

ON- AND OFF-LINE ULTRASONIC INSPECTIONS TO CHARACTERIZE COMPONENTS BUILT BY SLM ADDITIVE MANUFACTURING

Hans RIEDER¹, Martin SPIES¹, Joachim BAMBERG², Benjamin HENKEL²,
Hans-Uwe BARON²

¹ Fraunhofer-Institut für Zerstörungsfreie Prüfverfahren IZFP Campus E3 1, 66123
Saarbrücken, Germany; hans.rieder@izfp.fraunhofer.de

² MTU Aero Engines AG Dachauer Straße 665, 80995 München, Germany

Abstract

Additive manufacturing processes allow for the production of components by localized melting of successive layers of powder. Starting out from a CAD-representation of the part to be built additive manufacturing is particularly interesting for the production of geometrically complex aero engine components. In comparison with conventional, subtractive manufacturing such techniques provide considerably more freedom in designing. Additionally, this kind of manufacturing has a tremendous economic potential in view of saving resources.

Using Selective Laser Melting (SLM), sophisticated aero engine components have already been manufactured at MTU from the heat-resistant nickel alloy Inconel 718. For quality assurance, various on- and offline techniques are employed such as materials' science investigations (metallographic inquiries, tensile tests) as well as nondestructive inspections. Online measurements are performed using optical tomography and ultrasound.

We report on investigations in view of the influence of the process parameter 'laser power' on the microstructure of the manufactured component. It turned out that the online recorded A-scans allow inferring conclusions about the quality of the SLM process. To validate the ultrasonic results, metallographic and X-ray investigations have been performed. We report on recent experiments which have been performed to evaluate e.g. porosity. On the basis of the obtained results, we currently develop the concept of a 'smart', additively manufactured test block for online process control and offline materials characterization using ultrasound.

On- and Off-line Ultrasonic Inspections to Characterize Components Built by SLM Additive Manufacturing

7th International Symposium on NDT in Aerospace
Bremen, Germany - November 16-18, 2015

Hans Rieder*, Martin Spies*

Fraunhofer-Institut for Nondestructive Testing IZFP,
Campus E3 1, 66123 Saarbrücken

Joachim Bamberg, Benjamin Henkel, Hans-Uwe Baron

MTU Aero Engines AG, Dachauer Strasse 665, 80995 München

*Parts of this work have been elaborated at Fraunhofer ITWM, Kaiserslautern

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On- and Offline Ultrasonic Characterization of Components Build by SLM Additive Manufacturing

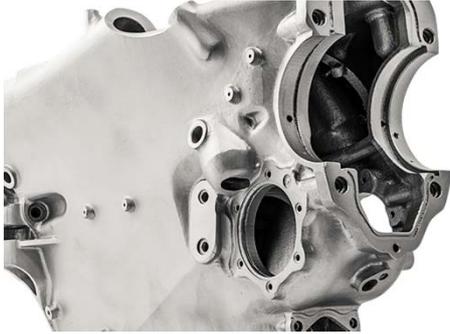
- Background
 - Selective Laser Melting
 - Ultrasonic monitoring on selected test specimens
 - Microstructure investigations
 - Outlook: smart SLM testblock
-

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Additive Manufacturing

- Rapid Prototyping: approx. 25 years of R&D
- Additive Manufacturing (AM) for the production of metallic parts: approx. 10 years



Gearbox

Source: FIT AG, Lupburg, Germany – www.pro-fit.de

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Additive Manufacturing

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- Additive Manufacturing (AM) for the production of metallic parts: approx. 10 years



Motorcycle frame

Source: FIT AG, Lupburg, Germany – www.pro-fit.de

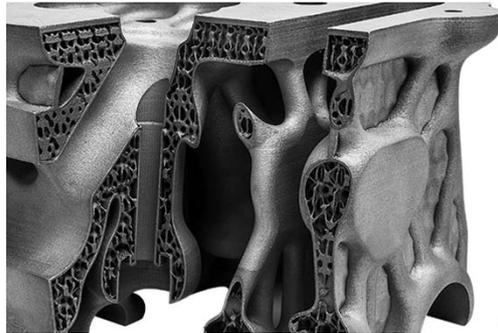
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Additive Manufacturing

- Rapid Prototyping: approx. 25 years of R&D
- Additive Manufacturing (AM) for the production of metallic parts: approx. 10 years



Cylinder head

Source: FIT AG, Lupburg, Germany - www.pro-fit.de

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Challenge in Today's Aviation

Fuel reduction

Weight reduction

Cost reduction



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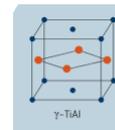


MTU-Approach

Innovative design ‚Fast rotating turbine‘



Innovative material TiAl-blades



Innovative production Additive Manufacturing



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Boroscope Bosses – First SLM-Produced Series Parts at MTU

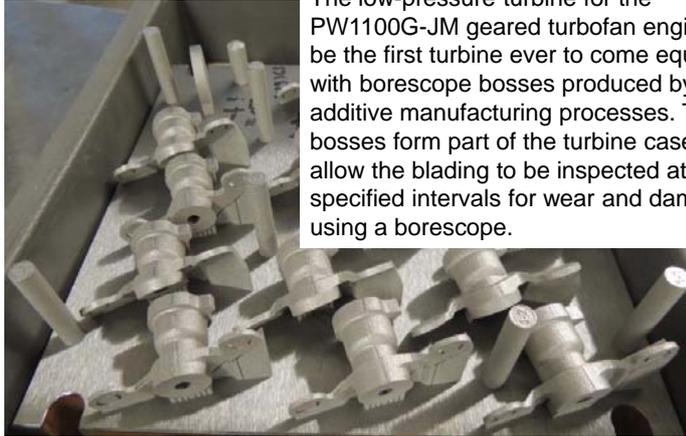


Platform with 16 boroscope bosses and tensile test specimens

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Boroscope Bosses – First SLM-Produced Series Parts at MTU



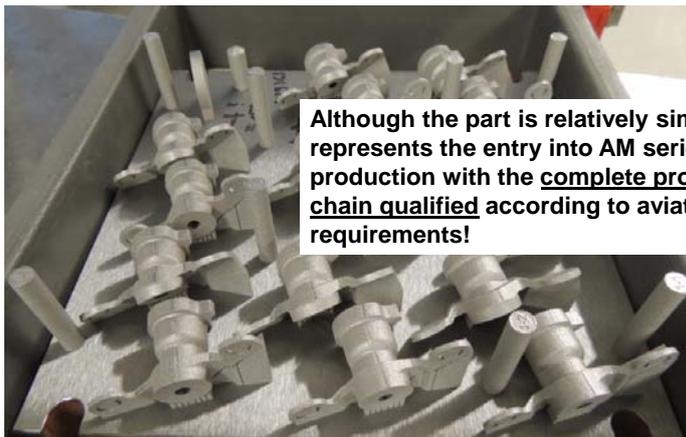
The low-pressure turbine for the PW1100G-JM geared turbfan engine will be the first turbine ever to come equipped with borescope bosses produced by additive manufacturing processes. The bosses form part of the turbine case and allow the blading to be inspected at specified intervals for wear and damage using a borescope.

Platform with 16 boroscope bosses and tensile test specimens

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Boroscope Bosses – First SLM-Produced Series Parts at MTU



Although the part is relatively simple, it represents the entry into AM series production with the complete process chain qualified according to aviation requirements!

Platform with 16 boroscope bosses and tensile test specimens

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Additive Manufacturing AM – Procedures and Quality Assurance

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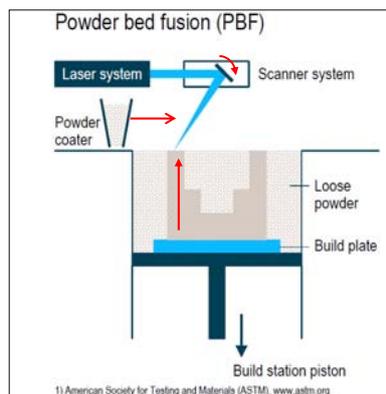


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Additive Manufacturing – (NOT) '3D-Printing'

- Powder bed fusion is the most frequently applied technique for 3D-printing of metallic objects
- Selective Laser Melting (SLM)



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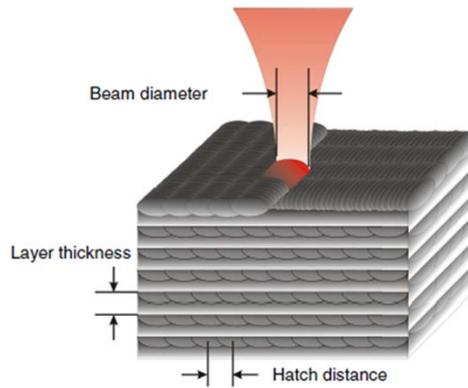
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Additive Manufacturing

■ Selective Laser Melting SLM

■ Principle

- 3D-CAD-Model
- Metal powder bed
- Layer-by-layer laser melting

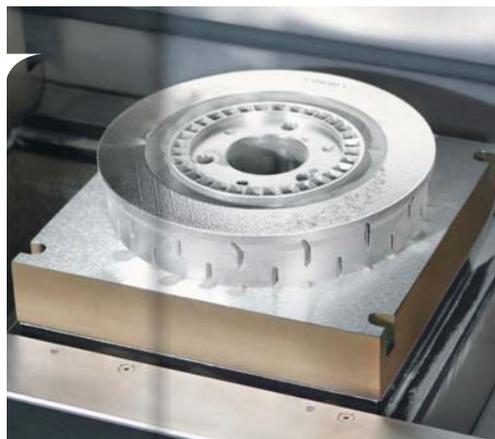


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Selective Laser Melting Process

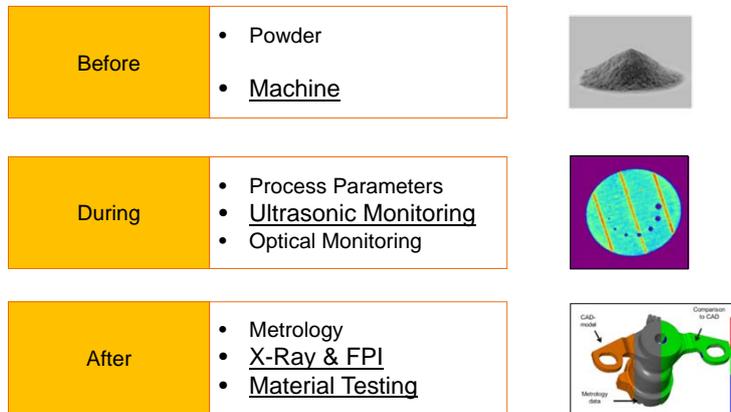


Final part on the platform →
Material: IN718

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Quality Assessment of the Complete Process Chain



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Ultrasonic Process Monitoring

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Monitoring Approach

- Monitoring during manufacturing process using ultrasound
 - Inspection from the lower side of the build-platform
 - Objectives: observation/surveillance of
 - Dynamics of the layer build-up
 - Interface coupling
 - Local material properties
 - Residual stresses/distortions
 - Porosity
- Only possible
,on-line'
during the
process!

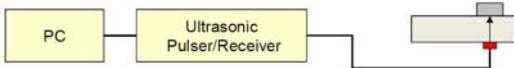
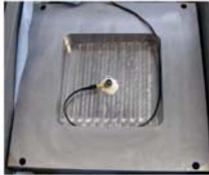
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Monitoring Set-Up

- **Problem: restrictions with respect to the installation of additional components in the build-chamber, specific ,environmental' conditions**
- Schematic set-up
- Sealed installation of the RF- and control cabling underneath the build-platform
- Transducer is fixed to the build-platform
 - 10 MHz probe, ¼ inch, unfocused
 - Grease coupling
 - Sensor glued

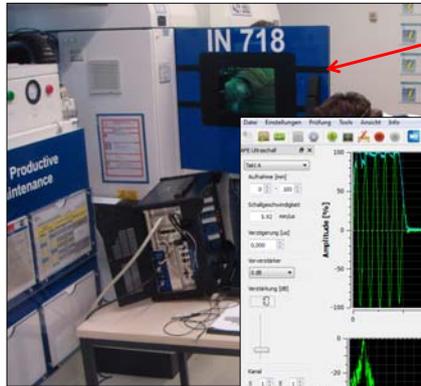
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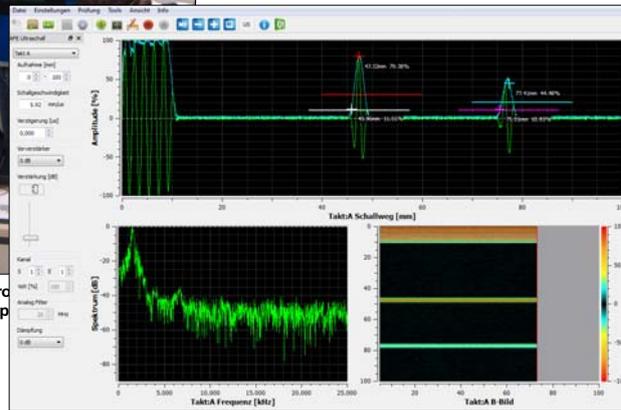


Monitoring Inspection System – Integration and Test



Build-chamber open:
pre-job arrangements

Manufacturing lab @ MTU Aero
Integration and test of the insp



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Demo: Build-Job and Ultrasonic Signals

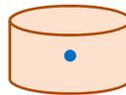
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Built-Up Test Part

- **Cylinder with interior defect:**

- 20 mm diameter
- 10 mm height
- pore (spherical, 2 mm Ø)



- **Build-job:**

- 40 µm layer thickness
- 250 layers
- 90 minutes build-up time

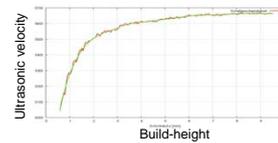
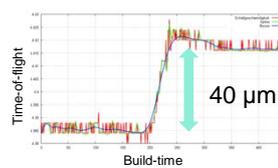


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Results

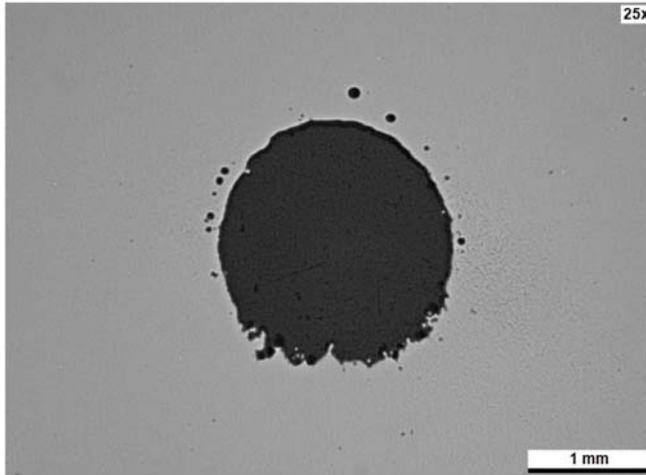
- Single layer fusion resolved, build-up continuously monitored
- Local ultrasound velocity determined
- Real-time detection of artificial defects



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Metallography – Spherical Pore



Microsection No.:
Specimen 1

Etchant:
No etchant

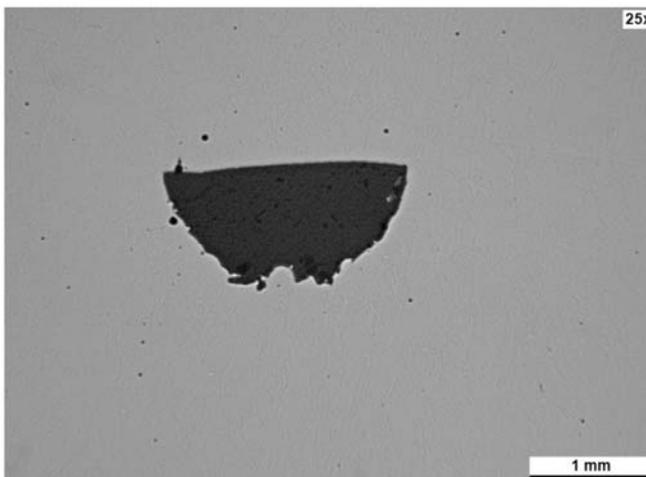
Remark:
Specimen with cavity

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Metallography – Half-Sphere – Circular Disk Reflector



Microsection No.:
Specimen 2

Etchant:
No etchant

Remark:
Cavity

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Investigation of the Influence of Laser Power on the Microstructure Development

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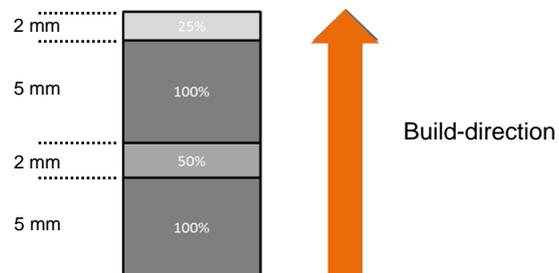


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Test Specimen – Variation of Laser Power

Build-up height	Laser Power
0 mm – 5 mm	285 W (100%)
5 mm – 7 mm	150 W (50%)
7 mm – 12 mm	285 W (100%)
12 mm – 14 mm	75 W (25%)



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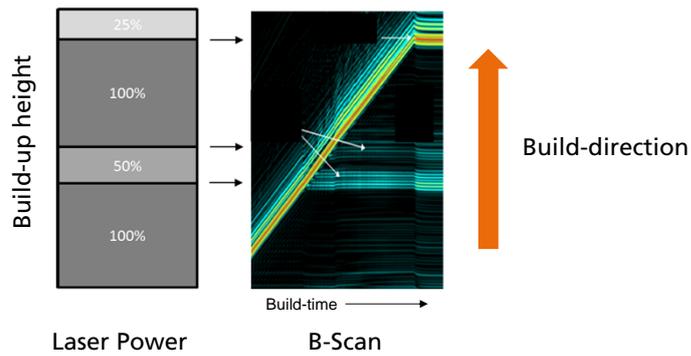


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B-Scan and Event Correlation

100 A-Scans/s * 60 seconds * 90 minutes = 540.000 A-Scans



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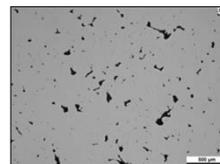


Validation

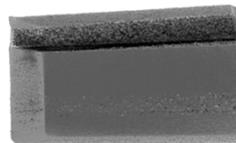


Examined specimens after removal
from platform

Metallography



X-Ray-CT



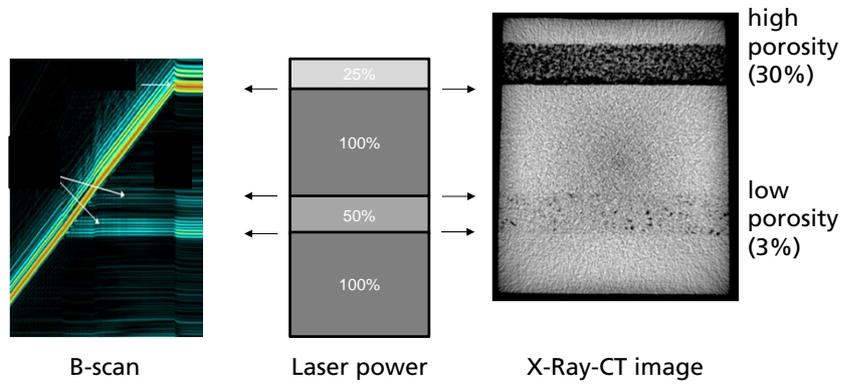
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Validation II

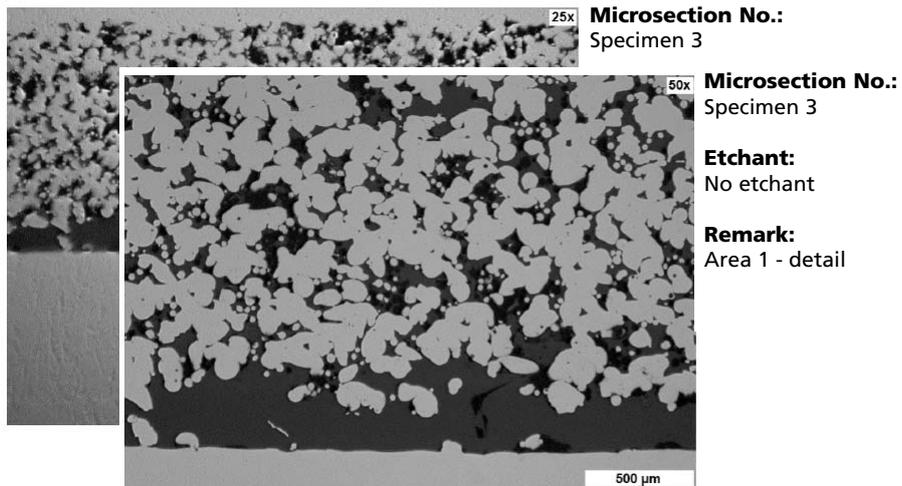


Ultrasonic online detection of low porosity (< 3%) is possible.

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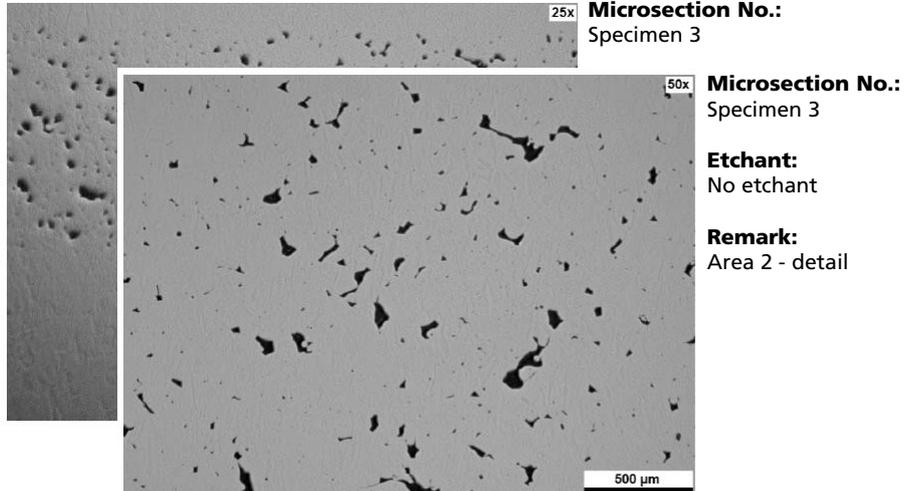
Metallography - Unetched



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Metallography - Unetched

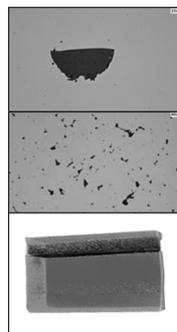


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Validation III

- UT monitoring referring to metallographic and X-Ray-CT results



Artificial defects: < 3 mm²



Porosity (metallogr.): < 3 %



Porosity (X-Ray-CT): < 100 µm axial resolution in build-up direction



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Lessons Learnt – How to Proceed?

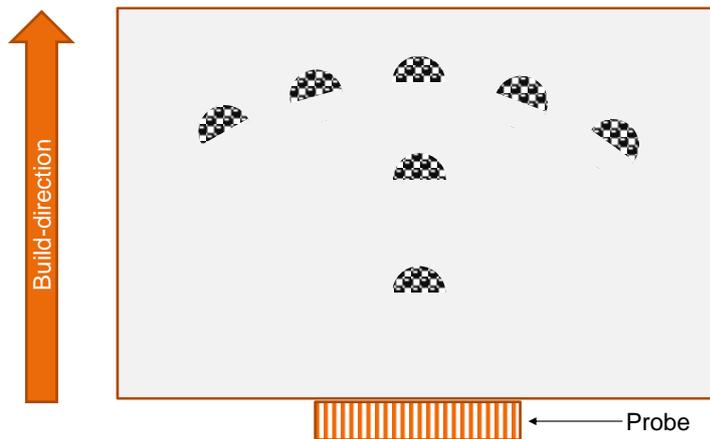
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SLM-Testblock with Semi-Spherical Reflectors



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Smart SLM-Testblock

Online-Testing

- Permanent measurement of sound velocities / determination of incremental sound velocity
- Measurement of the reflector amplitudes (relative to current backwall)
- Conclusions in view of microstructural homogeneity and local micro-porosity

Offline-Testing (e.g. with linear array)

- Sector scan -> information about anisotropy and texture
- Further: bi-axial testblock -> information about full 3D-texture



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Summary

- **Online surveillance using ultrasound** thru build-platform is feasible
- Observation of **surface dynamics** (backwall) during build-up is possible
- Characterization of material properties **layer-by-layer**
- Quantitative statements concerning **porosity** possible
- Fabrication of **test reflectors/model defects** (CDR)

Outlook

- Ultrasonic monitoring for control and reference procedures
- Surveillance using control specimens
- **Control of build-chamber!**

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