3D printed aluminium: corrosion mechanism and anodising behaviour

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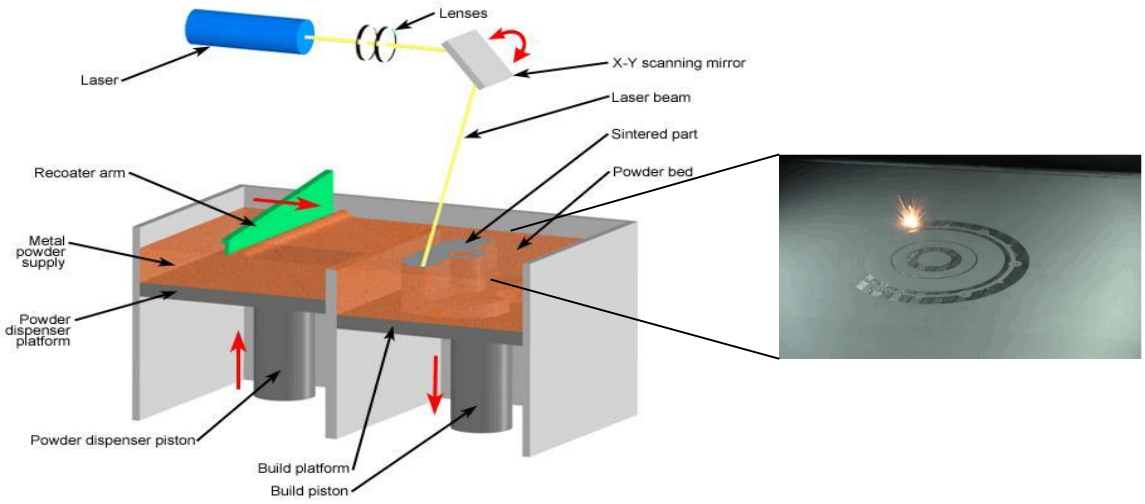
Why 3D printing ?

- Avoid assembly of complex parts
- Optimize design → weight saving
- Rapid in-house production
- Custom fit

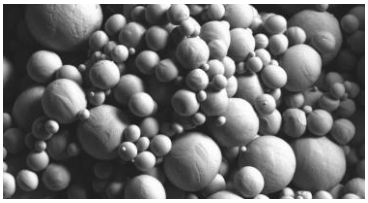
Research questions

- Corrosion mechanism of 3D printed aluminium ?
- Anodizing mechanism of 3D printed aluminium ?
  > Oxide film characteristics, anodizing efficiency?
- Influence of material post heat treatments on the corrosion and anodizing ?

Metal Additive Manufacturing
using Selective Laser Melting (SLM)



Selective Laser Melting > formation of fine microstructures



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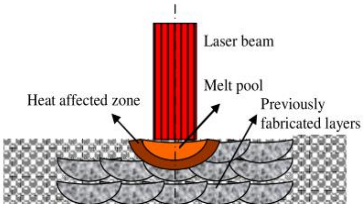

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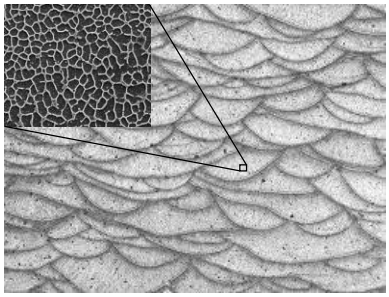
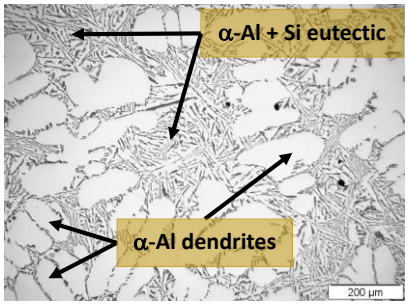


Alloy powder

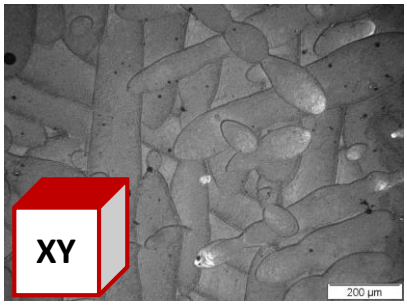
Small melt pools that rapidly solidify

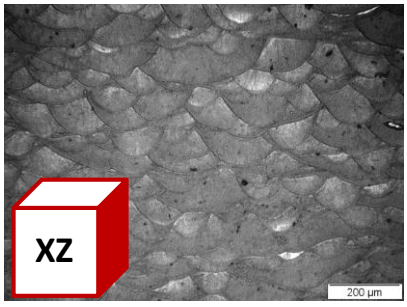
Optical images of the specimens' surface

Reference
Cast alloy (AA4420)



AM AlSi10Mg

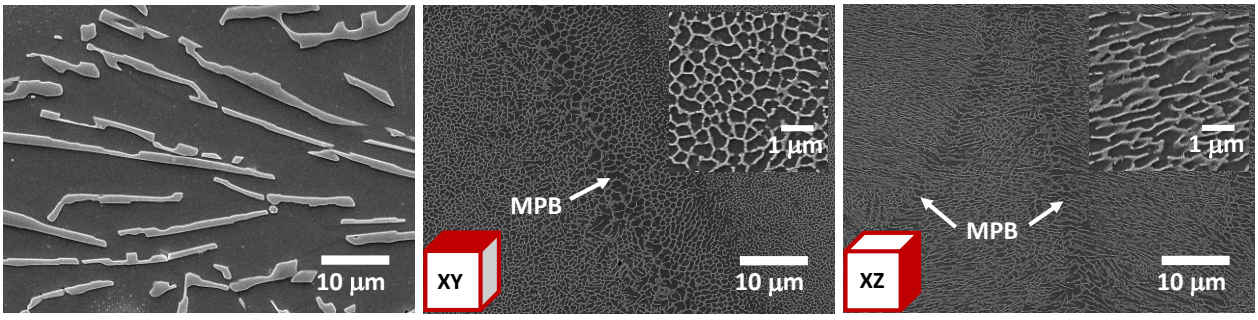




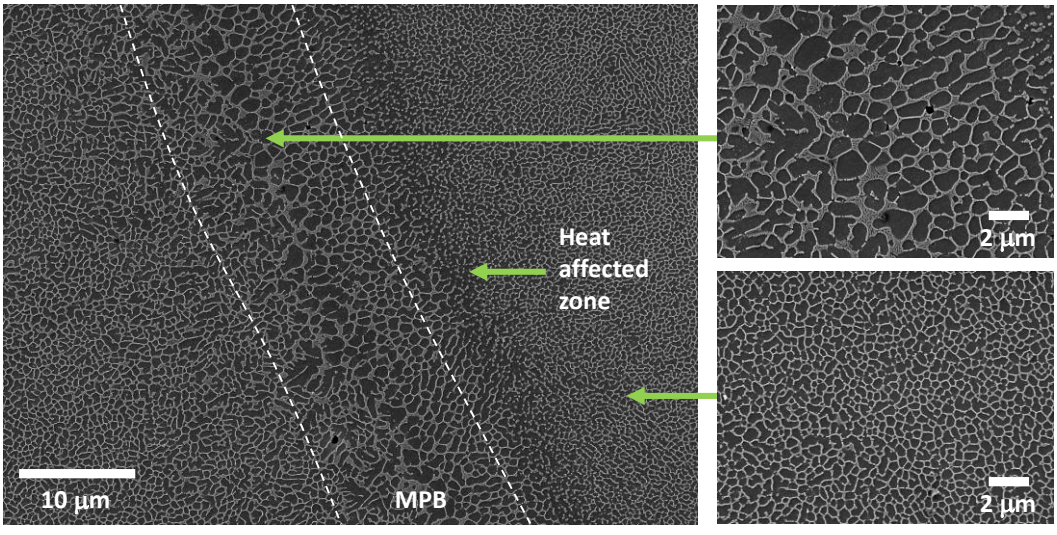
	Chemical composition (wt%)						
	Cu	Fe	Mg	Mn	Si	Zn	Al
AM AlSi10Mg	–	0.11	0.34	0.01	9.55	–	Remainder
AA4420	< 0.07	< 0.38	0.5 – 0.7	< 0.09	9.48 – 9.89	< 0.18	Remainder

SEM images of the specimens' microstructure

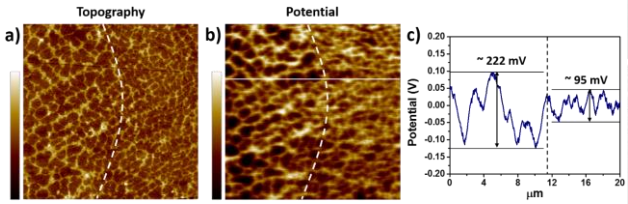
Cast alloy | **Additive manufactured specimen (as-built)**

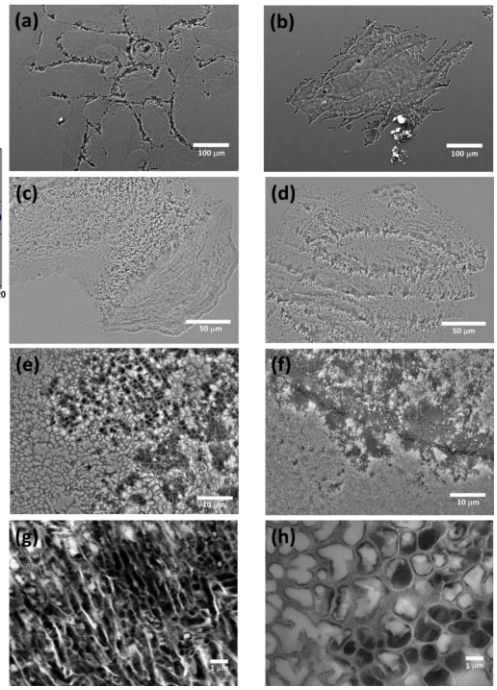


SEM image of the additive manufactured specimen's microstructure



Corrosion morphology of AM samples

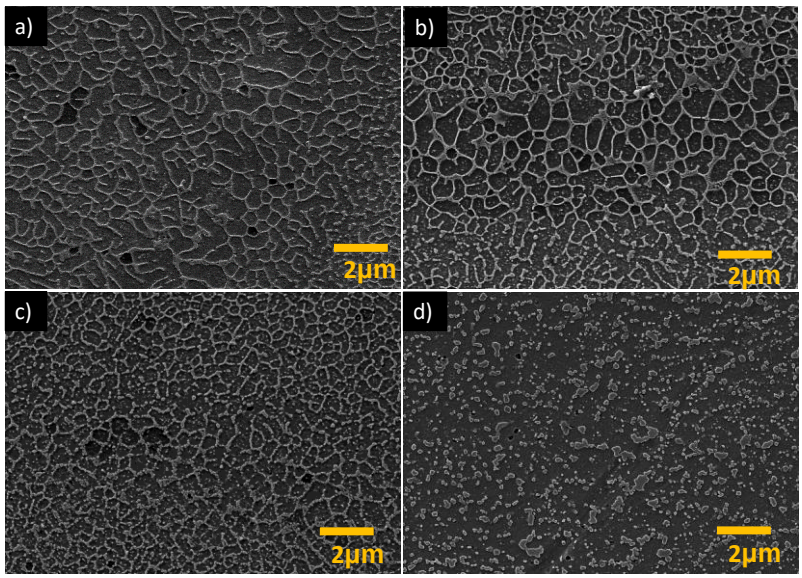




- SKPFM: higher potential difference between Al and Si in melt pool border compared to melt pool bulk
- Corrosion initiation at melt pool borders

For more details see:
REYNIER I. REVILLA CASTILLO, J. LIANG, S. GODET, I. DE GRAEVE,
Local corrosion behavior of additive manufactured AlSi10Mg alloy assessed by SEM and SKPFM technique,
JOURNAL OF THE ELECTROCHEMICAL SOCIETY, 164 (2) (2017) C27-C35.
DOI: 10.1149/2.0461702

Influence of heat treatments on the microstructure



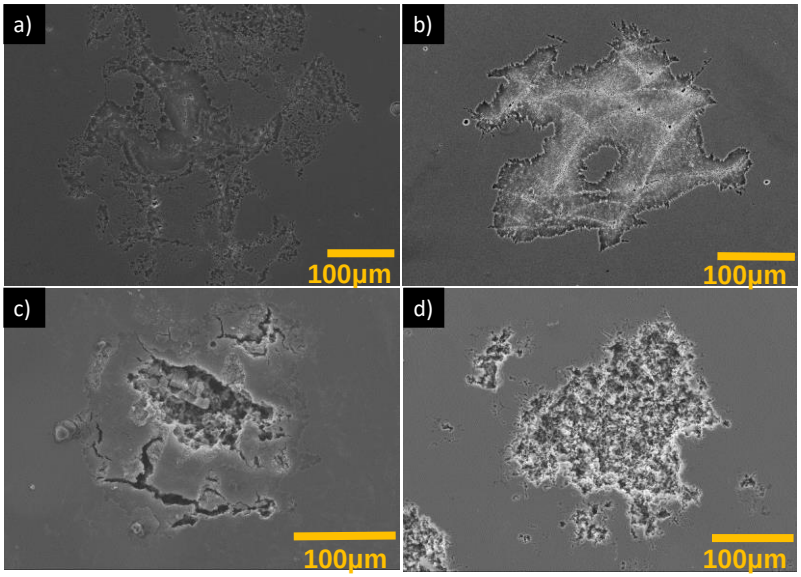
a) Non Heat Treated

b) Artificial Ageing at 170 °C, 6 hrs

c) Stress Release at 250 °C, 2 hrs

d) Stress Release at 300 °C, 2 hrs

Influence of heat treatments on corrosion



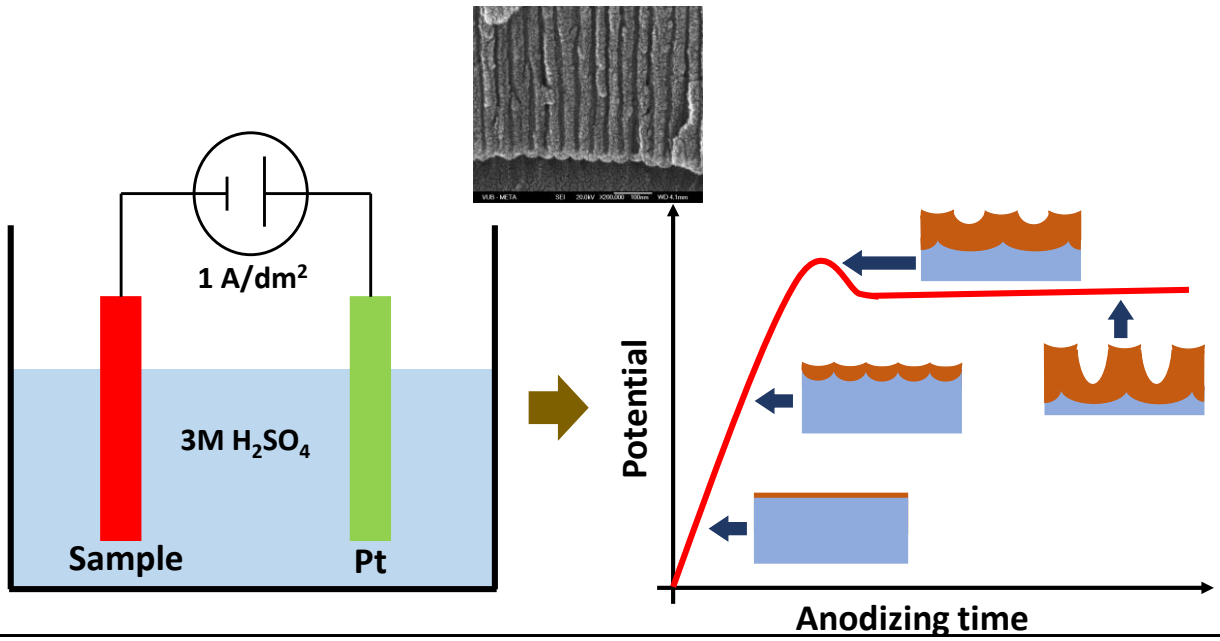
a) Non Heat Treated

b) Artificial Ageing at 170 °C, 6 hrs

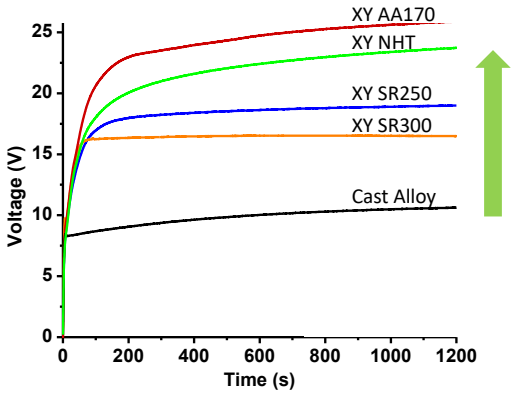
c) Stress Release at 250 °C, 2 hrs

d) Stress Release at 300 °C, 2 hrs

Typical behavior during galvanostatic anodizing in H_2SO_4 of "conventional" aluminium



Potential vs time behavior: AM versus cast alloy

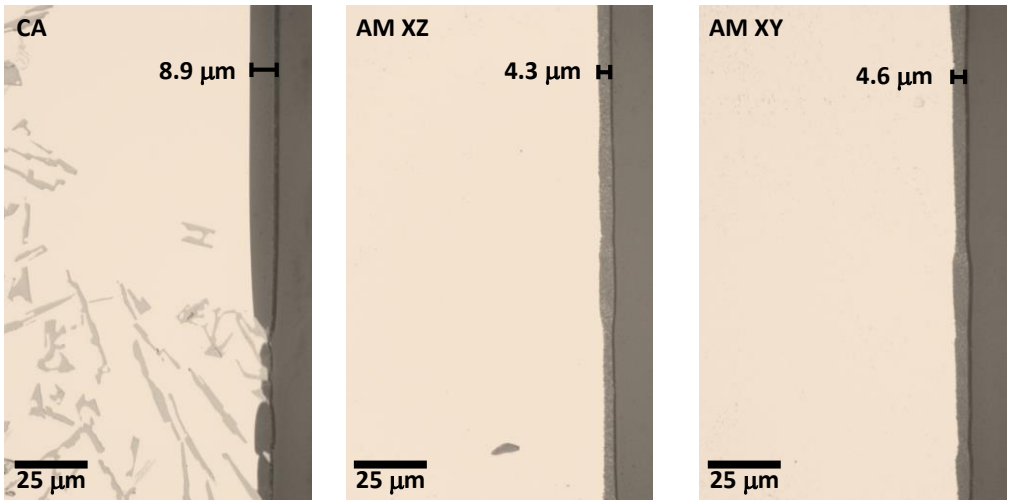


13 V higher

- AM much higher voltages than for cast Al
- Heat treatments have significant impact on steady-state anodizing voltage

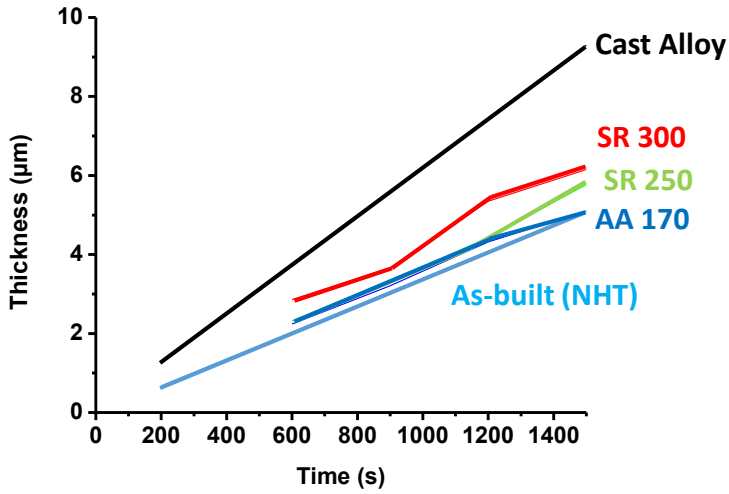
13

Optical image of cross-sections after anodizing for 20 min



- Formation of a thinner, more continuous oxide film…
- Anodizing efficiency of the as-built AM is only 50 % of that of the cast alloy!
- Film thickness independent of building direction

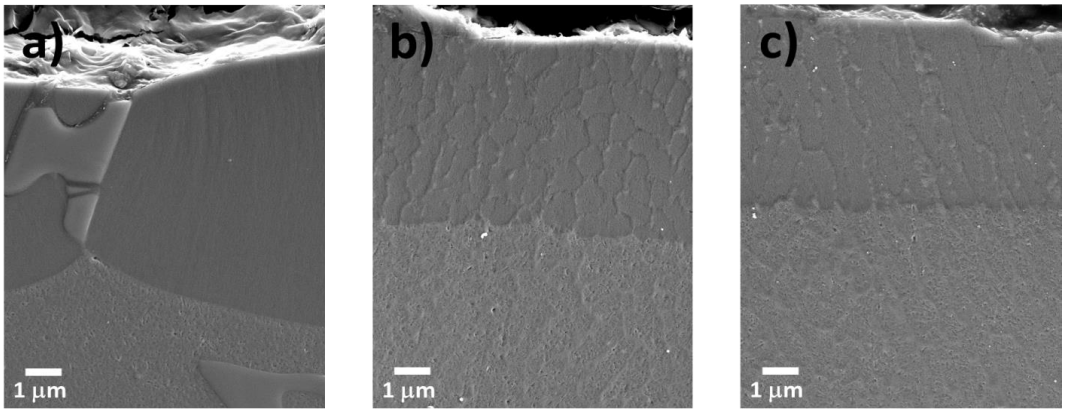
Oxide layer growth rate – anodizing efficiency !



- Cast alloy: 0.4 µm/min
- As-built AM: 0.2 µm/min
- Anodising efficiency improves by the heat treatments….
- **WHY?**

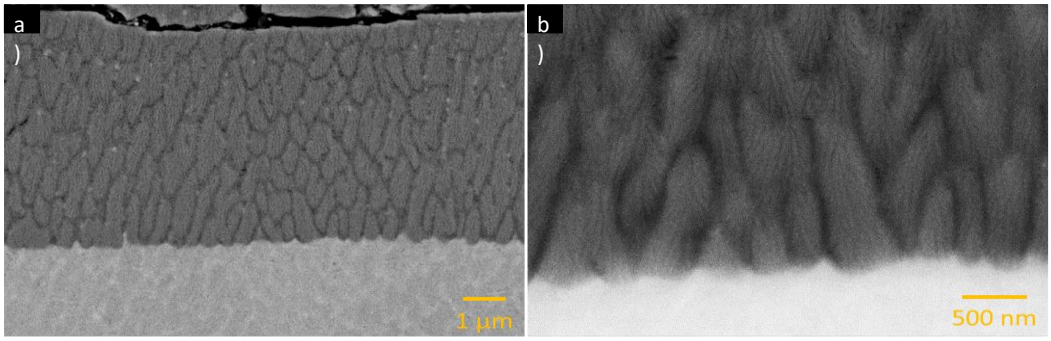
SEM of cross sections after anodizing for 20 min

Cast Alloy | **As-built AM XZ** | **As-built AM XY**

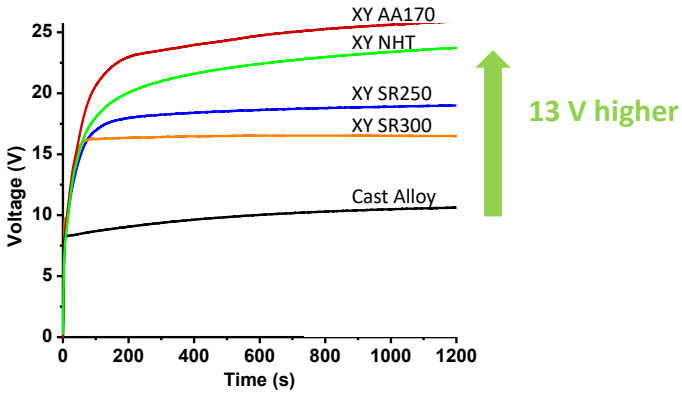


- Si slows down and deviates the oxide front
- On AM samples: connected network structure is preserved in the oxide

Anodic film on as-built Al10SiMg



- Si is fully oxidised in the non heat treated material (confirmed by XPS)
  - higher anodising potential because higher field-strenght required



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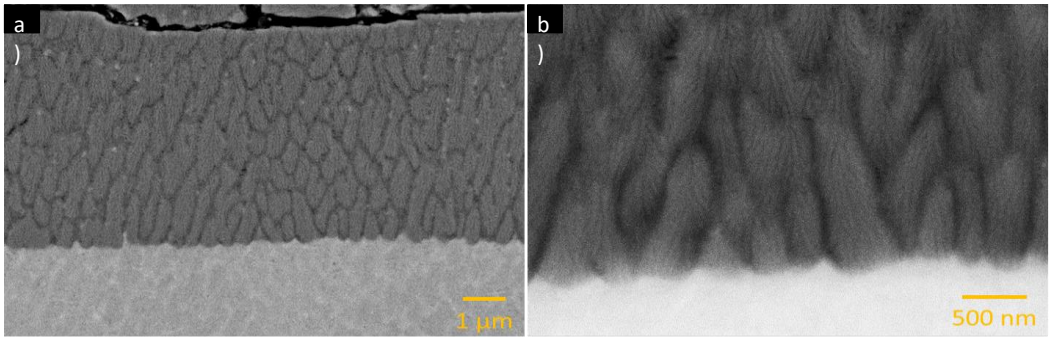
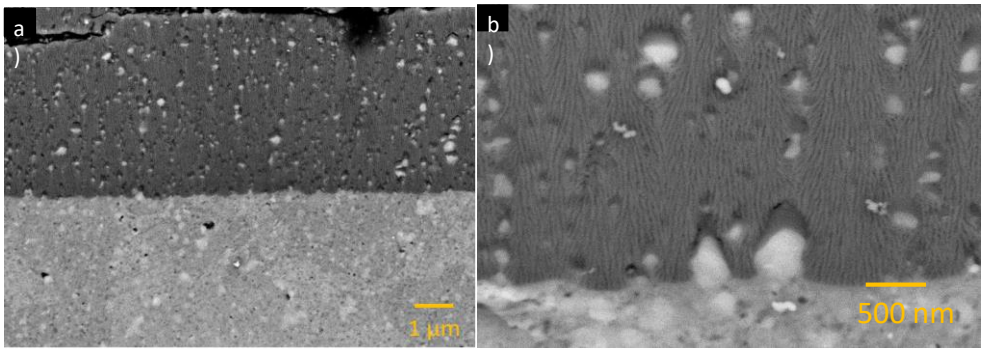
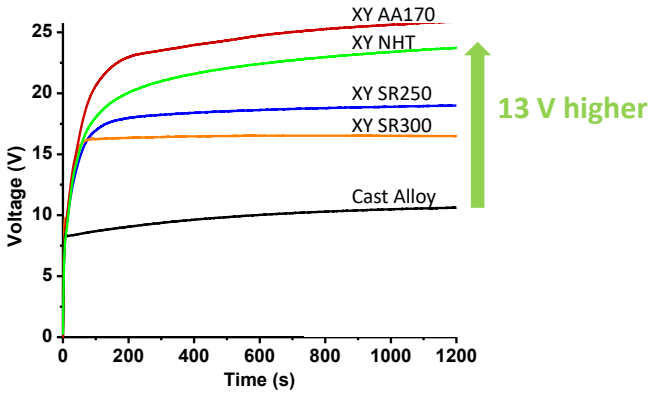


- Si is fully oxidised in the non heat treated material (confirmed by XPS)
  - higher anodising potential because higher field-strenght required
- The aluminium "cells" inside the Si network are anodised in a branched-like structure

Anodic film on stress released (300 °C, 2 hrs) Al10SiMg



- Top part of the Si particles is anodised in the stress released material (confirmed by XPS)
- Si is not completely anodised > voltage behaviour goes closer to that of the cast alloy



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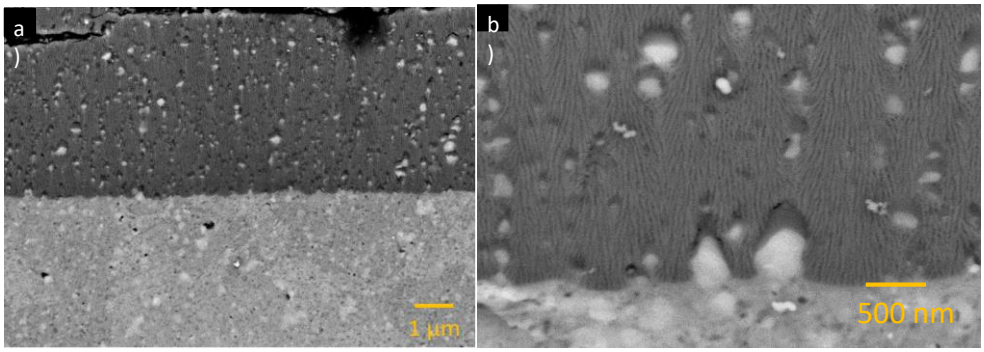

- Top part of the Si particles is anodised in the stress released material (confirmed by XPS)
- Si is not completely anodised > voltage behaviour goes closer to that of the cast alloy
- Oxide structure with non-perpendicular pores circumventing the Si particles

Conclusions

SLM microstructure: unique fine Si/Al network
- ➢ Level of connectivity in the Si network depends on heat treatments

Corrosion: initiation at more active melt pool borders
- ➢ Superficial spreading of the corrosion for as-built and artificially aged Al
- ➢ Superficial + in-depth penetration for stress relieved samples

Anodising mechanism:
- Higher field strength required & silicon phase partial to full oxidation (XPS)
- "Branched-like"/ non-perpendicular porous anodic oxide film structure
- Significant effect of heat treatments!
- ➢ Improves anodizing efficiency
- ➢ Changes the oxide-film structure…

Ongoing

- Corrosion protective properties of anodized AM as function of heat treatments
  - ➢ So far: good salt-spray test results!
- Fatigue properties
  - ➢ So far: no negative influence of anodizing on fatigue!

For more details see:

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JOURNAL OF THE ELECTROCHEMICAL SOCIETY, 164 (2) (2017) C27-C35. DOI: 10.1149/2.0461702

R. I. REVILLA CASTILLO, D. VERKENS, G. COUTURIAUX, L. MALET, L. THIJS, S. GODET, I. DE GRAEVE,
Galvanostatic anodizing of additive manufactured AlSi10Mg alloy,
JOURNAL OF THE ELECTROCHEMICAL SOCIETY, 164 (14) (2017) C1027-C1034.

R. I. REVILLA CASTILLO, I. DE GRAEVE,
Role of Si in the anodizing behavior of Al-Si alloys: Additive manufactured and cast Al-Si10-Mg,
JOURNAL OF THE ELECTROCHEMICAL SOCIETY, 165 (2018) C532-C541.

Thanks to …

S.A.B.C.A.

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