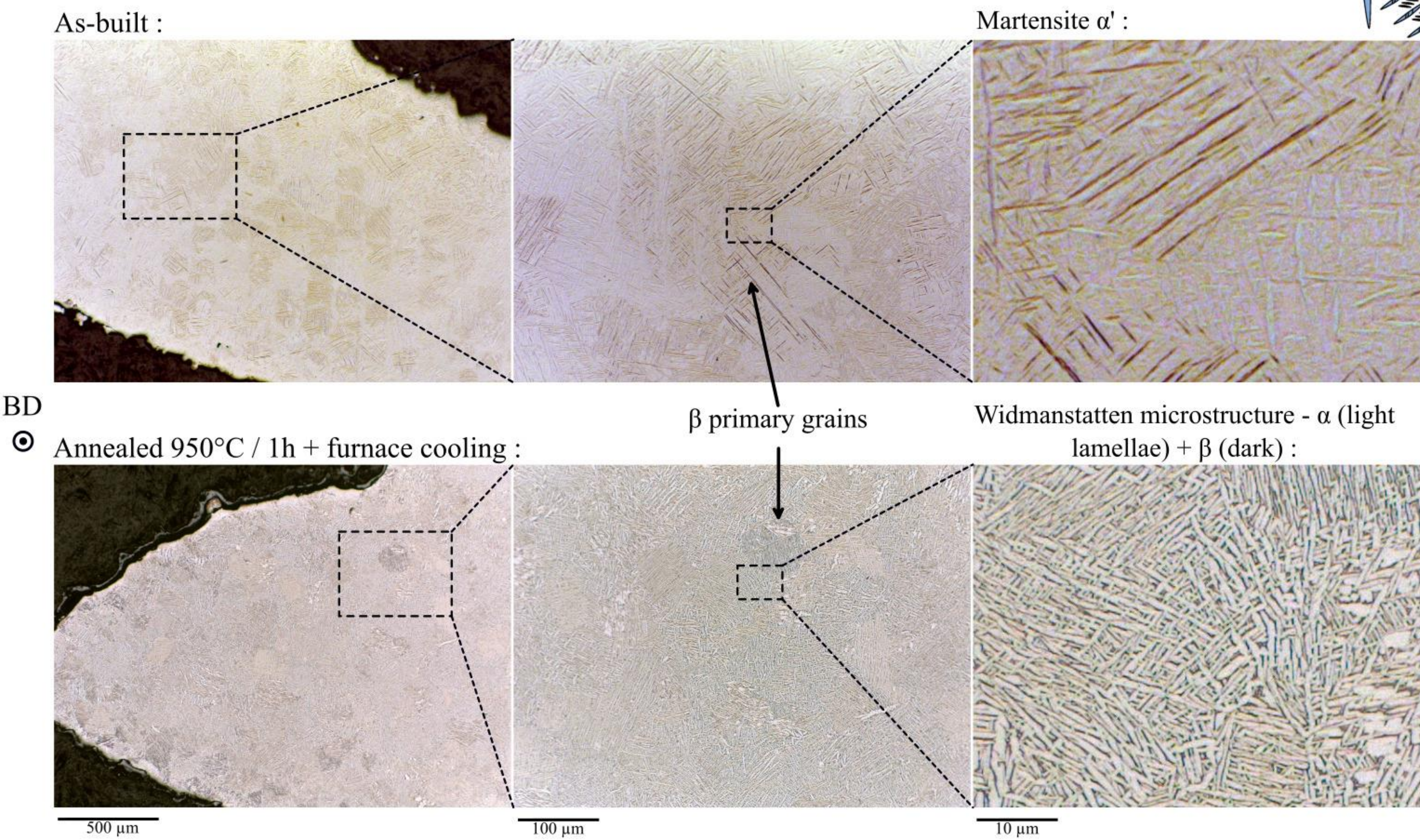
Microstructure SLM As-built vs SLM Annealed :

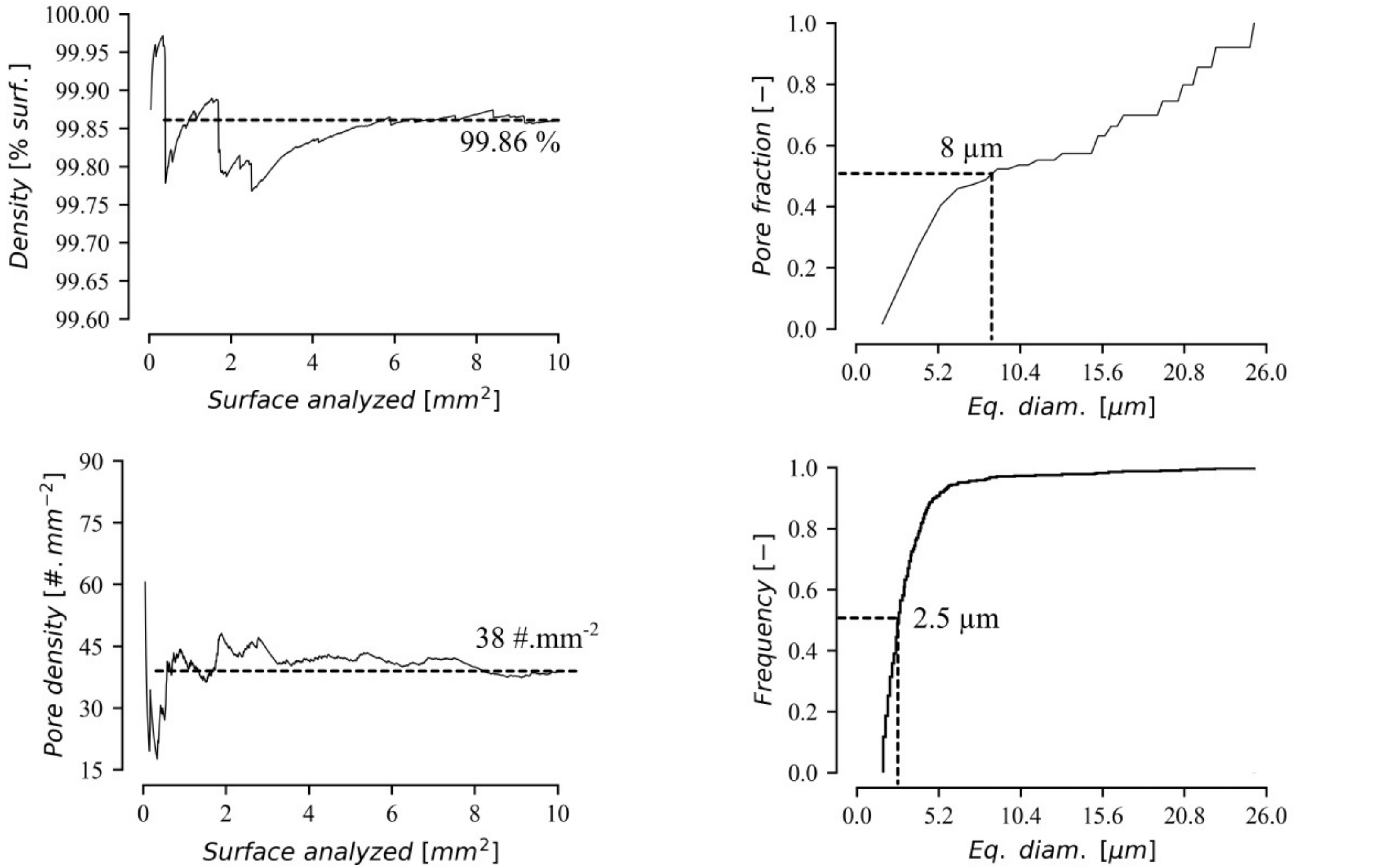




[Haa18] Gerrit Ter Haar et al., Selective Laser Melting Produced Ti-6Al-4V: Post-Process Heat Treatments to Achieve Superior Tensile Properties, Materials. 11 (2018) 146.

Results 2/4

Porosity analysis



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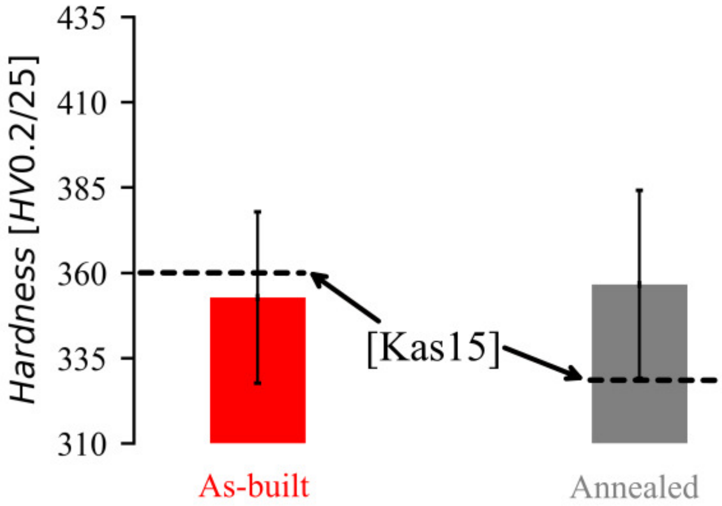
Hardness

- Same hardness value for as-built and annealed sample -> oxygen diffusion (embrittlement)



[Kas15] G. Kasperovich, J. Hausmann, Journal of Materials Processing Technology. 220 (2015) 202–214. doi:10.1016/j.jmatprotec.2015.01.025.

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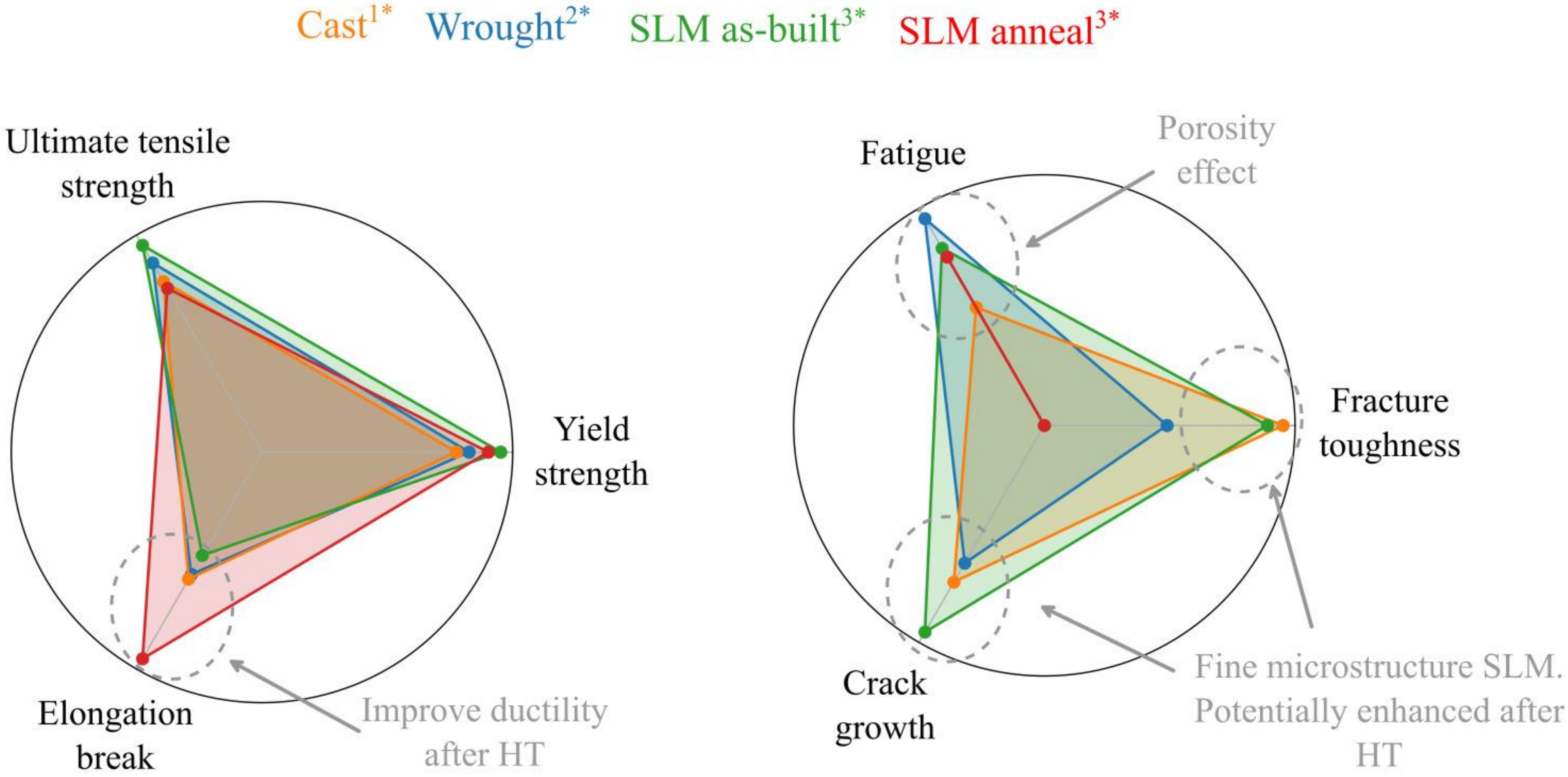
Mechanical properties - SLM vs conventional process (normalized data) from literature :



[1] data from [asm04]
[2] data from [asm04], tensile data : anneal 1065°c + WQ, fracture toughness and fatigue data : anneal
[3] data from [agi18,liu19]
[*] fatigue : number of cycle to failure for a load of 400 MPa, crack growth speed for a KIC=15 MPa.m$^{1/2}$

[Liu19] S. Liu, Y.C. Shin, Additive manufacturing of Ti6Al4V alloy: A review, Materials & Design. 164 (2019) 107552.
[Agi18] D. Agius, K. Kourousis, C. Wallbrink, A Review of the As-Built SLM Ti-6Al-4V Mechanical Properties towards Achieving Fatigue Resistant Designs, Metals. 8 (2018) 75.
[Asm04] ASM Handbook Volume 2: Properties and Selection: Nonferrous Alloys and Special-Purpose Materials - ASM International, (2004).

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Summary

- Full dense part, porosity value in agreement with EOS’s one
- Heat treated sample preferred : increase ductilty with potential better mechanical properties (fatigue, crack growth)
- Pay attention to oxygen when performed heat treatment (embrittlement)

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Conclusions

- SLM parts exhibit fine microstructure with enhanced mechanical properties compared to traditional routes
- Full dense 316L SLM and TA6V SLM parts produced by university of Padova
- Optimization of process parameters needed for special purpose (e.g. surface roughness)
- Heat treatments (HT) further increase mechanical properties of SLM parts
- Special attention has to be given when performed HT (oxygen contamination of TA6V parts)