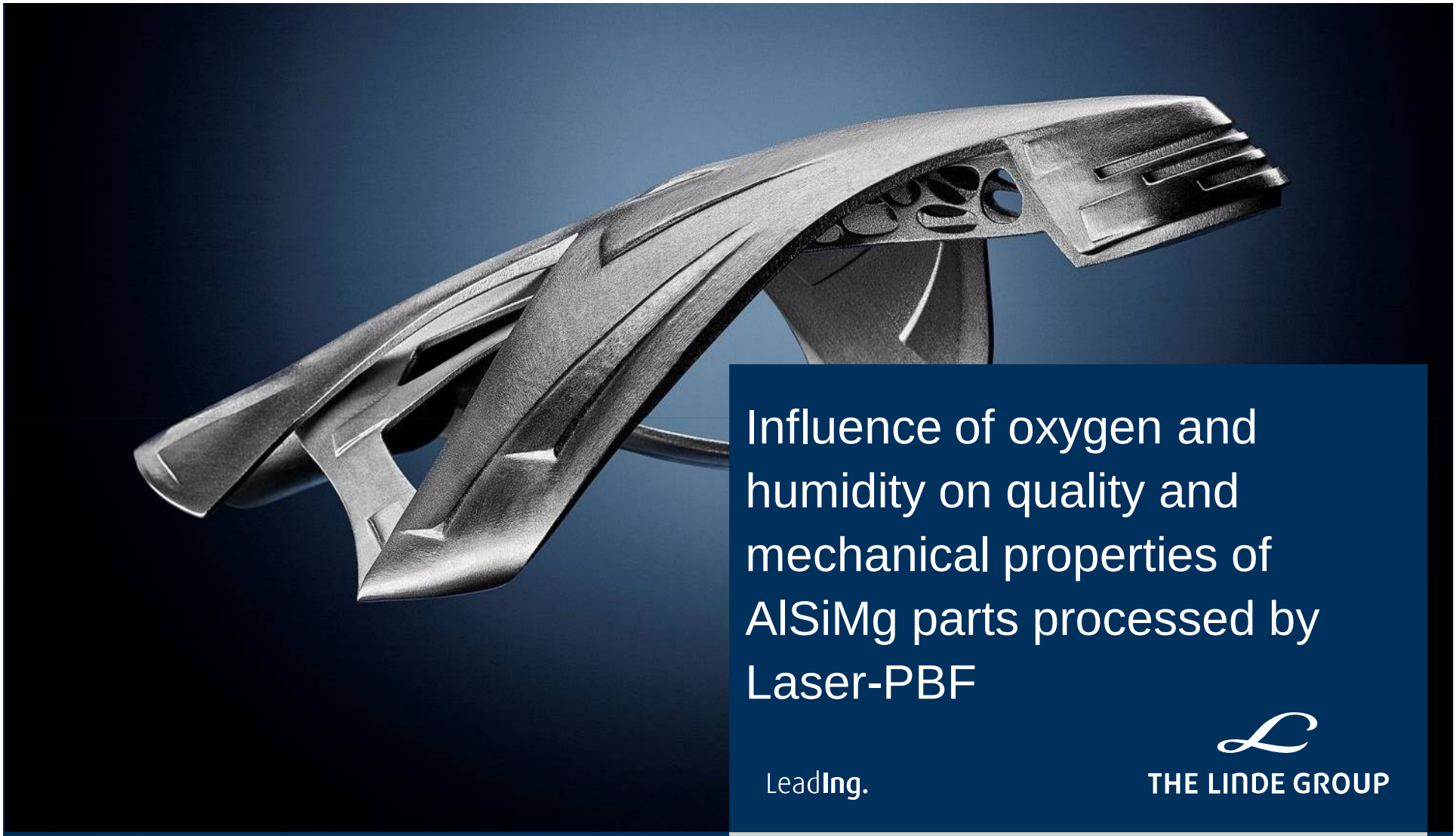


Influence of oxygen and humidity on quality and mechanical properties of AlSiMg parts processed by Laser-PBF

LeadIng.

THE LINDE GROUP

Juergen Scholz, Linde AG Linde Gases Division
Anders Astrom, AGA Gas AB

Content

1 Introduction - Motivation

2 Parameters in AM – The way to reproducibility

3 Results of AlSiMg

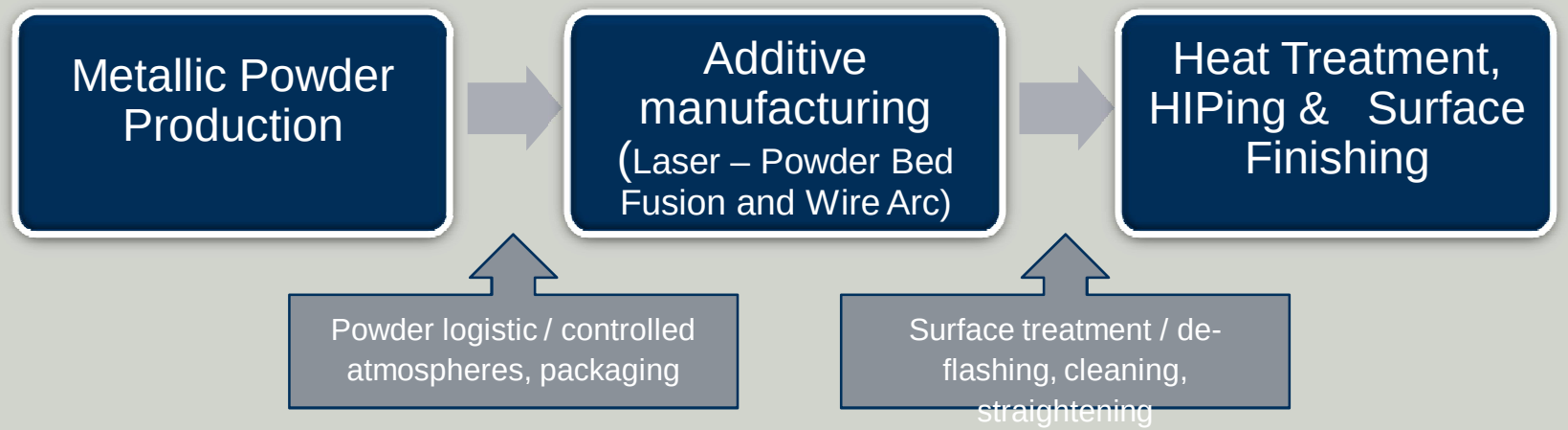
4 Conclusion & Outlook

Gases Division

GDC Additive Manufacturing

THE LINDE GROUP

Global Development Center Additive Manufacturing created in 2015:
Develops new solutions for the Additive Manufacturing industry along the value chain (Powder production/storage, Selective Laser Melting, Laser Metal Deposition, Wire Arc AM, post-treatments)



Critical capabilities:
metallurgy, chemistry and physics of gas-to-metal interfaces, gases safety and engineering

GDC Additive Manufacturing
AM Lab Uheim – Capabilities

EOS

Purpose:
In-house process development
Part production

Features:
- Build surface 250*250*350mm
- 400W Laser

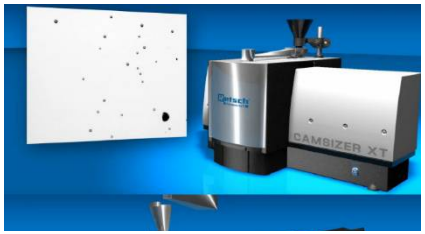
Trumpf TruPrint 1000

Purpose:
Process development & Demo and internal training

Features:
- Build surface ø100mm
- 200W Laser

Powder handling
- Powder storage
- Powder commissioning
- Post Processing
- Surface Finish

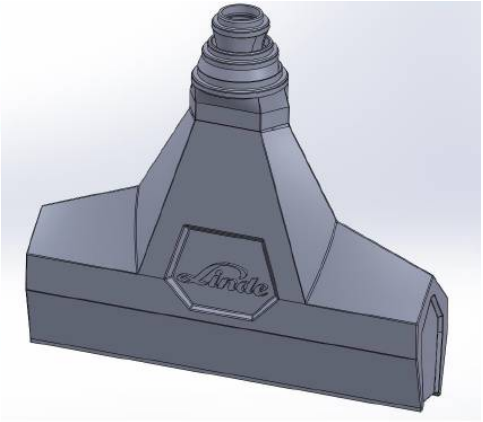
Clean Room / Analytics
- Powder characterisation (SEM, Revolution, CAMSIZER X2)
- Testing, Metallography
- *Chemical Analysis*
- Gas Analytic

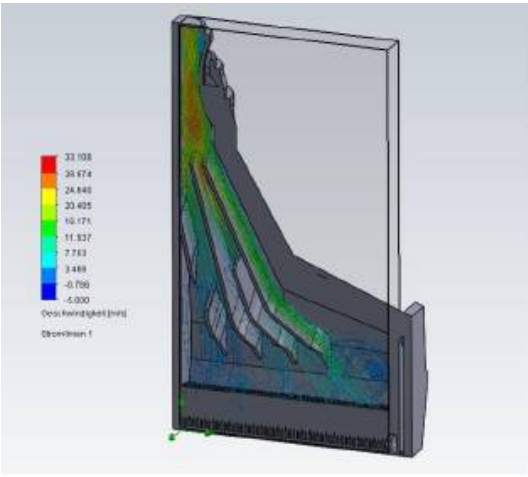


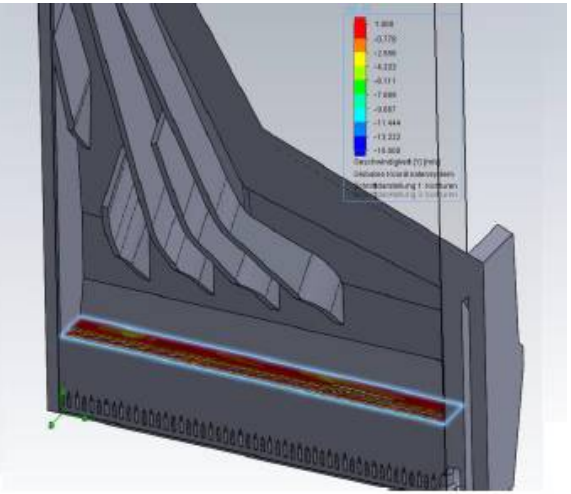
RAP, Source: Mercury Scientific

Additive Manufacturing for Linde technologies

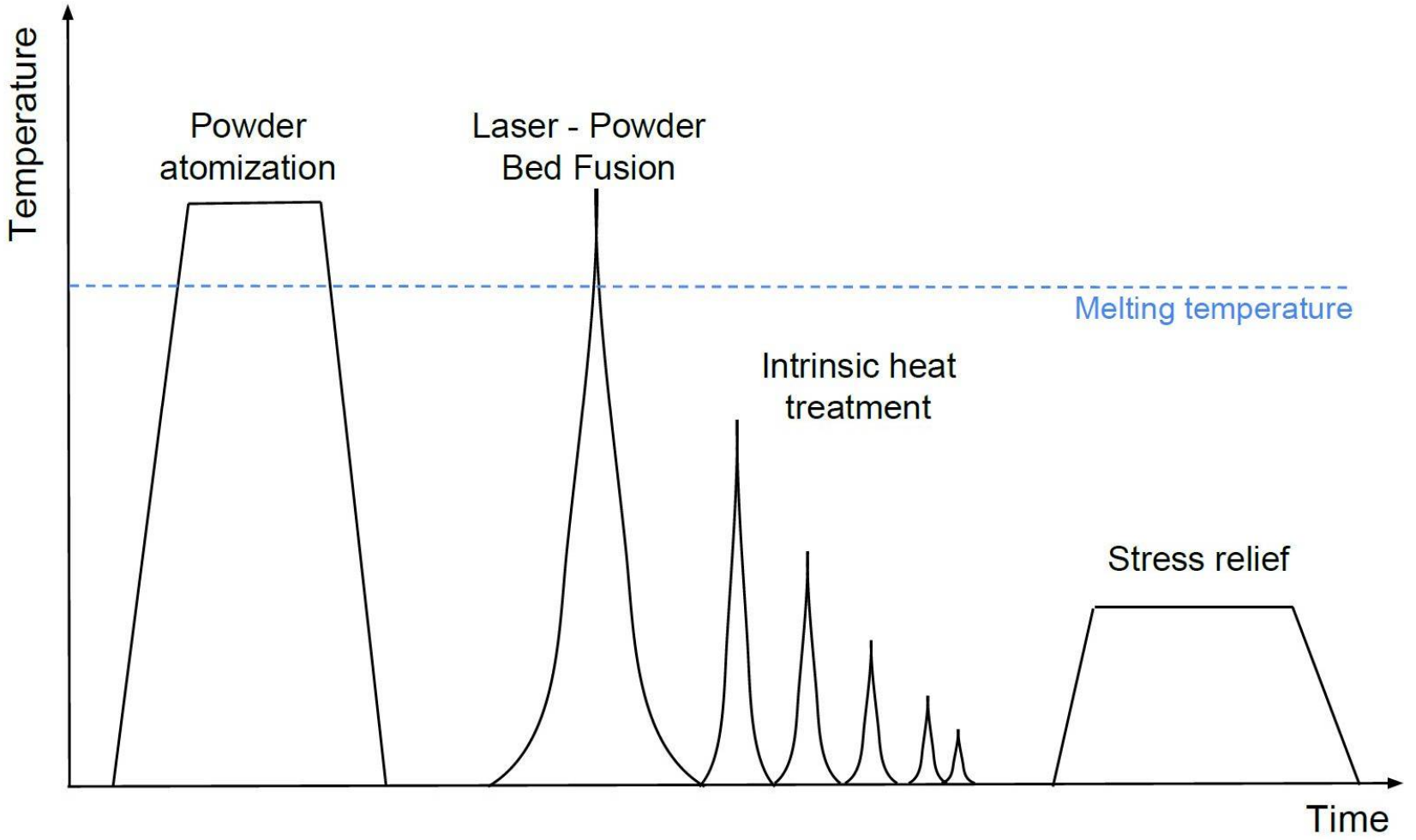
Example Hydropox burner (glass surface treatment)







During L-PBF, material experiences a unique thermal profile



Evolution of grain structure during laser additive manufacturing

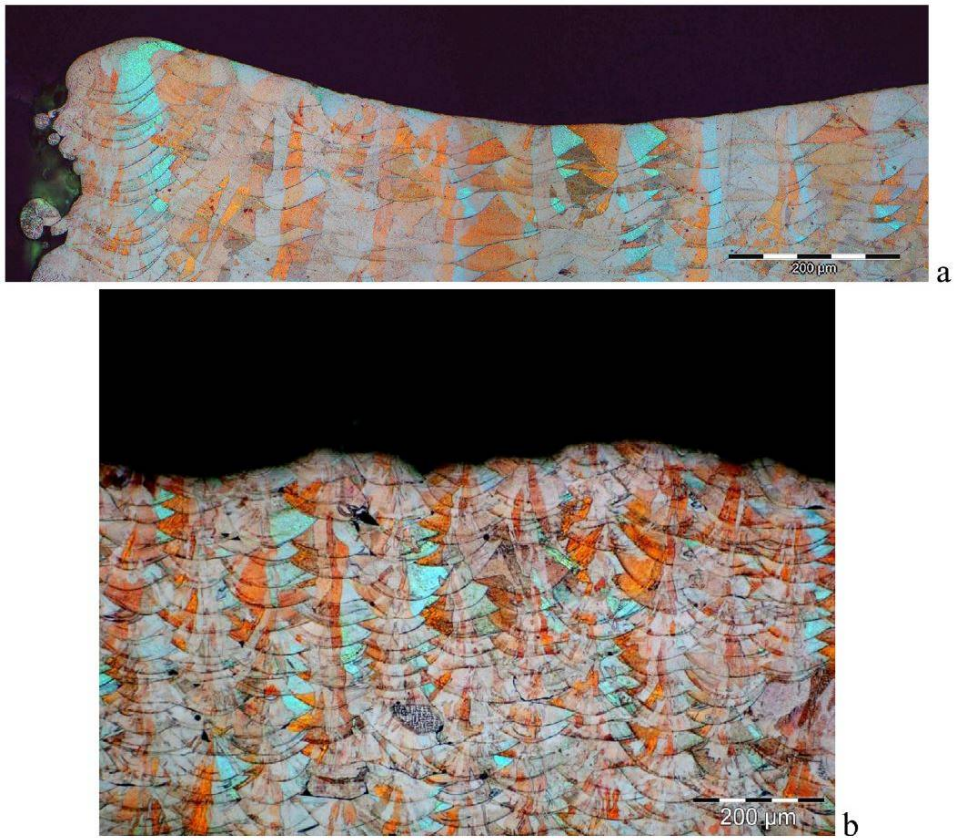


Fig. 8. Experimental grain structures of 316 L steel subjected to the SLM process. Experiments were performed in Neue Materialien Bayreuth GmbH.

- Fine microstructure:
rapid solidification => enhanced strength, properties comparable and/or surpassing conventional material

- Columnar microstructure with texture along the building direction

- Anisotropy : lower strength along the building direction due to superposition of layer

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Opportunities and challenges of AM for Aerospace

THE LINDE GROUP

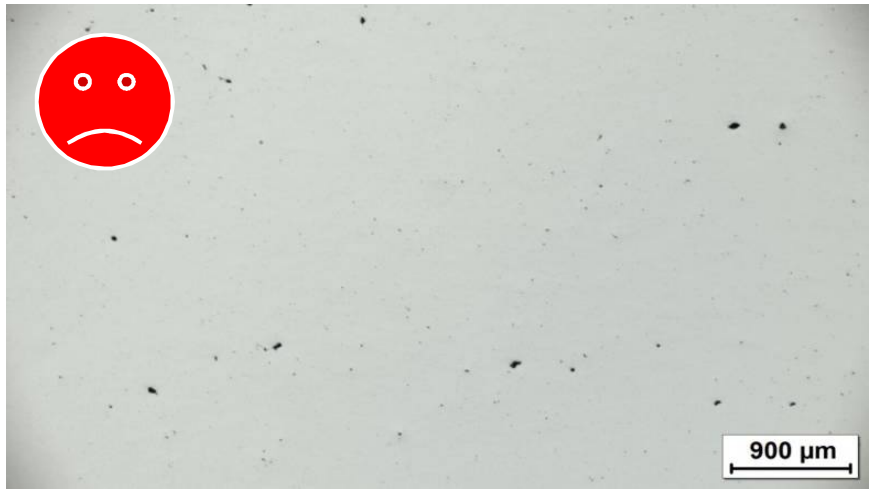
Challenges for aerospace materials and processes:

- Low mass
- Small production series
- Very high reliability
- Very high performances

Why AM?

- AM addresses majority of above challenges

BUT quality and reproducibility are key



Additive Manufacturing sounds easy ...

THE LINDE GROUP

A design

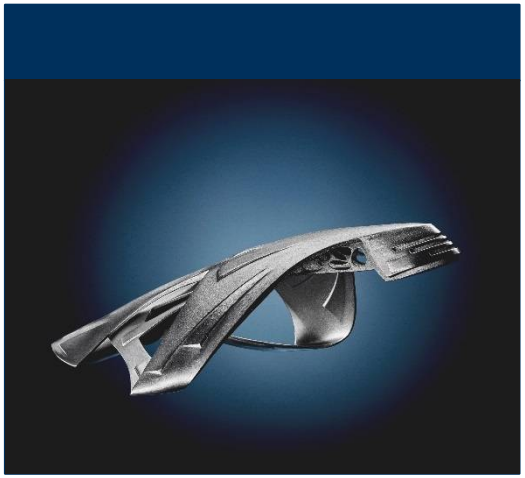
+

Powder

+

Printer

=



Which parameters influence the end product quality

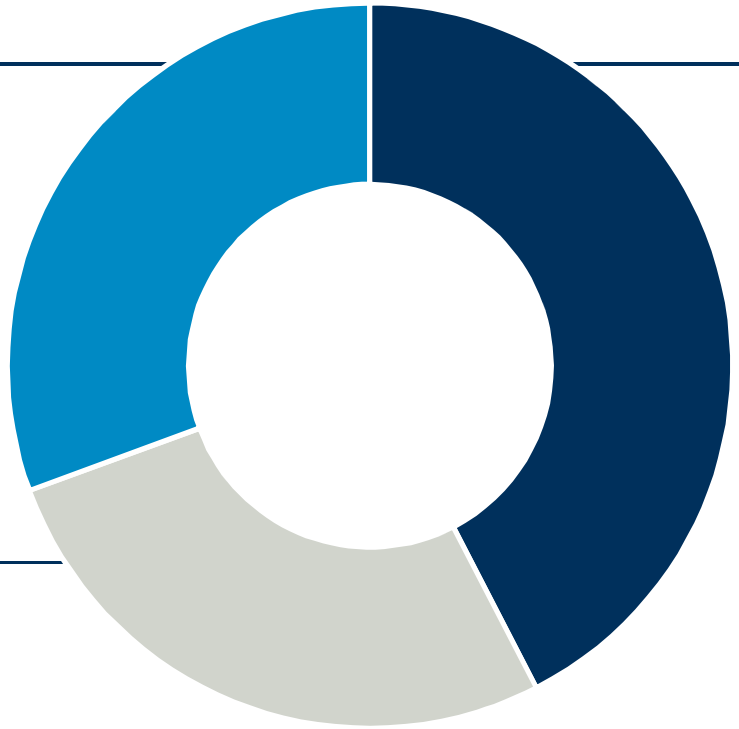
THE LINDE GROUP

Powder

Flowability, Particle size distribution, satellites, chemical composition, fine particles, morphology, topology, humidity…

Parameters

Laser power, laser speed, scanning speed, build strategy, hatching distance, layer thickness …



Machine

Laser, scan, software, gas flow, chamber size, recoating strategy …

Which parameters influence the end product quality

THE LINDE GROUP

Powder

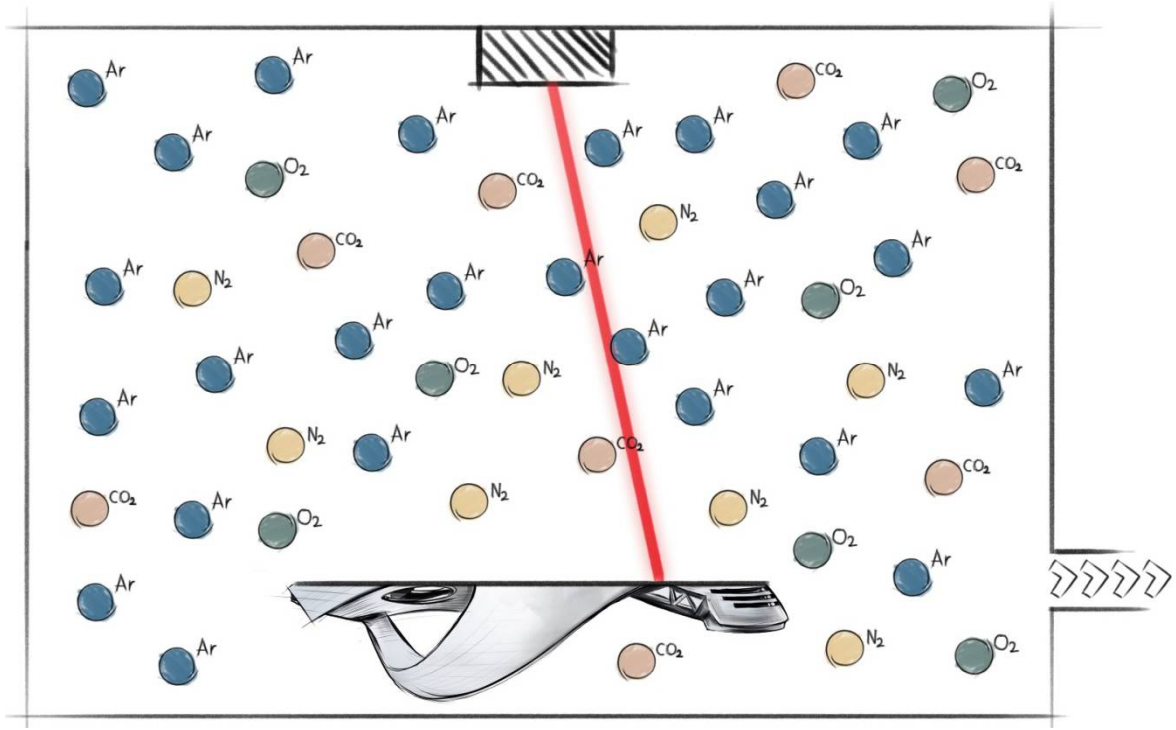
Machine

Parameters

Atmosphere

Gas type, gas purity, humidity, atm. composition, flow speed, temperature

Atmosphere composition inside the chamber



Atmosphere composition:

— Argon or Nitrogen

— Oxygen

And much more:

— H_2O

— Hydrogen

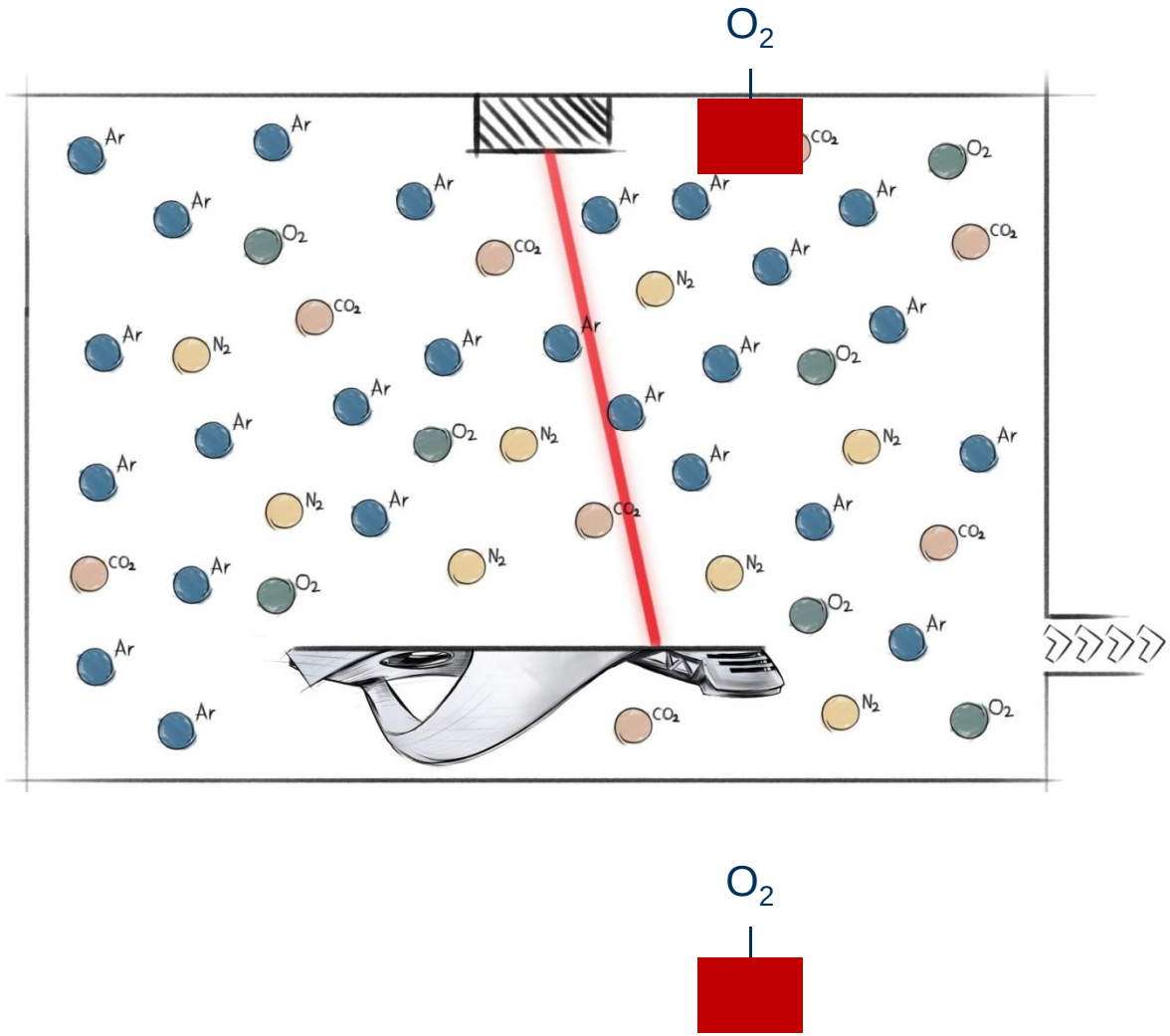
— CO

— CO_2

— Nitrogen

— ...

Atmosphere composition inside the chamber



Atmosphere composition:

— Argon or Nitrogen

— Oxygen

And much more:

— H_2O

— Hydrogen

— CO

— CO_2

— Nitrogen

— ...

What is the right amount of oxygen?

In welding	0,005% (50ppm)
In AM	0,1% to 1,5%

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Joint study with Airbus Group

THE LINDE GROUP

1) Investigate the impact of different powders on the final mechanical properties

2) Investigate the impact of oxygen in the chamber on the final mechanical properties

3 powders from 3 different suppliers

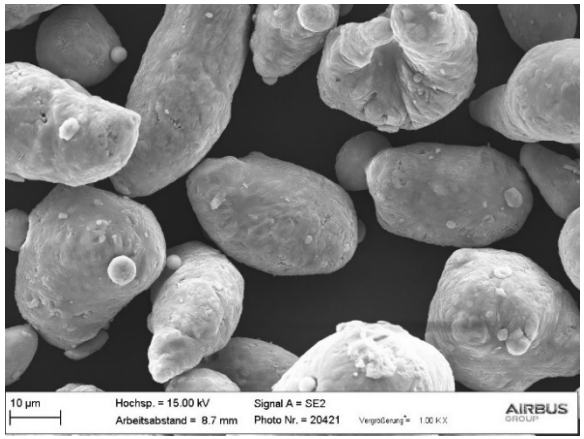
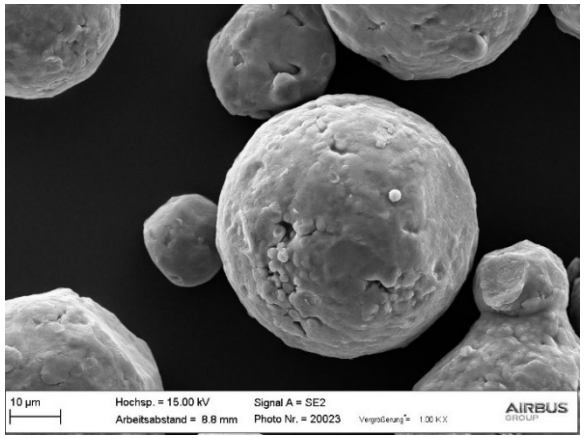
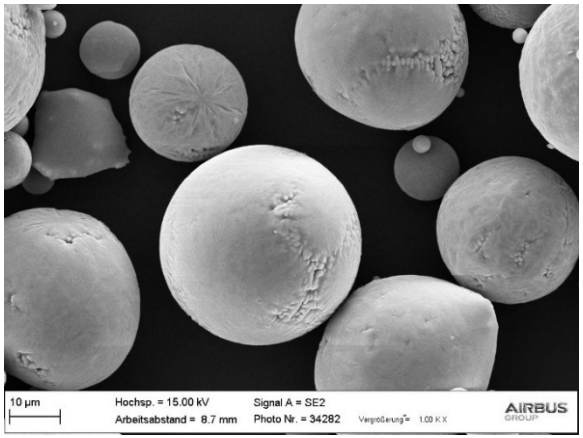
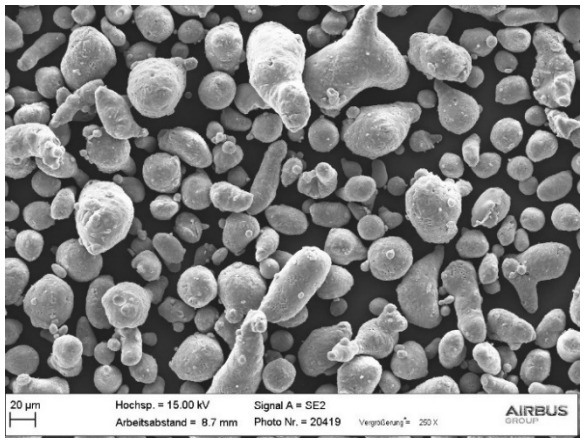
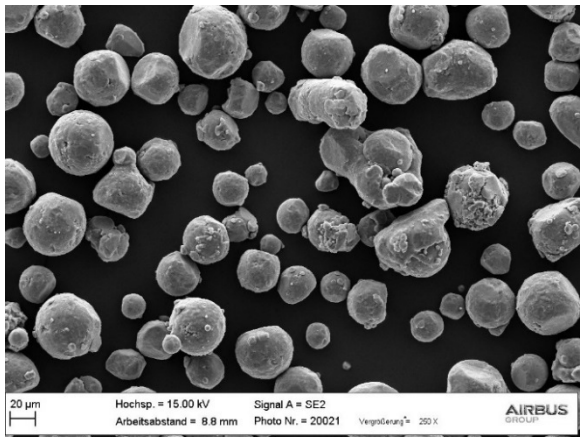
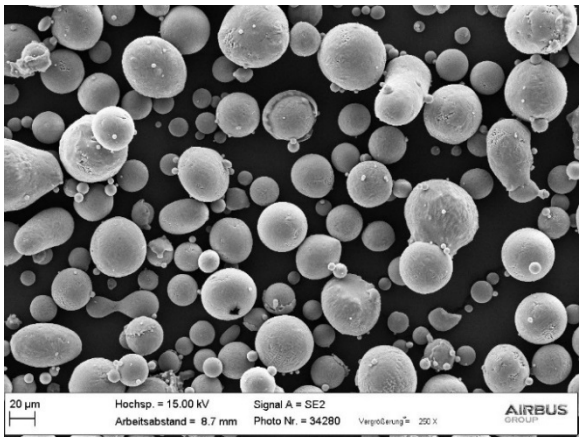
- AlSi10Mg
- Same particle size distribution 20 – 63um

3 oxygen concentration

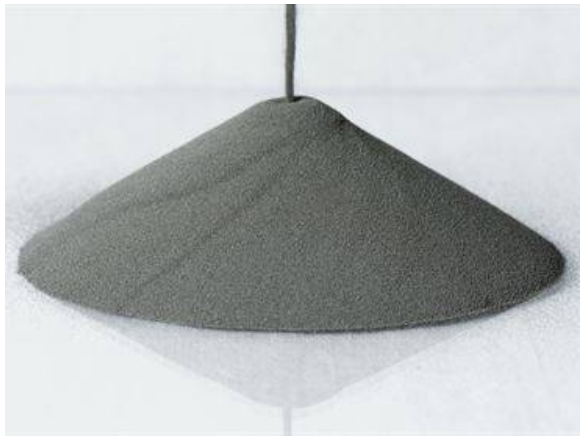
- 30ppm
- 500ppm
- >1000ppm

Powder

THE LINDE GROUP

ALU_1	ALU_2	ALU_3
		
		

Chemical composition
Particle shapes



	Rest [%]	Non-Spherical [%]	Spherical [%]
ALU1	3	87	10
ALU 2	1	59	40
ALU 3	-	-	High

Malvern, Morpholgi G3

	Oxygen concentration
ALU1	950
ALU 2	270
ALU 3	230

LECO, TCH600, 5% measurement uncertainty

	Avalanche Angle [°]
ALU1	47.7
ALU 2	48.1
ALU 3	50.9

Revolution analyzer, 600 avalanches per powder

How to compare two powders?

THE LINDE GROUP

- Chemical composition
- Flowability
- Particle size distribution
- Morphology
- Influence of hole particles
- …

→ Reproducibility is key!

SLM 125 HL – key parameters

SLM 125HL
SLM Solutions, Lübeck, Germany
Major SLM machine supplier

Parameters:

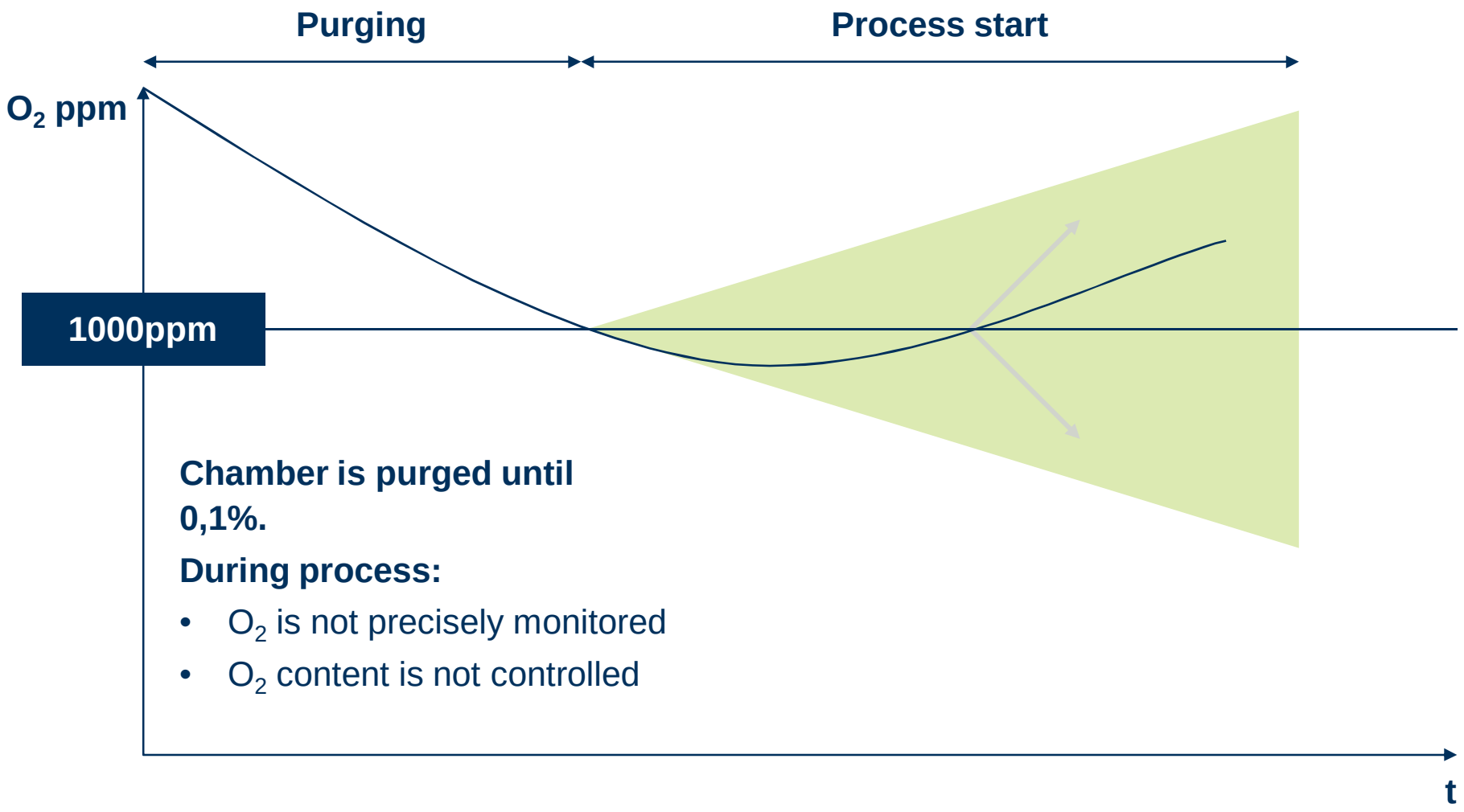
— Build volume of 125*125*125mm³
— Single 400W IPG fiber laser
— Build rate up to 25cm³/h
— Layer thickness 20µm – 75µm
— Max. scan speed 10m/s

State of the art use of Argon:

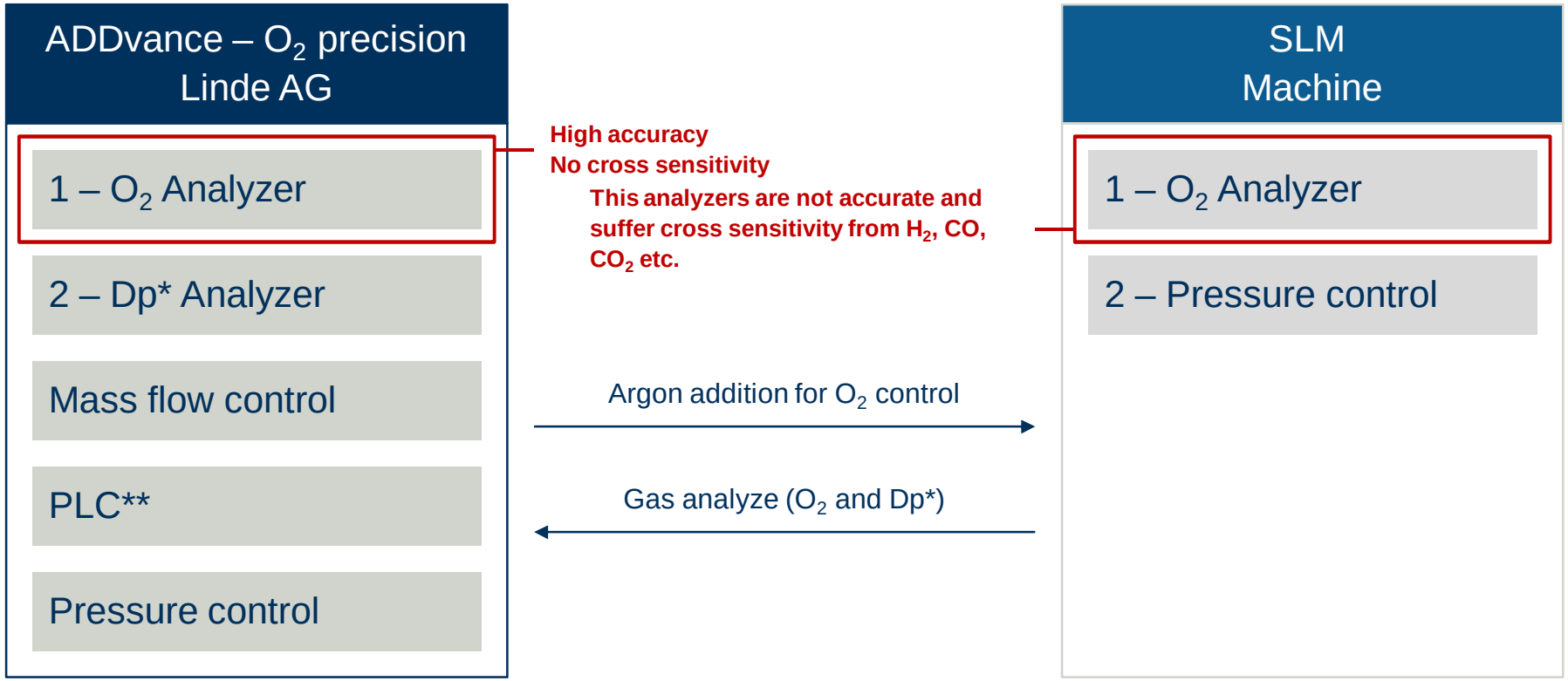
— Purging phase until O_2 content decreases to 0,1%
— Control of chamber overpressure and addition of Argon if the pressure is below 12mbar

Source: www.slm-solutions.com

Current machines do no monitor/ control accurately the oxygen content



Influence of O_2 in Additive Manufacturing
Oxygen and humidity monitoring and control



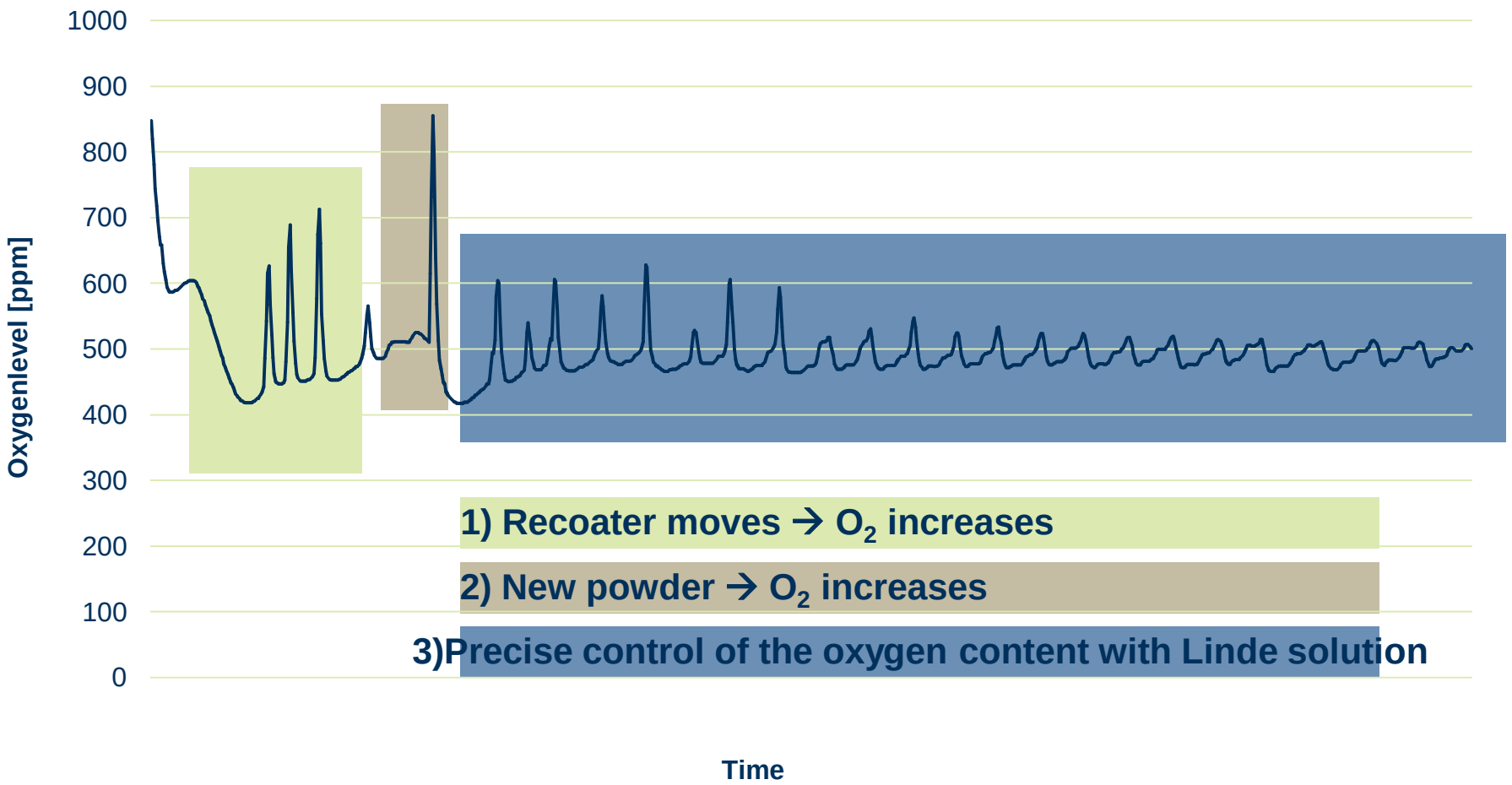
*Dp Dew point | **PLC Programmable Logic Controller

ADDvance O2 precision

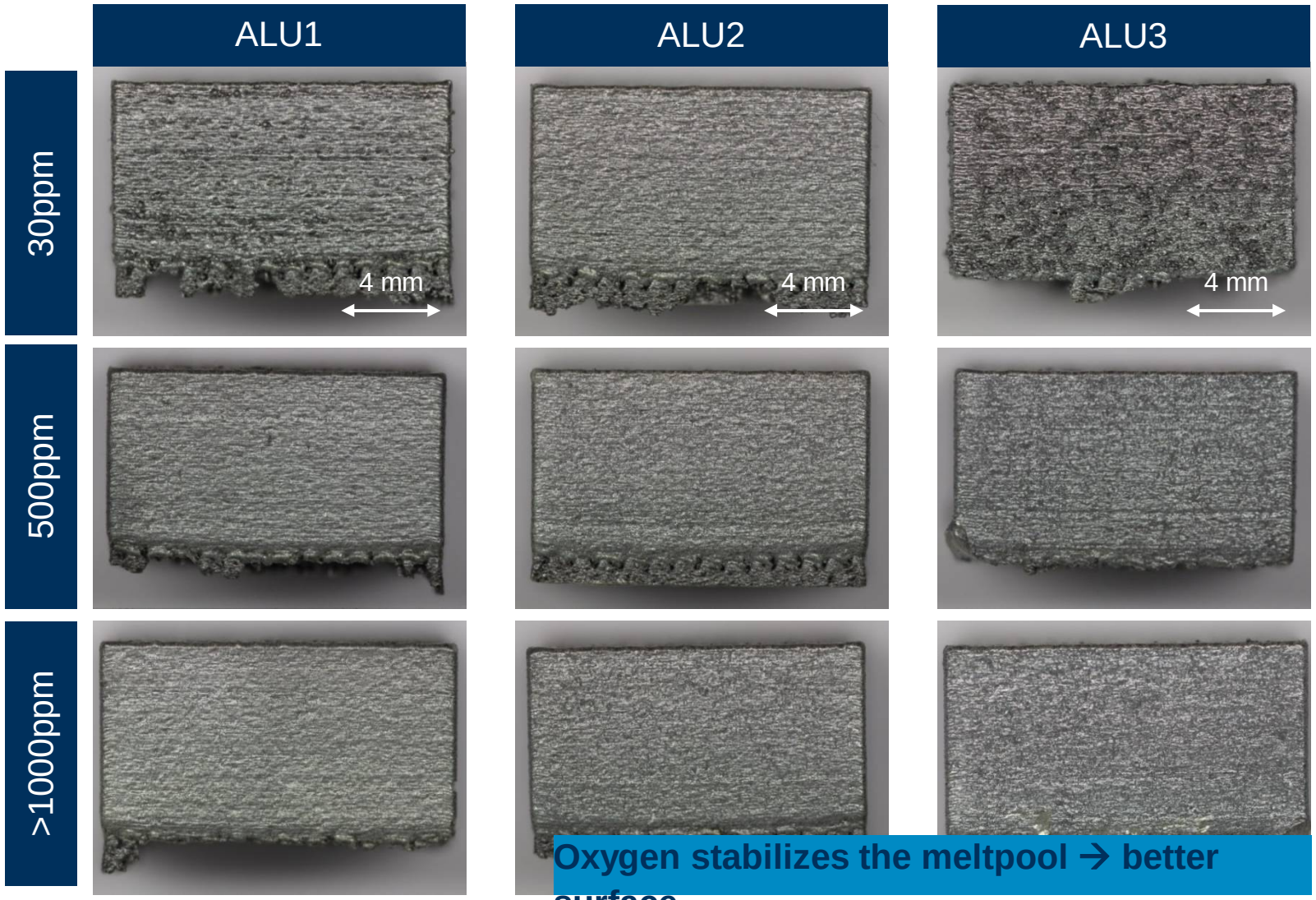
Example installation EOS M290

ADDvance – O_2 precision developed by Linde AG

Example of O_2 variation during start

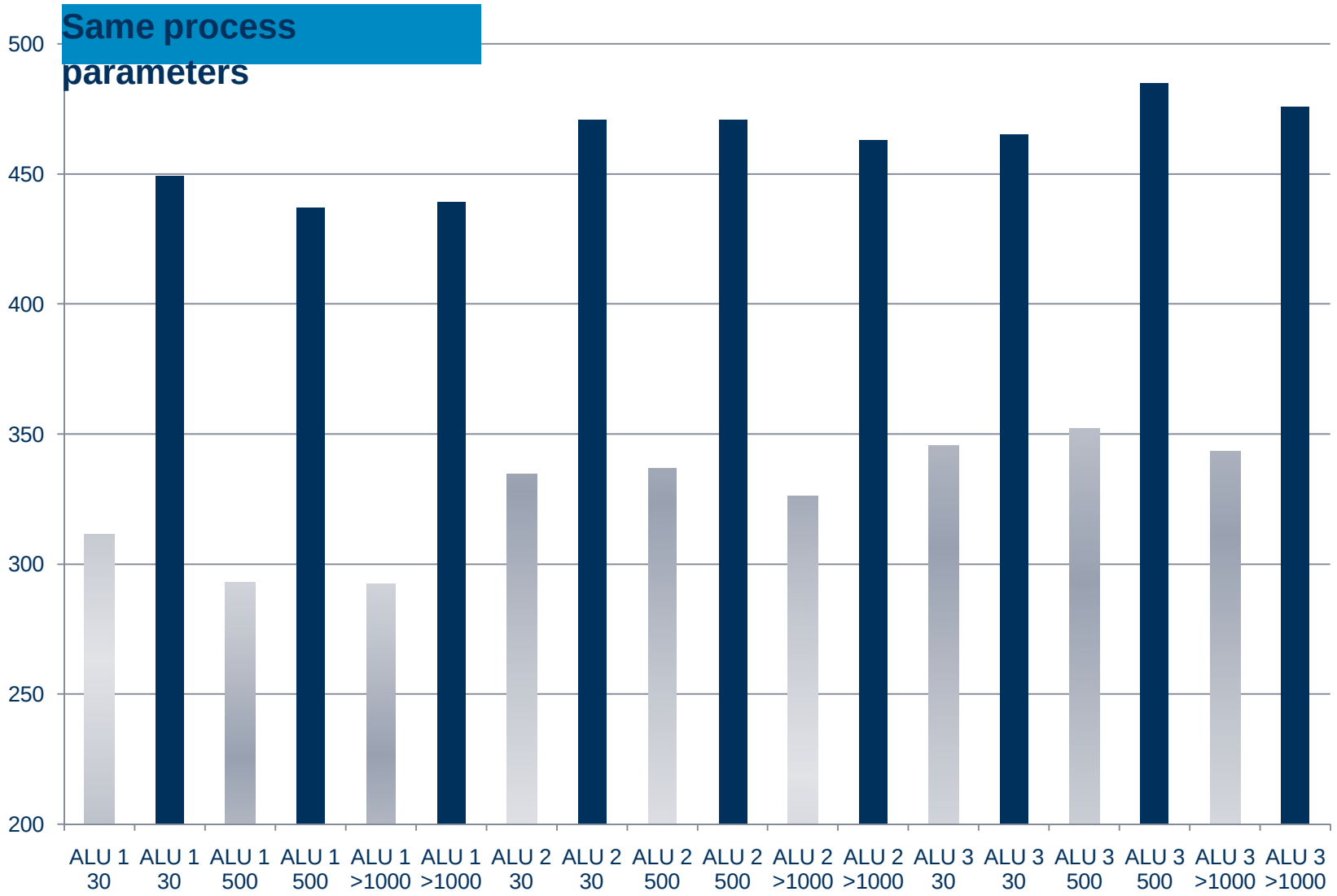


Influence of Oxygen on AlSi10Mg – Surface

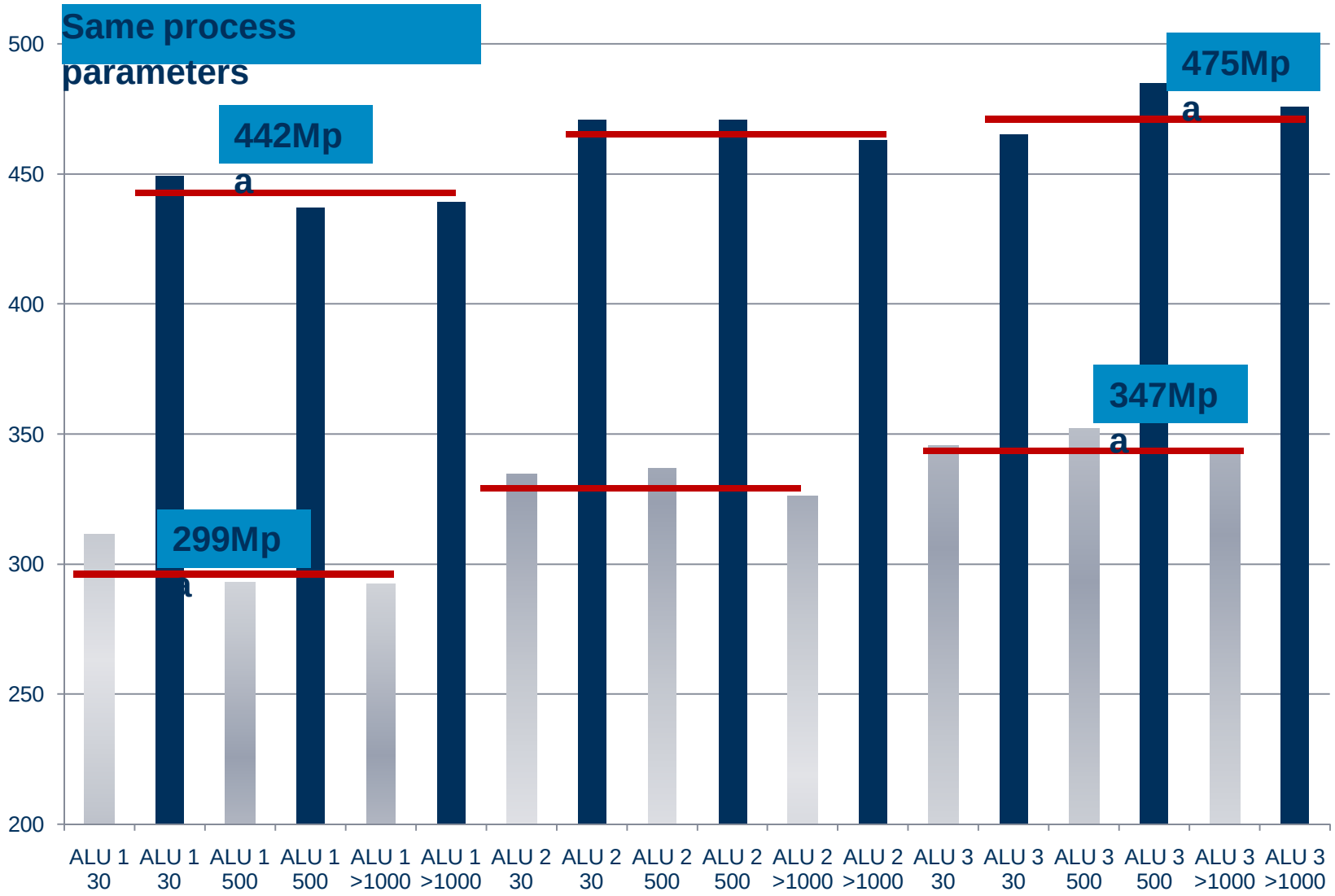


Oxygen stabilizes the meltpool → better surface

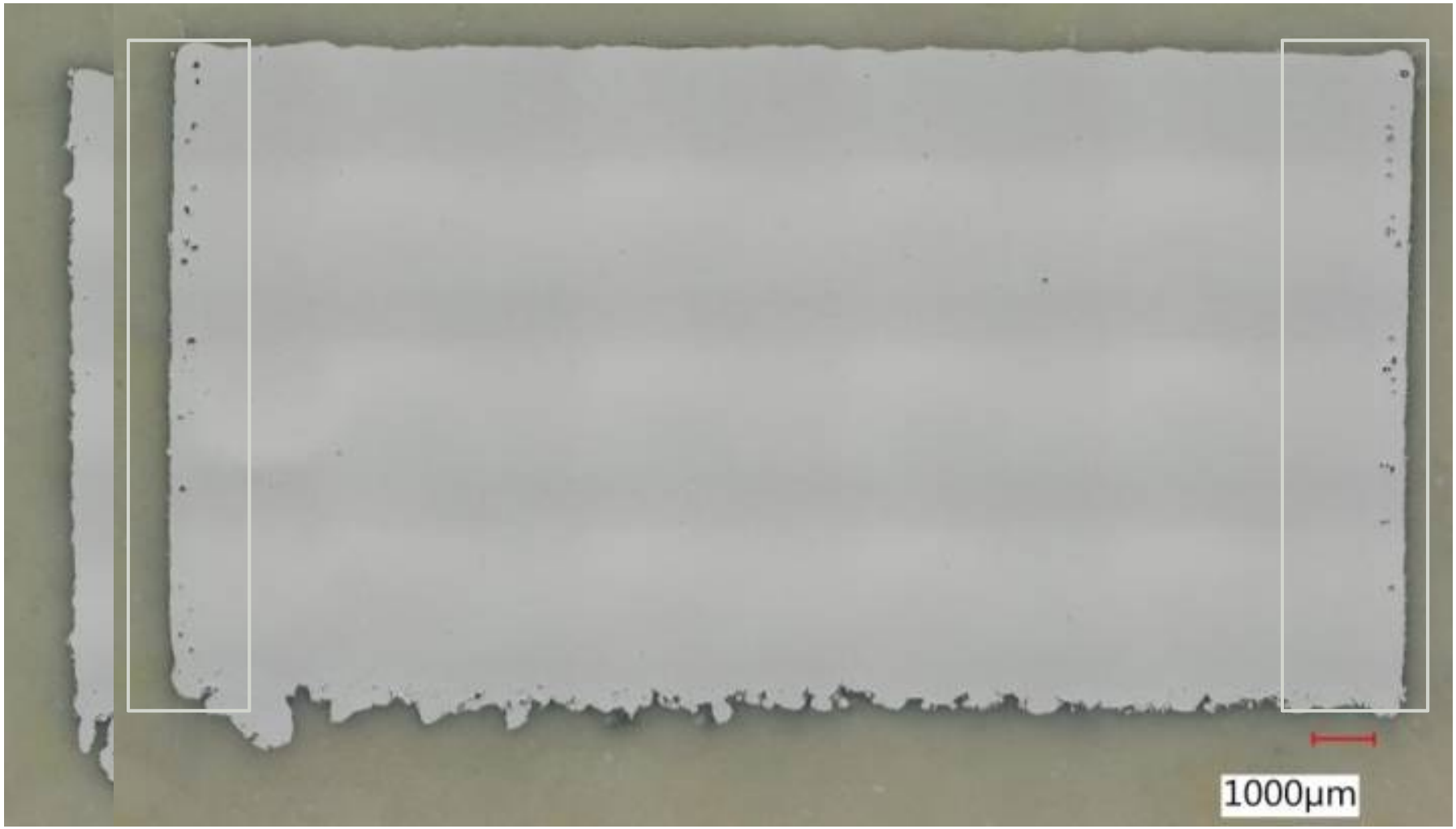
Mechanical properties – Rp0,2 and Rm



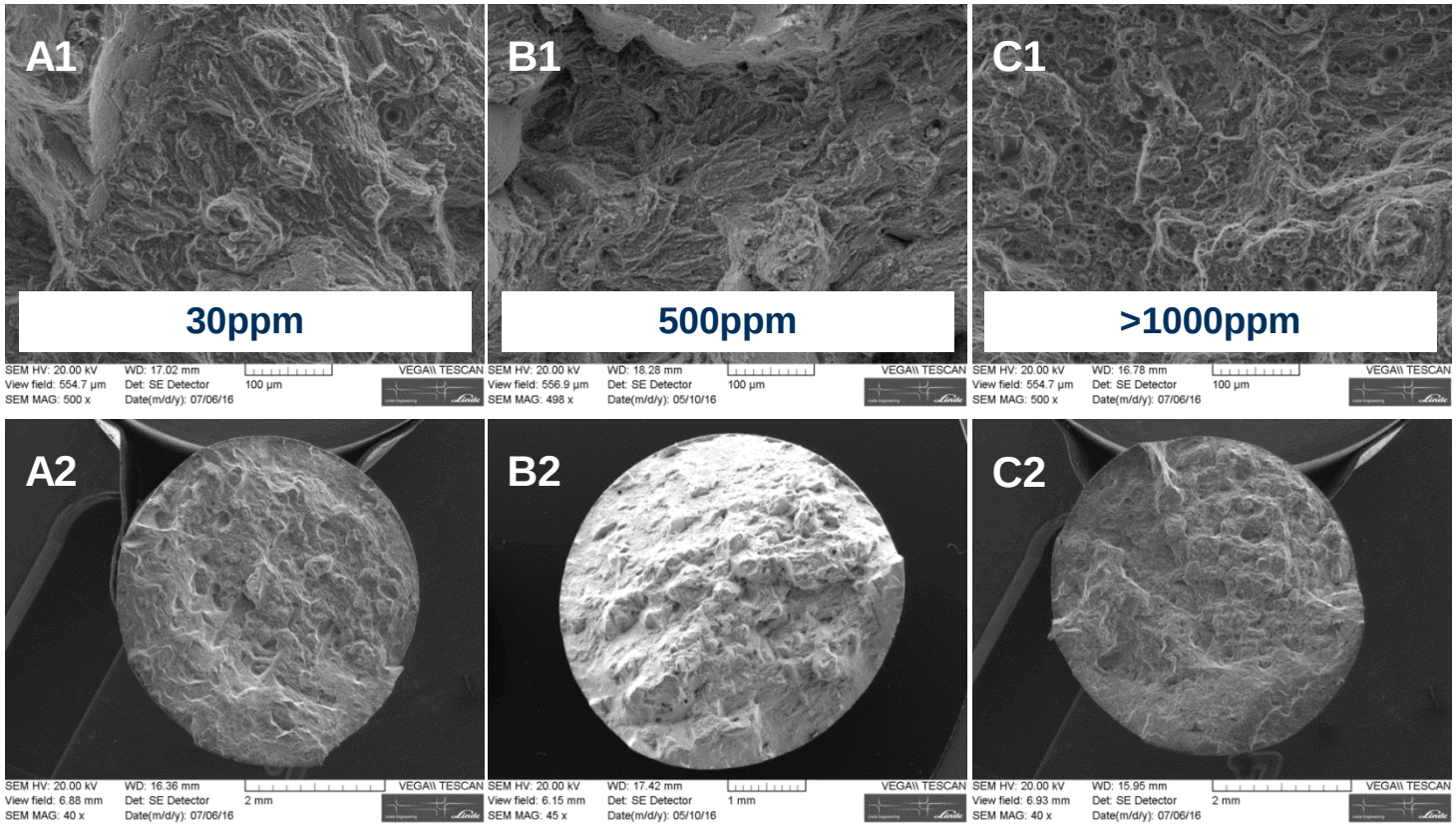
Mechanical properties – Rp0,2 and Rm



Influence of Oxygen on AlSi10Mg – Density



Influence of Oxygen on AlSi10Mg – Fracture analysis ALU_2

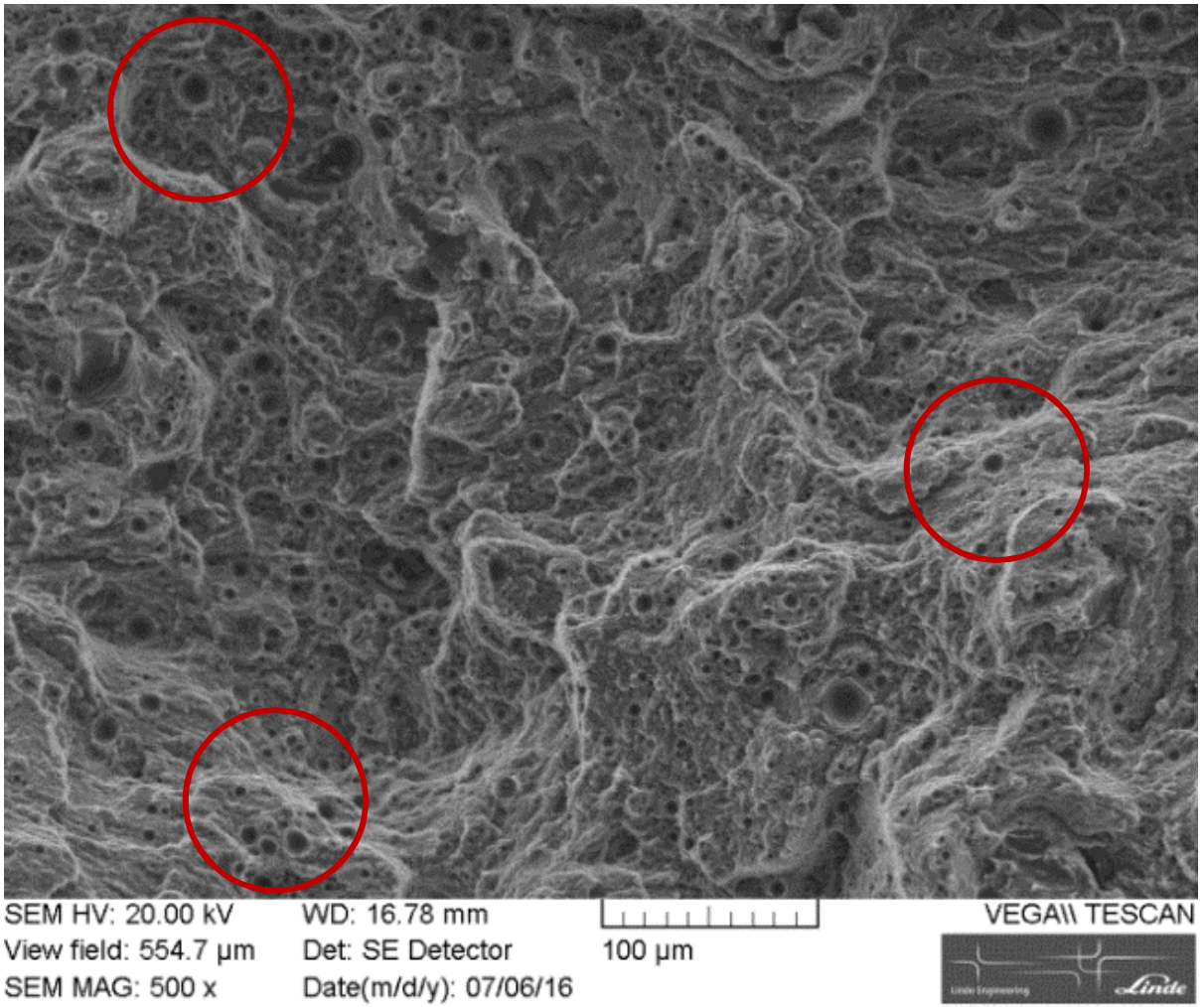


SEM images of the breakage of the tensile strength specimen of [ALU_2]

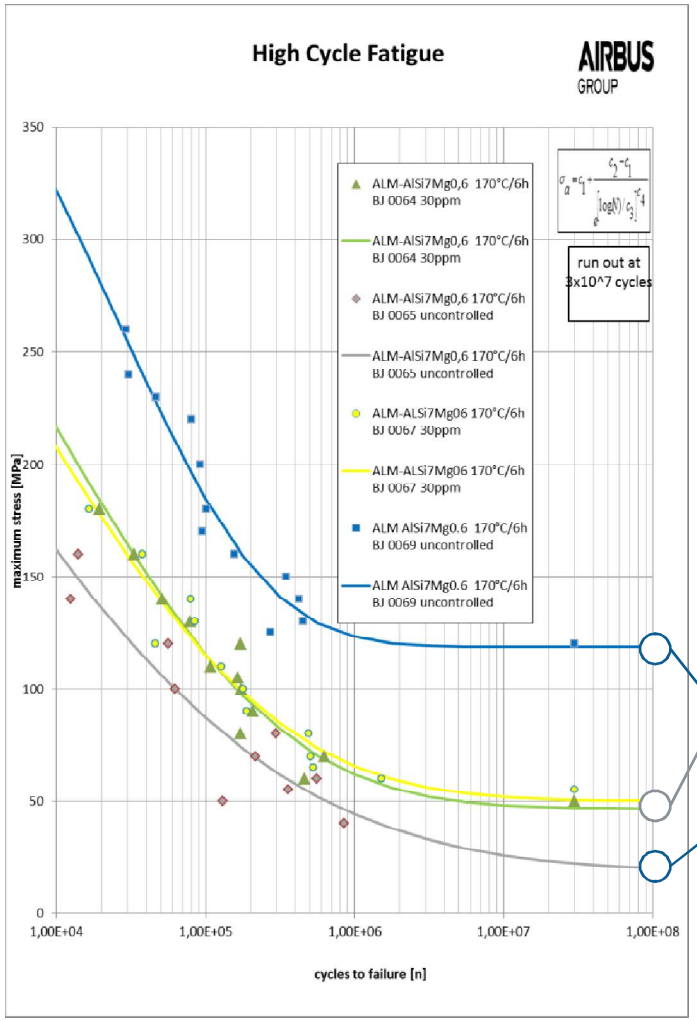
→ The more oxygen the more gas pores

Influence of Oxygen on AlSi10Mg – Fracture analysis ALU_2 >1000ppm

THE LINDE GROUP



Fatigue test performed by Airbus on AlSi7Mg parts produced with and without our technology



- **Reproducible results need an accurate oxygen control**
- **Process parameters with 30ppm can be optimized to improve fatigue resistance**

Yellow and green curves from parts produced with ADDvance™ O_2 precision at 30ppm oxygen

Blue and grey curves from parts produced without oxygen control

GDC Additive Manufacturing

Public funded project

THE LINDE GROUP

BADGE B, Germany

Investigate influence of parameters (GAS!) on operational strength

3 years, Total: €4.5m

AIRBUS

eos

BOSCH

EDAG

Heraeus

SOGETI

Fraunhofer LBF

Conclusion

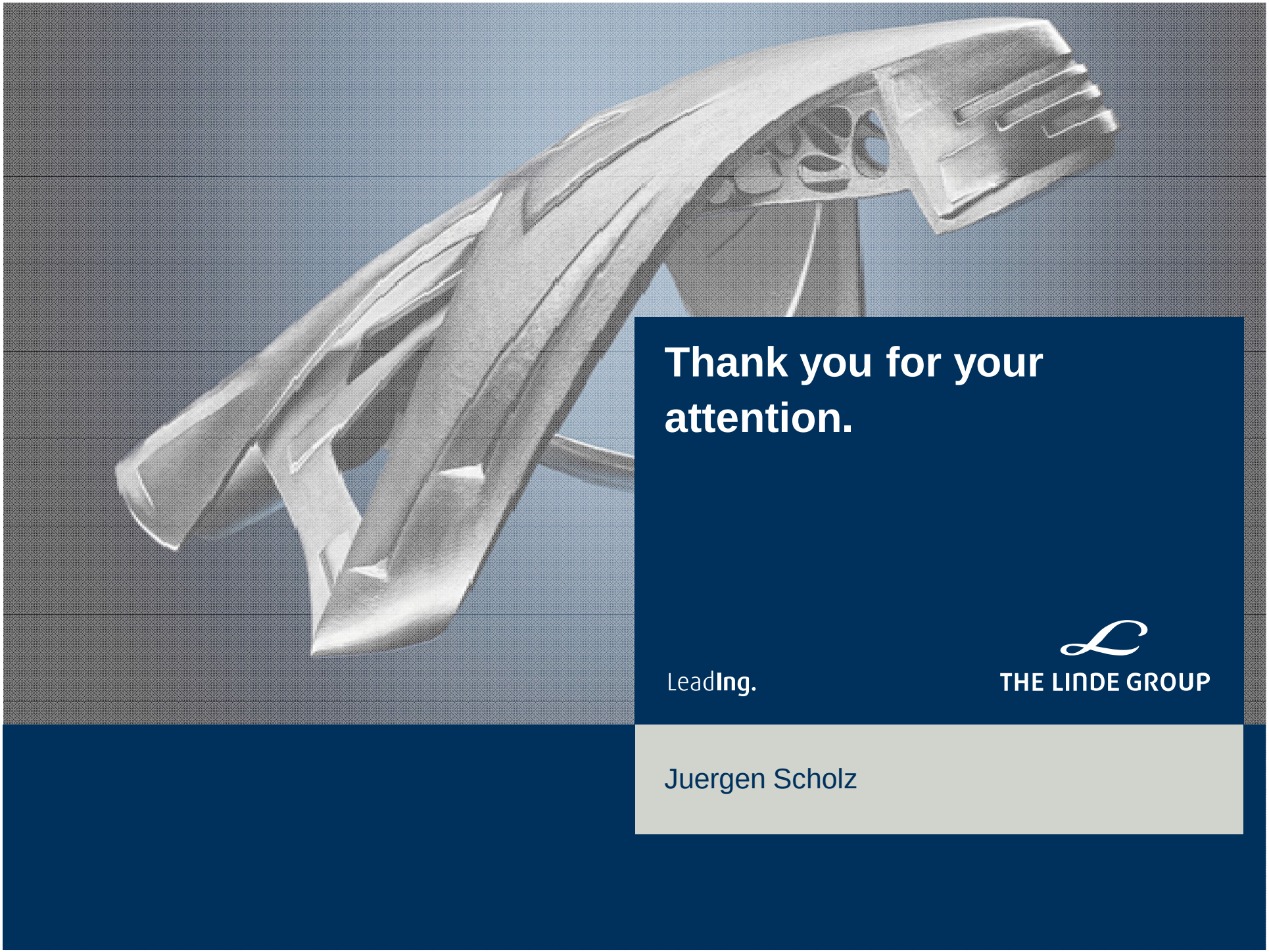
THE LINDE GROUP

The experiments show that:

- AlSiMg parts manufactured by AM for aerospace requires accurate process control to ensure very high product reliability
- the oxygen level inside the chamber plays a significant role on the fatigue mechanical properties of the final part
- the powder characteristics have a clear impact on the final product

Future work will focus on:

- investigating the correlation between oxygen and fatigue resistance of AlSiMg alloys
- optimizing the processing parameters for low O2 levels with assistance of Addvance™ O_2 Precision.



Thank you for your attention.

LeadIng.

THE LINDE GROUP

Juergen Scholz