Effect of SiC addition on processability of AISI S2 tool steel for laser powder bed fusion

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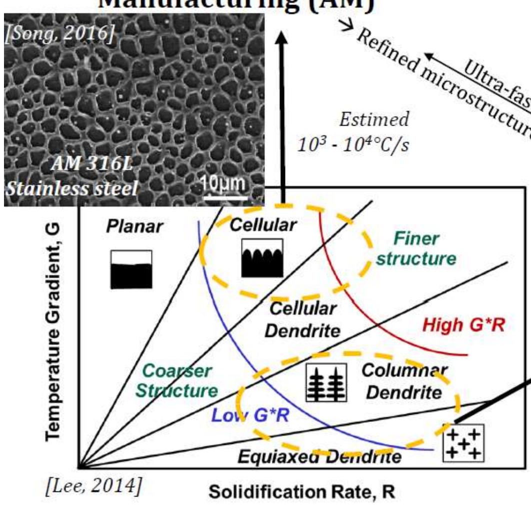
Background

Ultra-fast heating and cooling rates in Laser Powder Bed Fusion lead to out-of-equilibrium microstructures

Refined microstructure

Metals in Additive Manufacturing (AM)



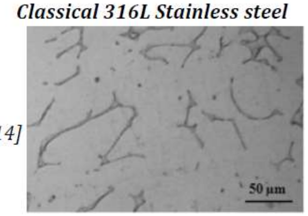
Refined microstructures and improved properties

Ultra-fast cooling rates

Estimed
10 to 300°C/s

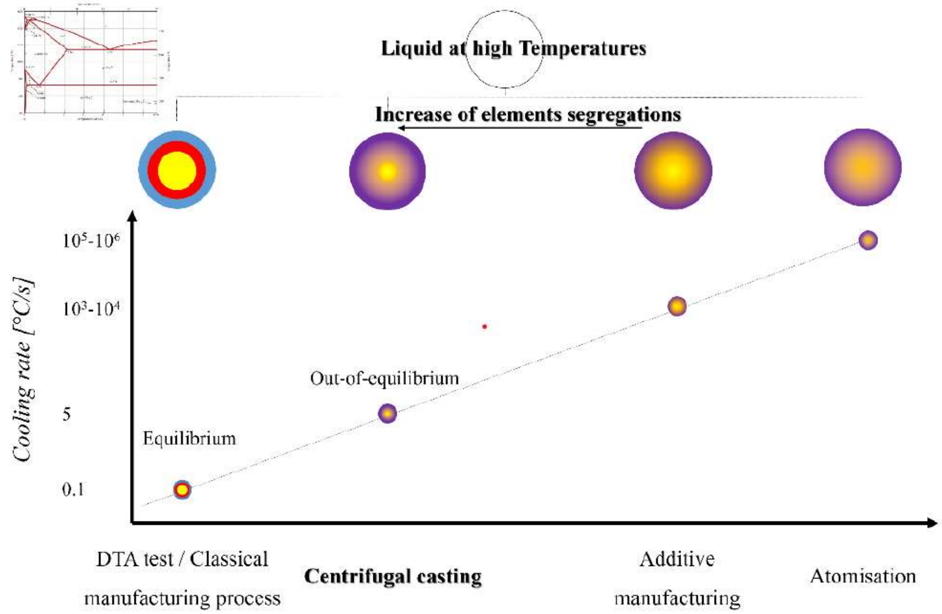
Classical 316L Stainless steel

[El-Hadad, 2014]



Classical manufacturing process

Powder Metallurgy
Metal Injection Molding
Sintering



Supersaturated solid solution and other metastable phases

Background

Opportunity to create new alloys tailored for AM, i.e. taking advantages of the ultra-fast thermal cycles

Metals in Additive Manufacturing (AM)

→ Conventional Alloys BY AM →

Process	Commercial materials	Researched materials
DED	Stainless steel, Ni-based alloys, tool steel, Ti alloys	FeTiNi,[161] TiZrNbMoV,[160] ceramics,[162] CoCrMo,[262] WC-Co[163]
EBM	Ti–6Al–4V, Ti, CoCr[263]	Inconel 718, Inconel 625, Al 2024,[73] high purity copper,[183] GRCop-84,[164] Niobium,[264] bulk metallic glass,[158] stainless steel 316L,[87] TiAl,[265] CMSX-4[266]
LM	Ti–6Al–4V, stainless steel, various steels, Ti, CoCr, Al–Si–10Mg, bronze, precious metals, Inconel 718, Inconel 625, Hastelloy X	Tantalum,[177] W-Ni,[267] AlSi10Mg[175]
Sheet lamination[257]	Al/Cu, Al/Fe, Al/Ti	Ta/Fe, Ag/Au, Ni/stainless
Binder deposition	316 Stainless steel infiltrated with bronze, 420 stainless steel infiltrated with bronze (annealed & non-annealed), bronze, iron infiltrated with bronze, bonded tungsten,[26] Inconel 625[268]	FeMn,[269] pure alloys (no infiltration), ceramics[270]

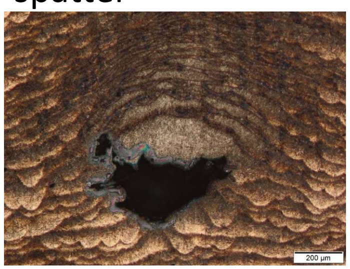
[Sames, 2016]

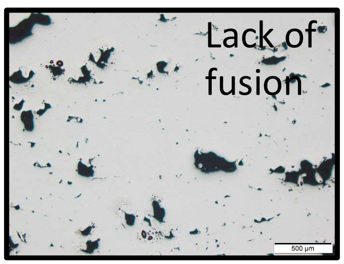
→ "New" Alloys FOR AM

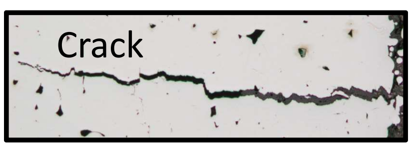
- **Processability ?**
- In-situ microstructures with innovative / improved properties

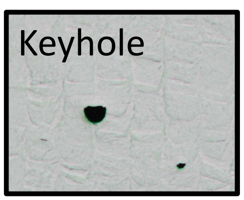
Here, goal is to enhance tribological properties by modifying tool steel

Porosity within spatter





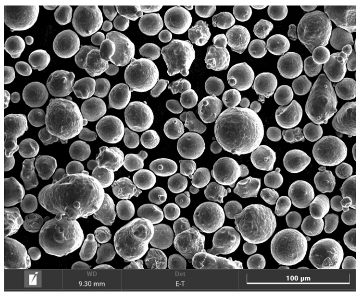




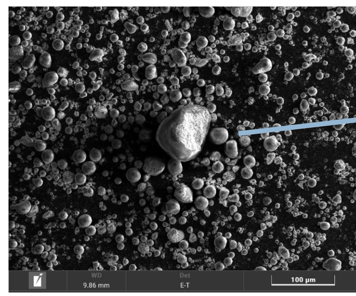
Materials

Mixture of powders

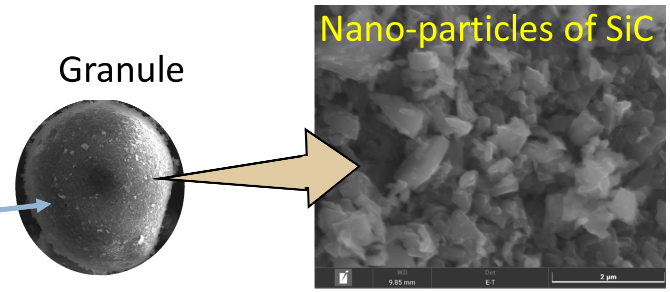
AISI S2 Steel



Silicon Carbide α-SiC
5 or 10 % (in vol)



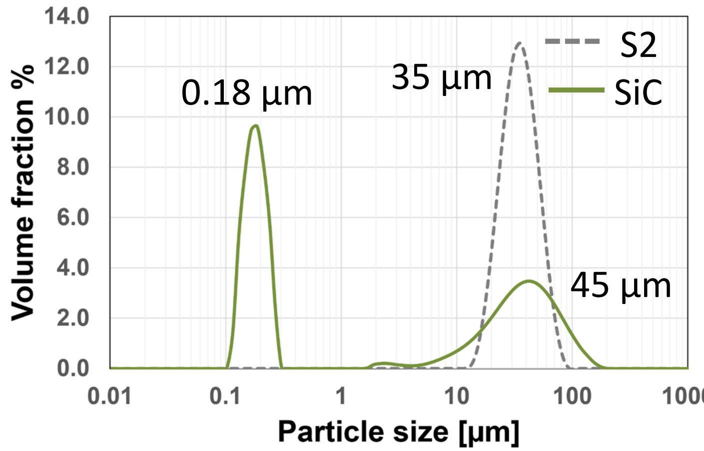
Granule



wt%

Fe	C	Si	Mo	Mn
Bal.	0.49	1.2	0.6	0.6

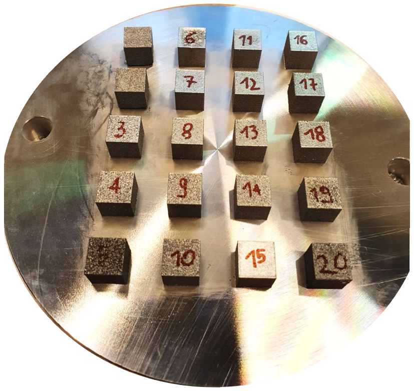
Particle size distribution



Experimental methods - LPBF

Aconity Mini LPBF Printer

Optimization of printing parameters, on 1 x 1 x 1 cm^3 cubic samples → **Processing map**



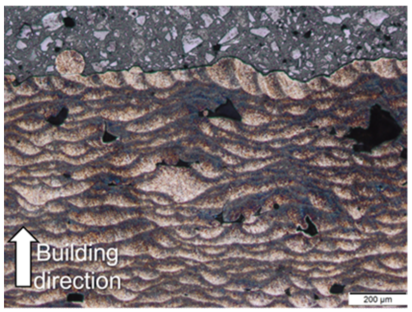
- **Power** (P, up to 200W)
- **Scan speed** (v_s, up to 2000 mm/s)
- Layer Thickness (t, 30 µm)
- Hatch Spacing (h, 80 µm)
- Laser beam size (80 µm)
- Scan Strategy (Bidirectional 90°)

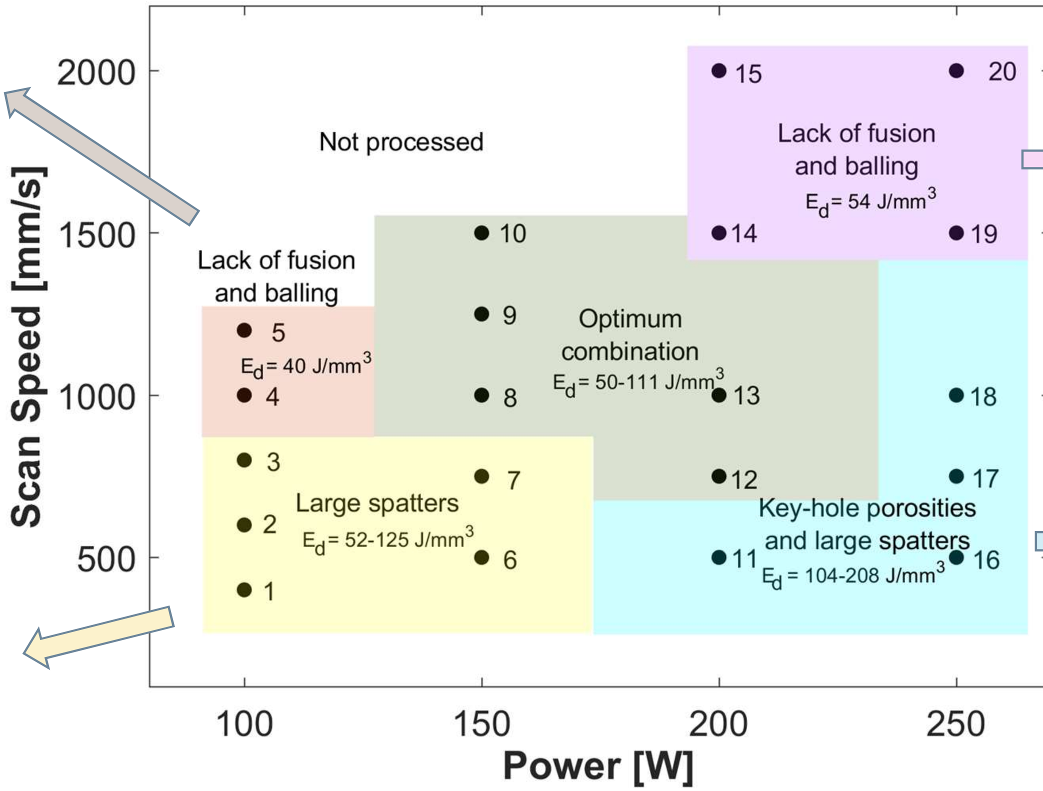
Volumetric Energy Density

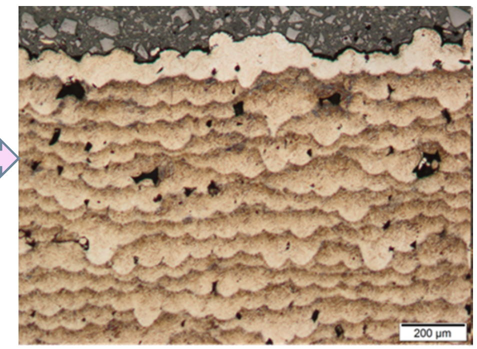
$$E_d = \frac{P}{t \times h \times v_s} \quad [J/mm^3]$$

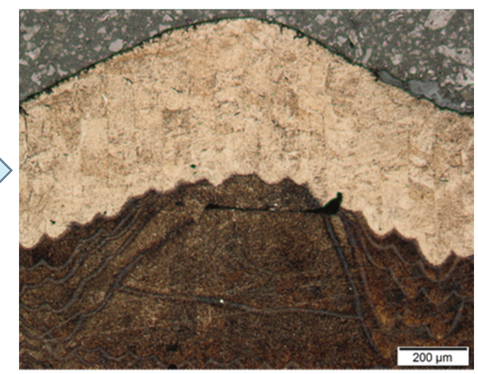
LPBF – S2 powder

Process map was established for S2 alone : Medium VED should be preferred





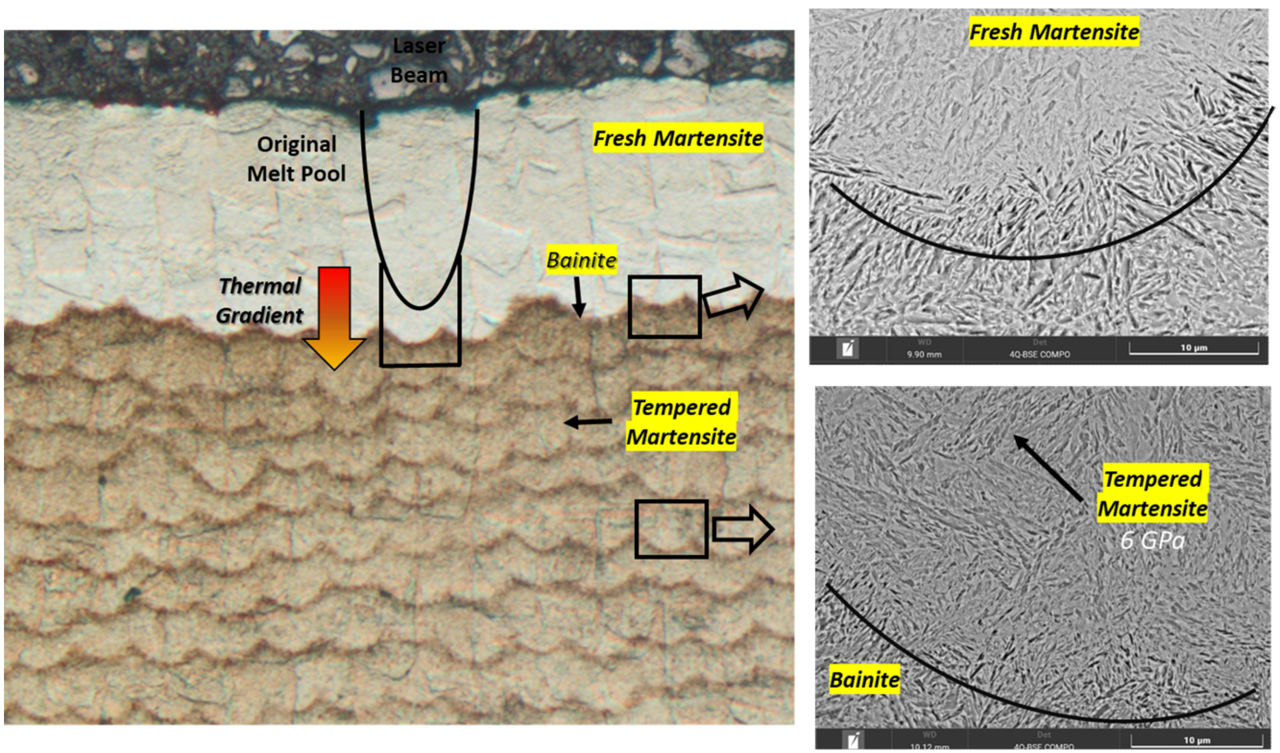




[Saggionetto et al., Esaform 2023]

LPBF – S2 powder

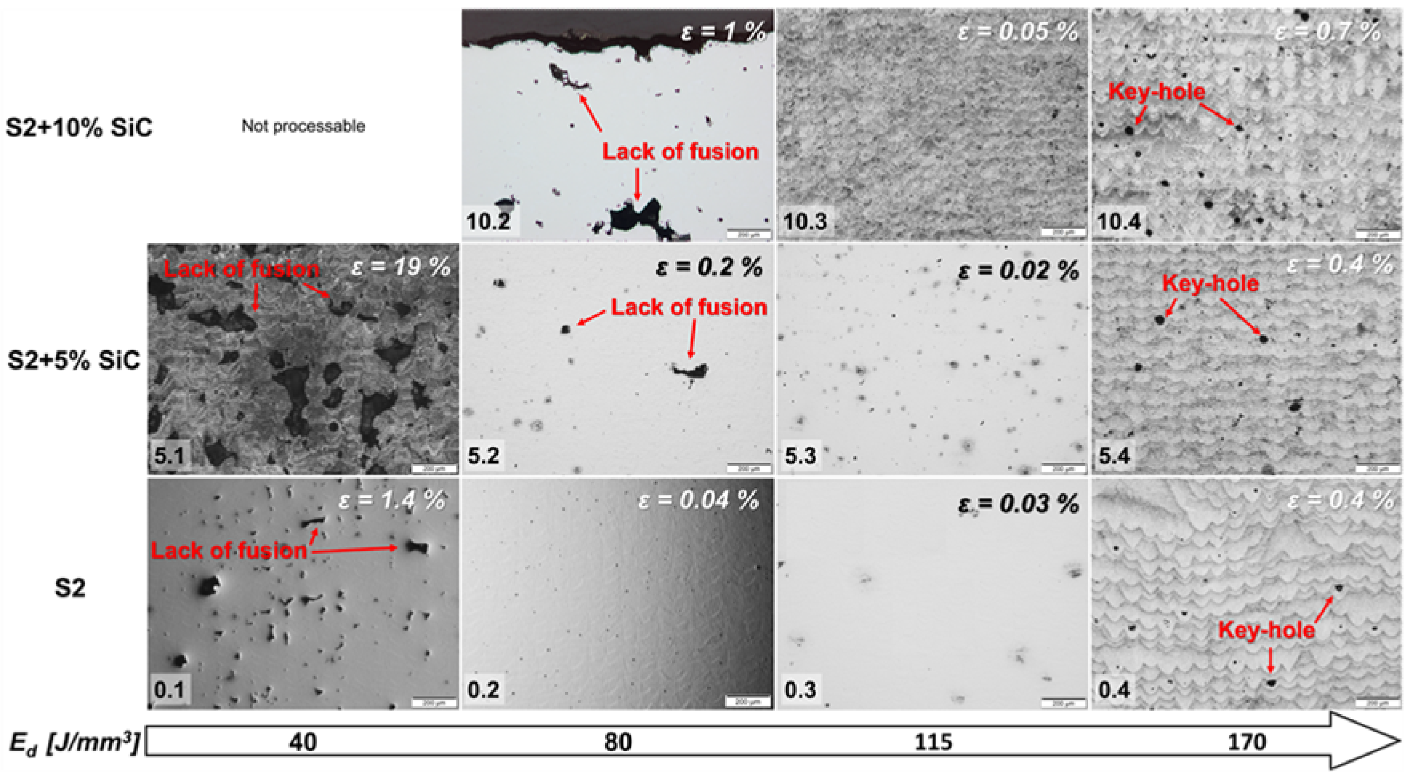
For S2 alone :
Microstructure associates martensite (fresh or tempered) and bainite



LPBF – S2 + SiC

Processing window becomes narrower with SiC addition

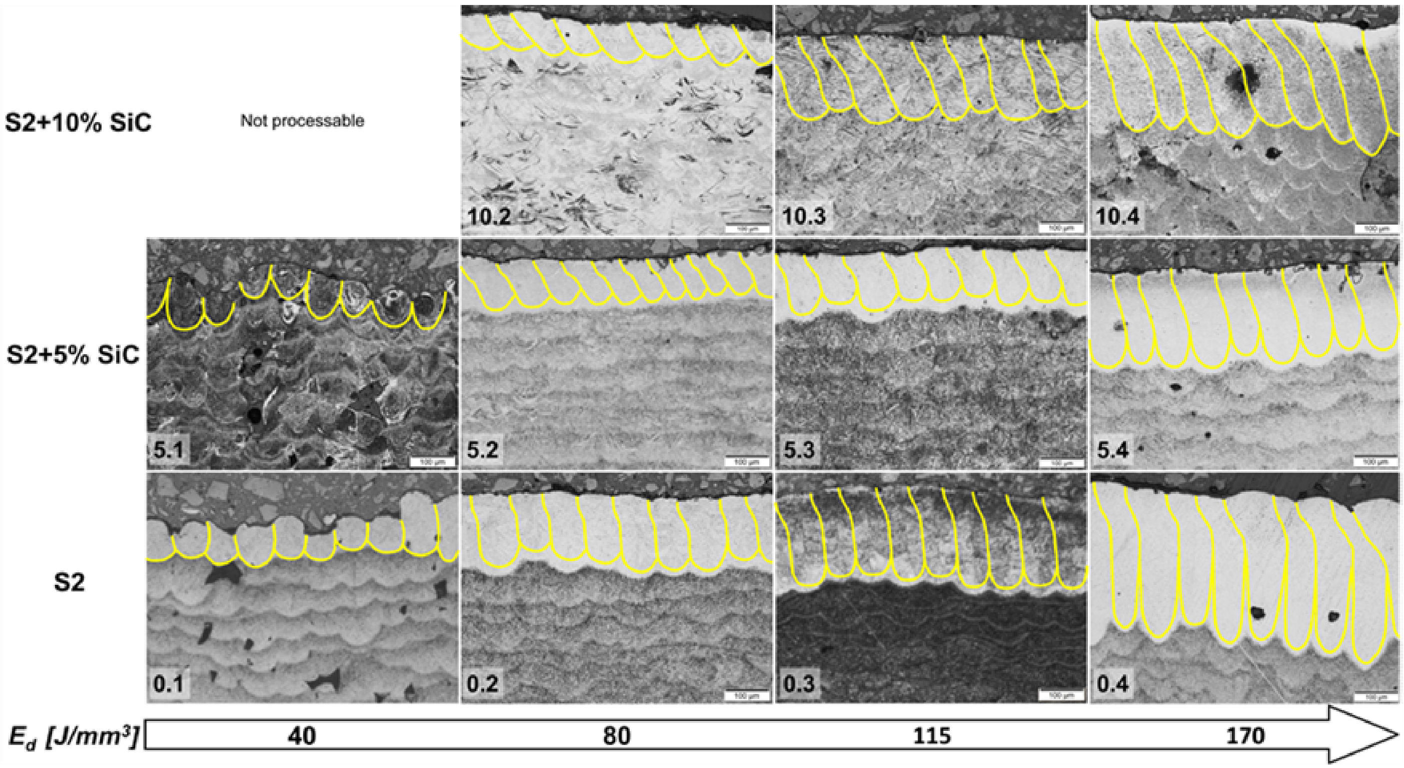
Higher E_d is needed in order to avoid lack of fusion defects



LPBF – S2 + SiC

Processing window becomes narrower with SiC addition

This change can be correlated with changes in melt pool depth and morphology



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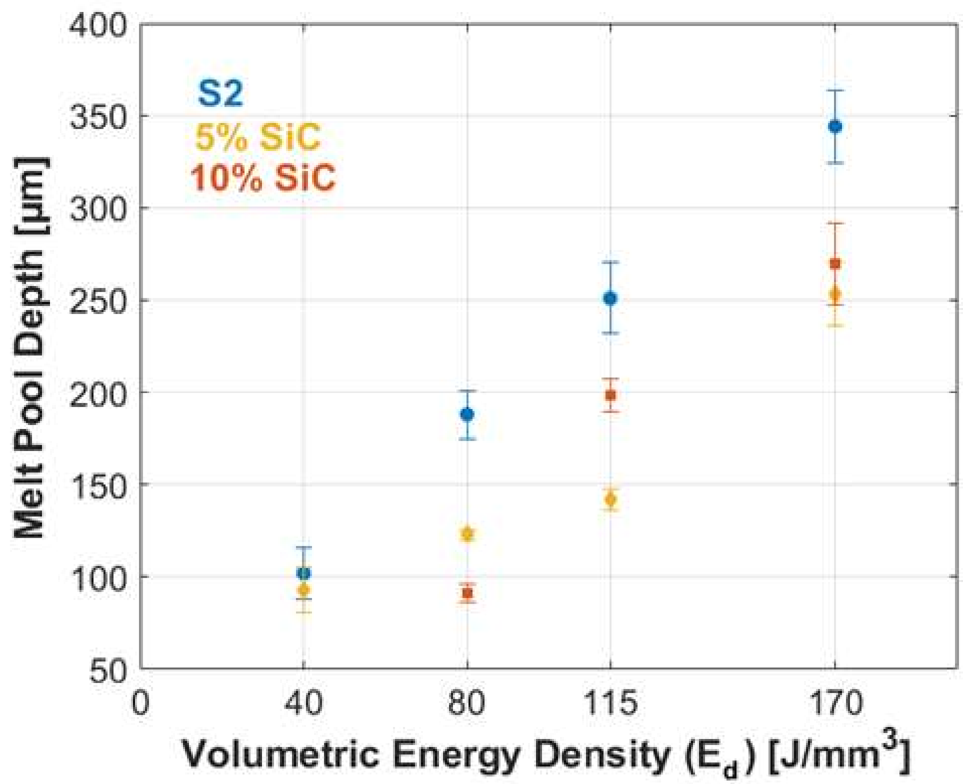

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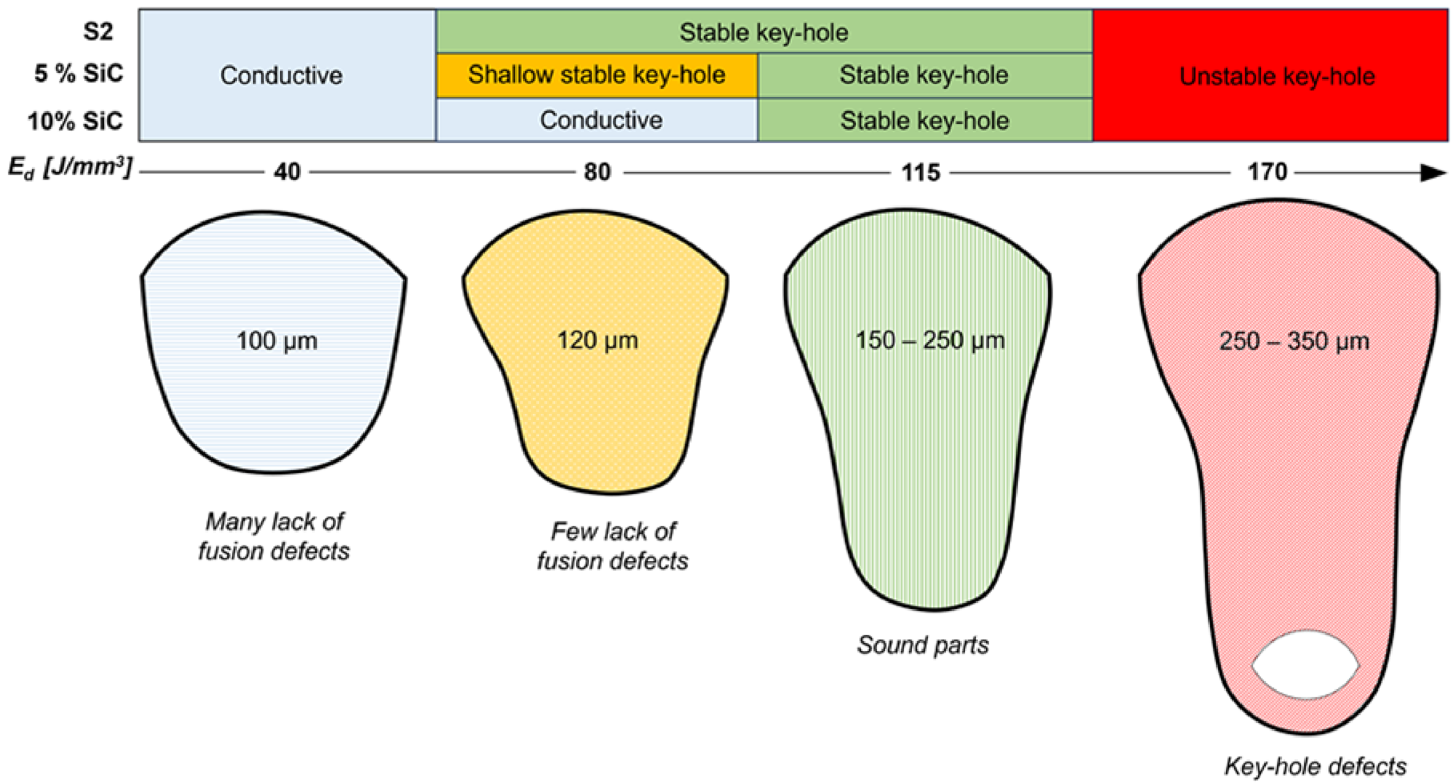
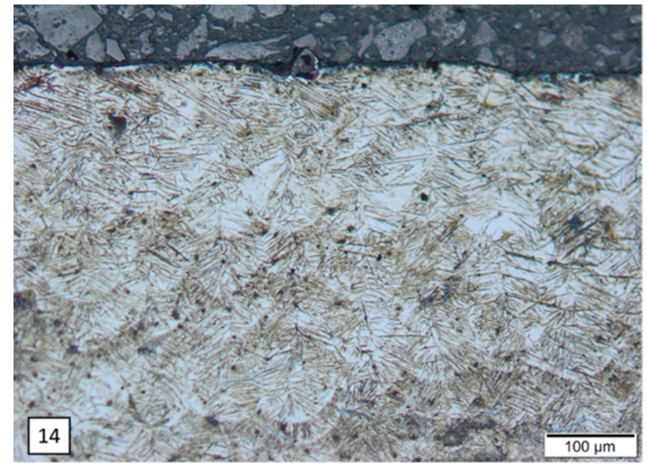
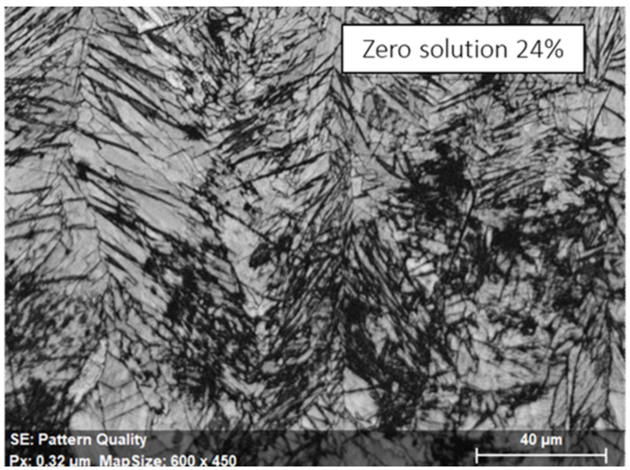
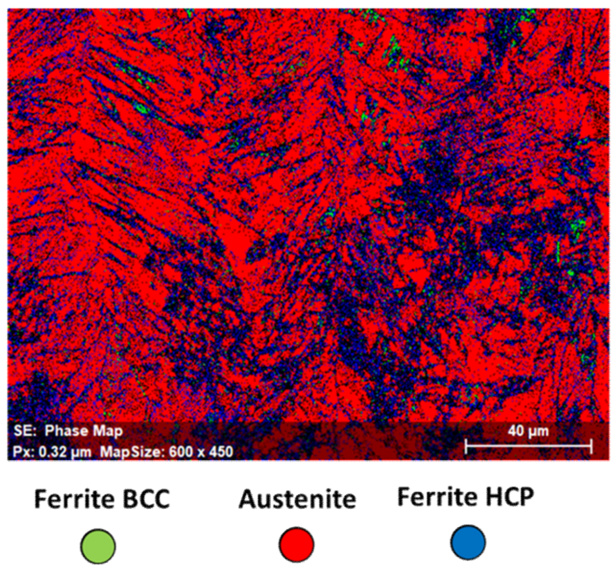


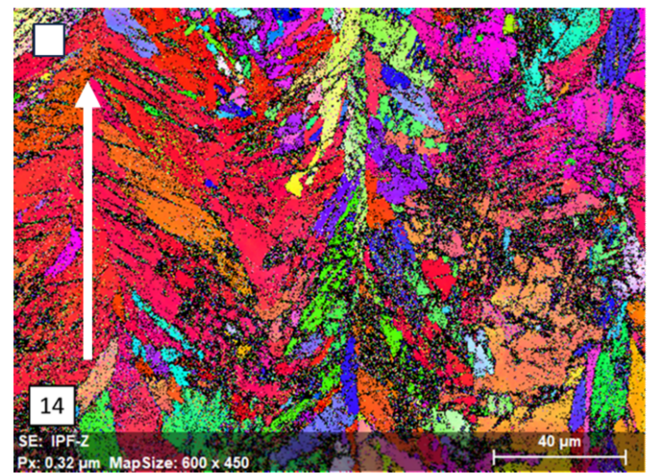
LPBF – S2 + SiC

- Microstructure: martensite + **retained austenite**, little bainite
- Epitaxial growth of columnar grains









[Roger Vila 2023]

Conclusions and prospects

- Processing maps for S2 and S2 + SiC in LPBF have been established
- Additions of SiC $\Rightarrow$ need to increase VED to produce dense samples, in correlation with changes in melt pool depth and morphology
- Microstructure changes
    - from martensite and bainite in S2...
    - ... retained austenite, martensite (with little bainite) in S2+SiC...

- Further investigation of the solidification and transformation sequence in S2+SiC
- Investigation of laser absorptivity and thermal conductivity changes with SiC addition
- Investigation of mechanical properties (macro- and micro-hardness, nano-indentation)
- Investigation of tribological properties, cfr Sagionetto et al., EMMC19 (Madrid, May 2024)

References

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- E. Saggionetto et al., Materials Research Proc. (Esaform 2023), **28**, 41
- W.J. Sames et al., Int. Mater. Rev. (2016) **61**, 315

All references from ULiège can be obtained from the institutional repository at: https://orbi.uliege.be/

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- **Thank you for your attention!**