BAM
Bundesanstalt für Materialforschung und -prüfung

Sicherheit in Technik und Chemie

07/03/2024

Towards component safety in laser powder bed fusion of metals

Dr.-Ing. Gunther Mohr

www.bam.de

Science with impact in Berlin since 1871

Prussian Royal
Laboratory for
Mechanical Testing

Fabeckstraße
Branch

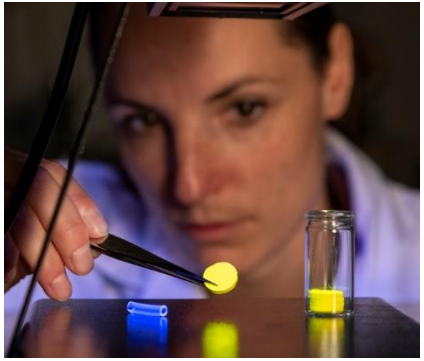
Adlershof Branch

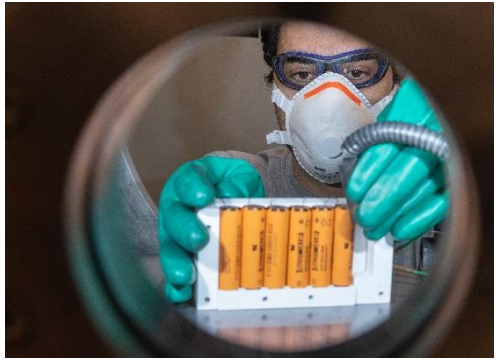
Lichterfelde Headquarters

Test Site for Technical
Safety, Horstwalde

Our mission:
safety in technology and chemistry

Federal Ministry
for Economic Affairs
and Climate Action





Our main areas of work and research

FOCUS AREA
ENERGY

FOCUS AREA
INFRASTRUCTURE

FOCUS AREA
ENVIRONMENT

FOCUS AREA
MATERIALS

FOCUS AREA
CHEMISTRY AND
PROCESS ENGINEERING

Some Figures

- Staff: **1550** employees
- Organization: **11** departments, **75** divisions and sections
- Budget (in Mio. EUR): **171** basic funding, **19** third-party funding, **9** services

As at: 12/2023

Competence Center AM@BAM

- Broad range of services along the additive process chain
- **Interdisciplinary cooperation of various expert groups**
- Further development of AM processes and testing concepts
- Focus on metals, ceramics and concrete
- Various third-party-funded projects & cooperations with external partners

- **AM excellence for safe industrial applications**

FOCUS AREA MATERIALS

PBF-LB/M and peripherical equipment in Div. 9.6

EOS M300-4

SLM Solutions 280HL

3D Scanner

Heat Treatment

Aconity3D Midi+

Pulsed laser for surface treatment

Thermography

Metallography/REM/BSE/EDX

Mechanical testing

RS analysis

HCF/LCF/ Creep

Surface metrology

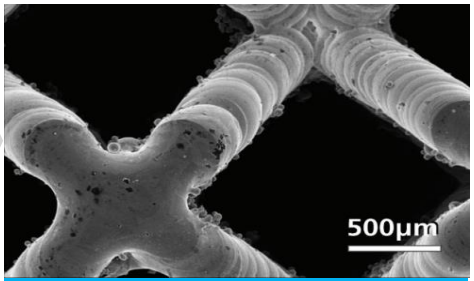
Computed tomography

Advanced thermography

How to ensure safety of AM components? R&D approach of Div. 9.6

PBF-LB/M-Process

Complex relationship of material, geometry, process, microstructure, defects and resulting properties



Material properties

- Adapted process strategies for desired properties
- Design and testing concepts for safety-relevant components
- Quality assurance through sophisticated multi-sensor process monitoring and documentation
- Understanding of defect mechanisms and their avoidance

Towards component safety
- On the concept of representative test specimens

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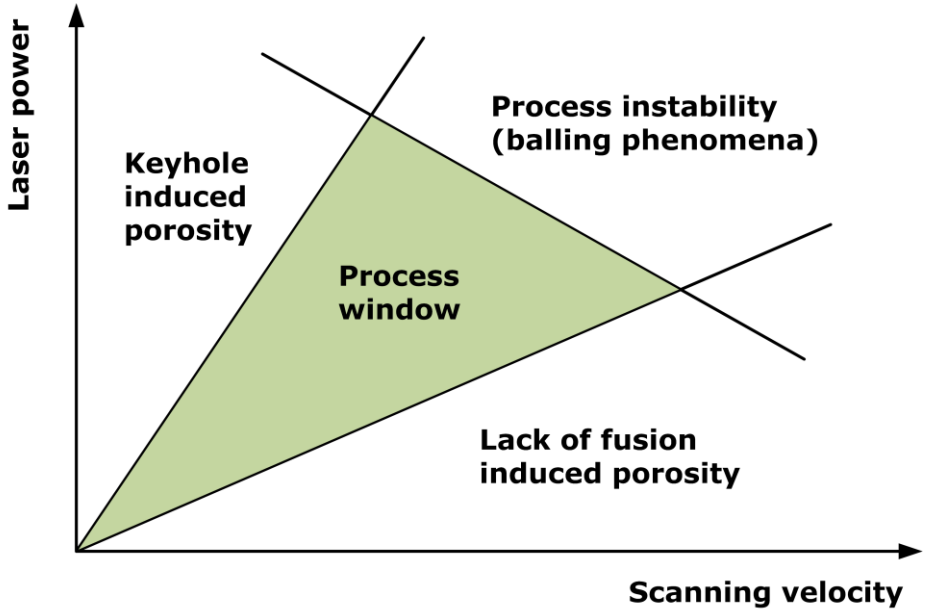
Challenges to overcome in PBF-LB/M

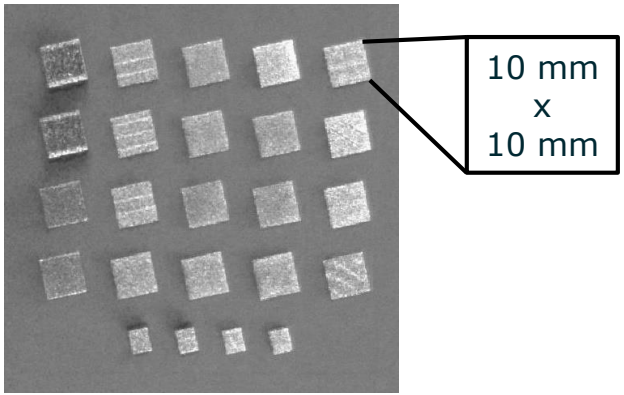
Excerpt:

- Variations in thermal history of part manufacture
- Unexpected and unpredicted local inhomogeneities impede use of PBF-LB/M in safety critical applications
- Lack of knowledge regarding the complex relationship between process, structure, and resulting properties
- Lack of reliable reference data

Process window determination – state of the art

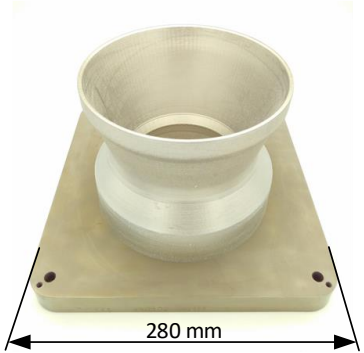


Parameter optimisation by batch production of „density cubes“



Small and simply shaped test coupons are used to determine the material and machine specific process parameters.

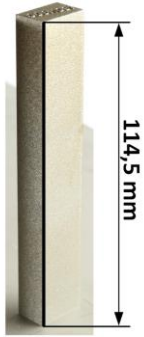
Real component vs. test coupon – Comparability?



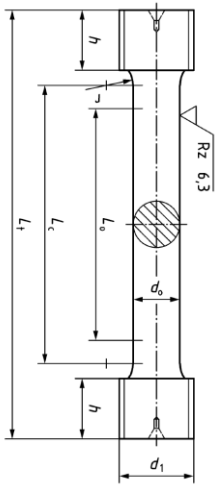
Gas turbine pilot cone,
Siemens Energy

Pressure vessel,
BASF

?



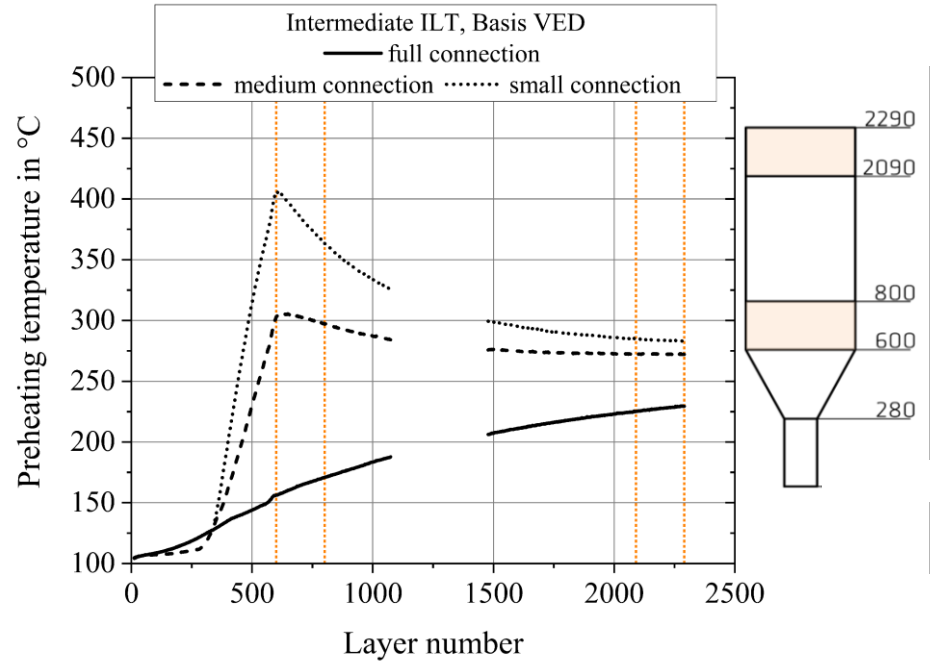
Testing rod



[DIN 50125]

Do constant process parameters for specimen production sufficiently consider complex thermal history of real components? → No, they do not.

Heat accumulation due to geometry variation



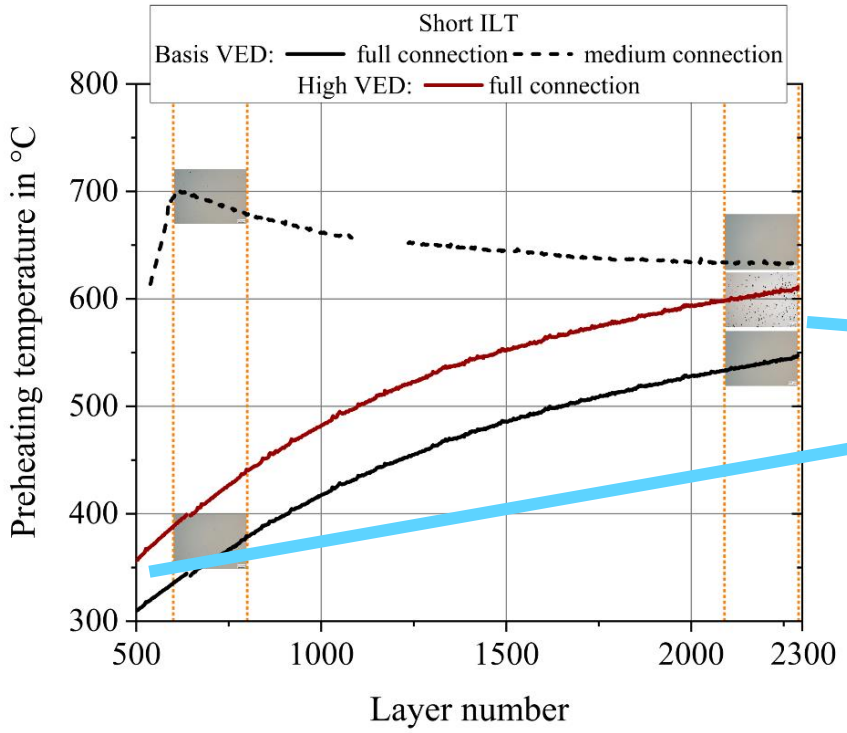
[JLA 2023, doi: 10.2351/7.0001080]

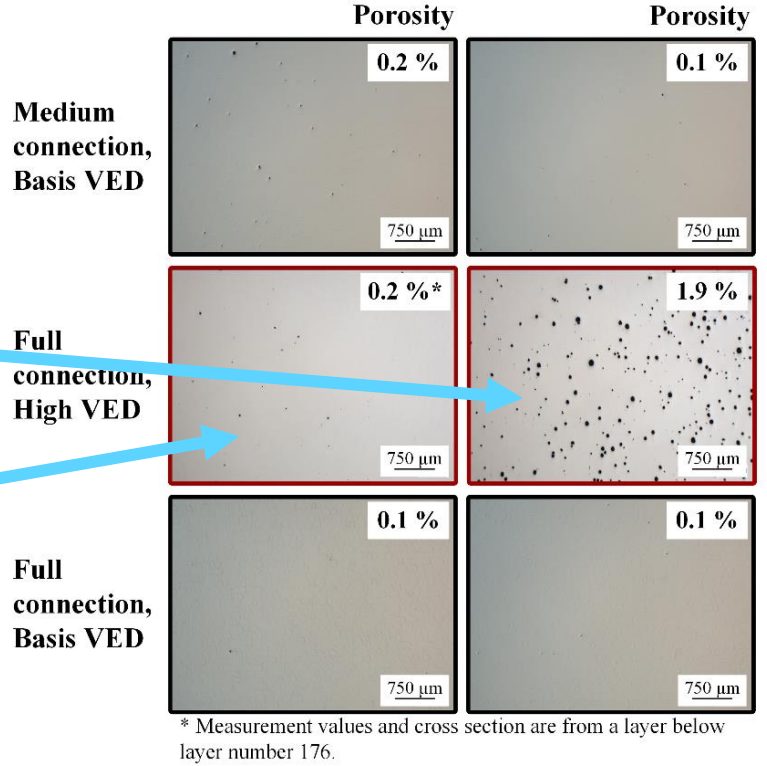
- Significant heat accumulation over height
- Significant temperature increase in frustum elements
- Successive reduction and levelling in growing part

Further geometry and process related factors can increase the accumulation of heat, e.g. short inter layer times (ILT).

Effects of heat accumulation on part density

[JLA 2023, doi: 10.2351/7.0001080]





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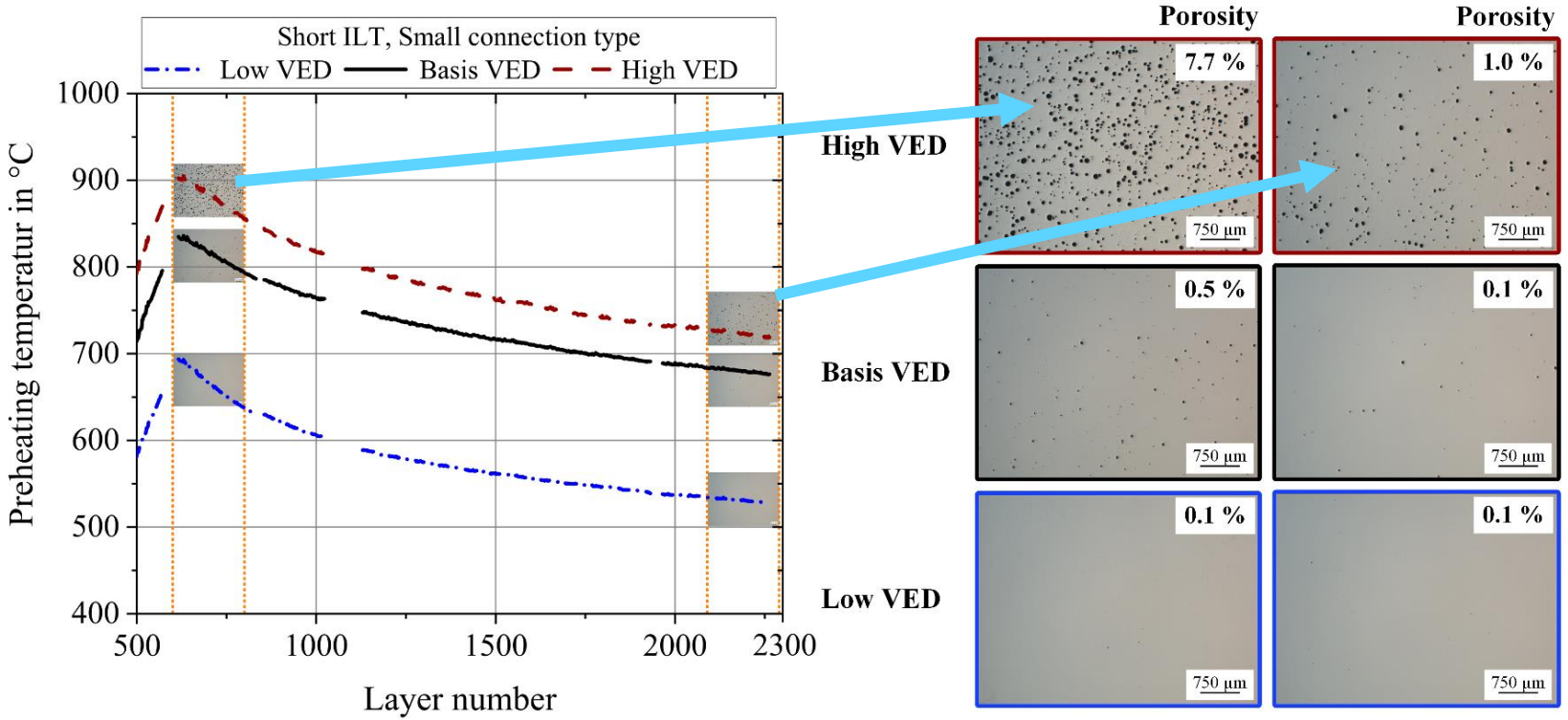
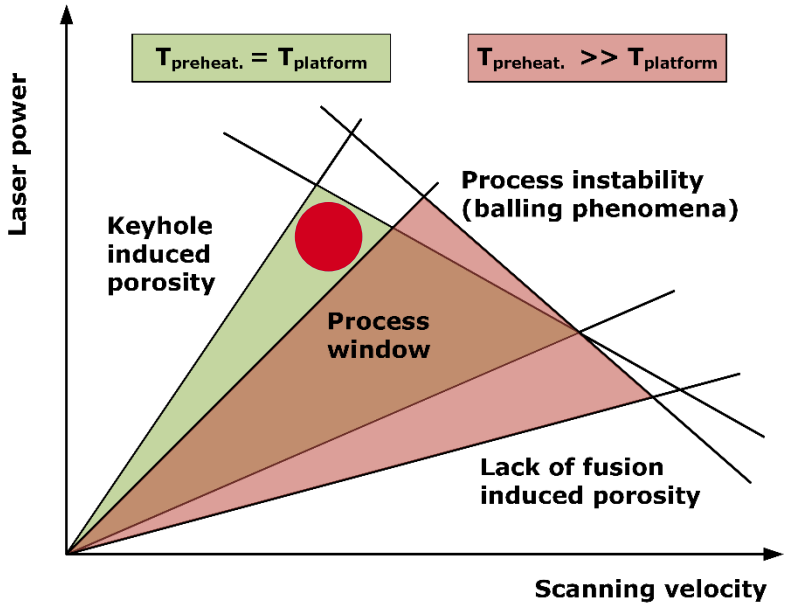


[JLA 2023, doi: 10.2351/7.0001080]

Effects of heat accumulation on process window



[JLA 2023, doi: 10.2351/7.0001080]

Process intrinsic heat accumulation can induce shifts of the process window towards unstable melting conditions.

Effects on:

- porosity
- microstructure
- mechanical properties

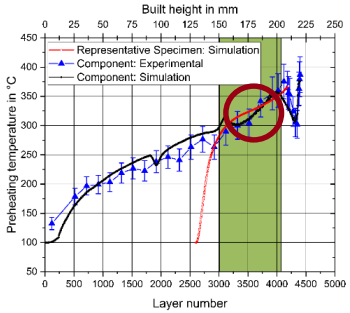
→ [Metals 2021, doi: 10.3390/met11071063]

Thermal variations must be incorporated into built process assessment! → Transfer them to test specimens.

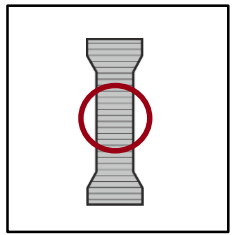
Process- und test specimen development: Representative test specimens

Development of a fracture-mechanical design concept for AM components by determining material characteristics on representative test specimens

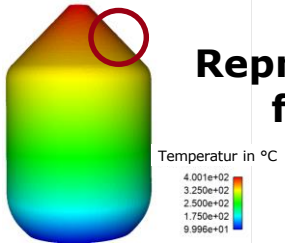
Complex AM component



Validation of temperature transfer through in-situ thermography



Representative test specimen for mechancial testing



FEM macro scale thermal simulation + transfer of temperature field on specimen geometry

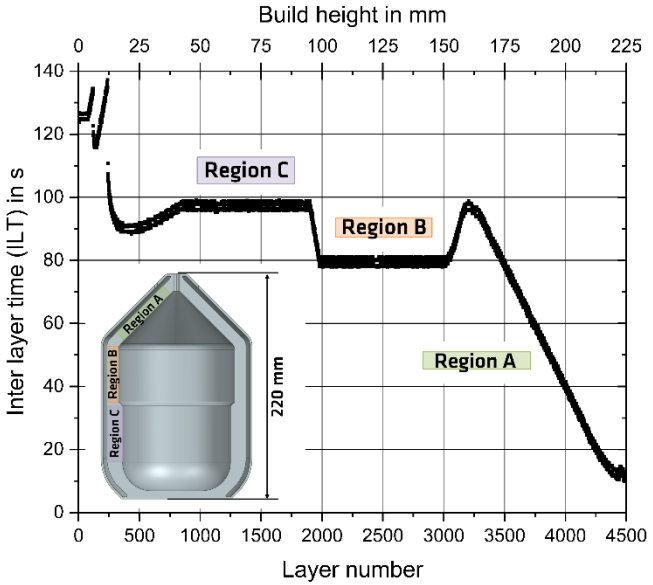
○ Region of interest

In cooperation with BASF We create chemistry

Complex AM component: Pressure vessel from chemical industry, material AISI 316L

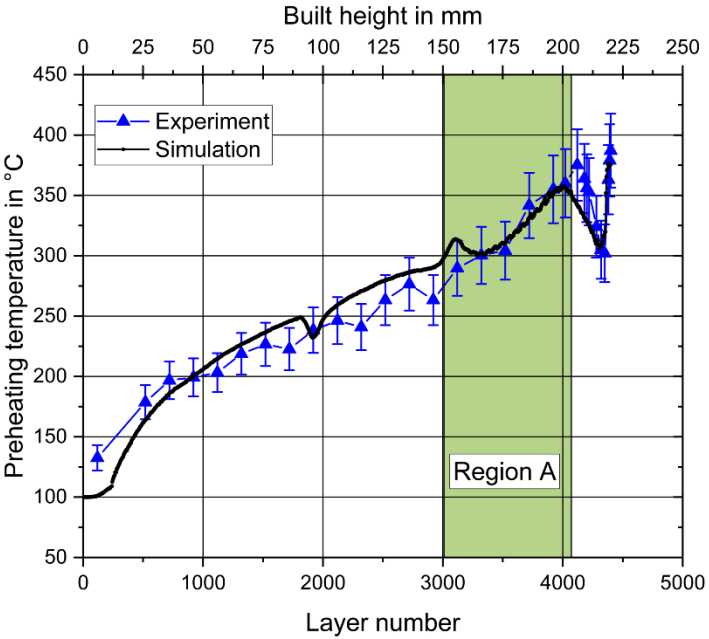
[Submitted to PIAM]

- Double walled component
- Variations of wall thickness and cross sections

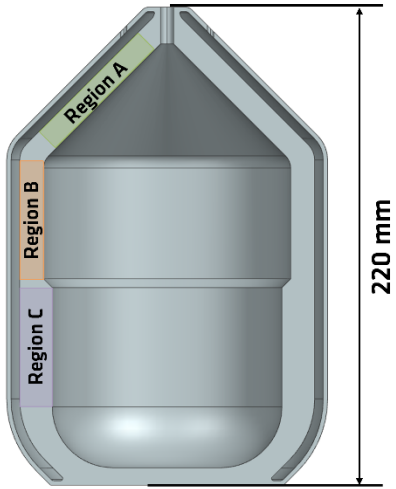


- Variations of inter layer time over build height

Intrinsic preheating temperature calculated by FEM macro scale thermal simulation



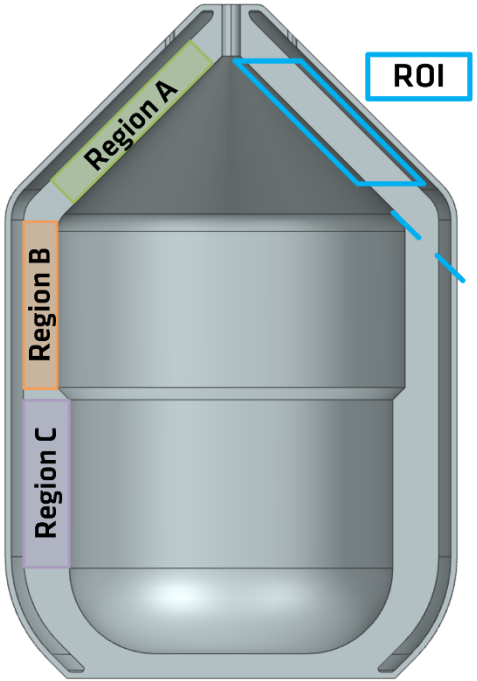
[Submitted to PIAM]



Comparison of simulated layer temperatures and experimentally measured layer temperatures

- Good agreement between model and experiment
- Significant variations of temperature with respect to geometry and build height

Thermal history transfer from component to representative test specimen



ROI

Parameters kept:

- laser power
- scanning velocity
- hatch distance
- scanning pattern and rotation
- build-up angle

Adapted parameters:

- inter layer time

Transfer of $T_{0,ROI}$ from start layer of the ROI to upmost base segment layer

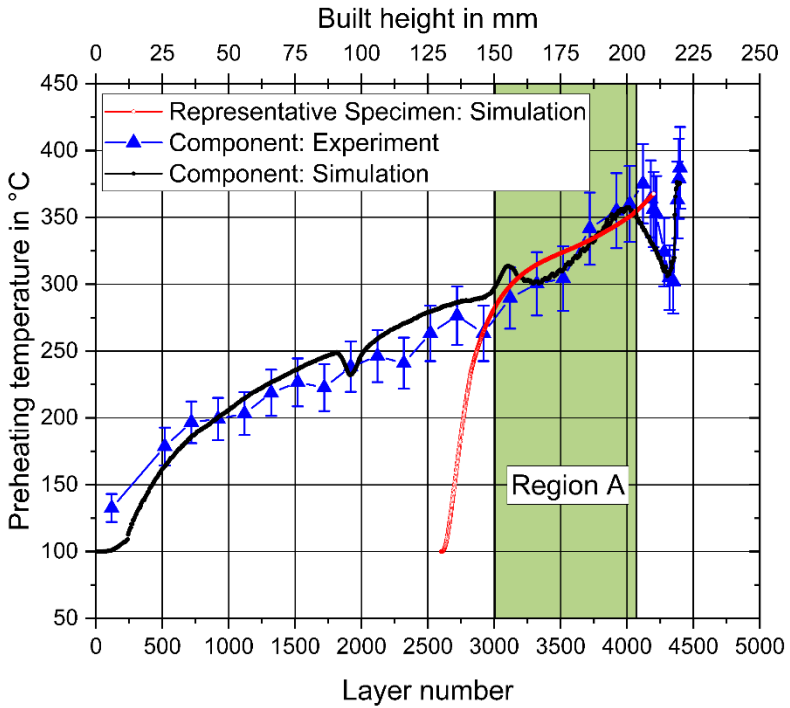
representative segment

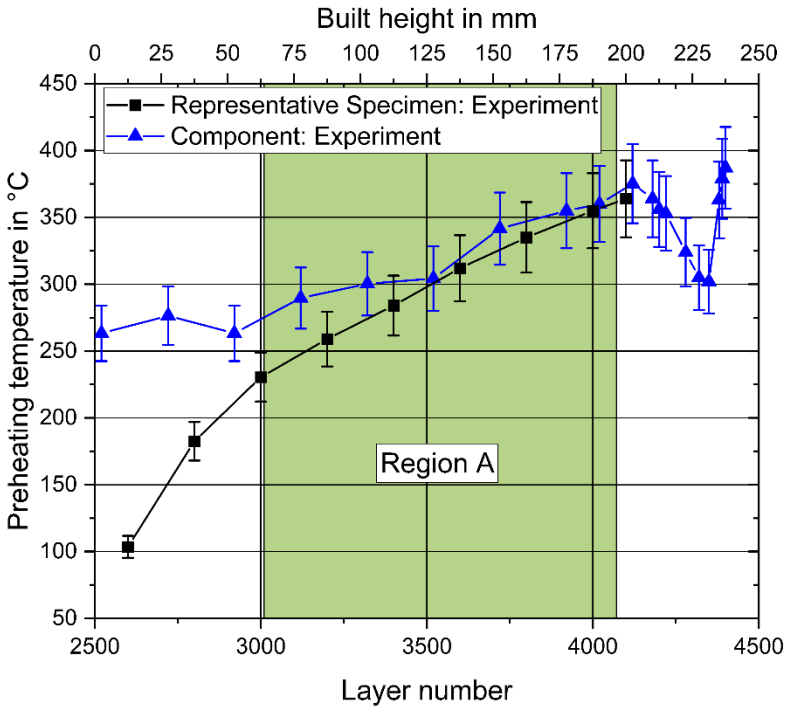
base segment

[Submitted to PIAM]

Thermal history transfer from component to representative test specimen

[Submitted to PIAM]





Conclusions and outlook

Introduction of representative test specimens

- Awareness of easily overseen infuencing factors such as ILT
- Process adapting strategy without changing the key parameters
- Successfully proved thermal transfer from component to test specimen on macro scale

What is next?

- Comparative mechanical testing (LCF ongoing)
- Transfer to smaller structures

+ Enhancing safety through standardised data collection and data management

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Thank you for your attention and be invited to collaborate with us on the journey to safety.

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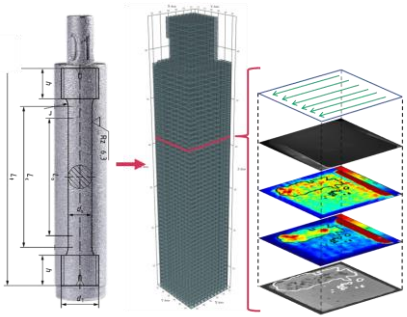
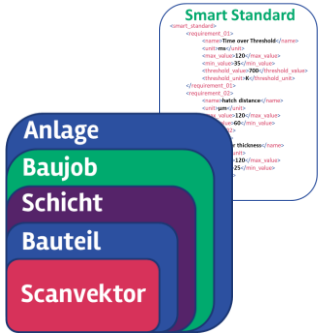
Projektaufruf: Digitale Qualitätssicherung

Datenmanagement und qualitätsrelevante Merkmale

Maschinen-, Bauteil- und Monitoringdaten



Ableiten von Prozess-anforderungen



Automatisierte Erfassung aller wesentlichen Prozessdaten mittels ETL-Datenpipeline

Registrierung und Analyse der Daten und Identifikation qualitätsrelevanter Prozessmerkmale

Anwendung von Smartstandard mit Kriterien zur Bewertung der Prozessqualität

Ziele des Projektes:

- Identifikation, Bereitstellung und Registrierung qualitätsrelevanter Prozessdaten
- Entwicklung einheitlicher Datenspeicherung → Normentwurf auf ISO-Ebene eingebracht
- Entwicklung einer vollumfänglichen digitalen Laufkarte
- Erarbeitung eines Entwurfes für AM spezifischen Digitalen Produktpass (DPP)

Projektantrag - Digitale Qualitätssicherung in der additiven Fertigung

Bedarfe

- Keine durchgängige digitale Prozess- und Bauteil-dokumentation zur QS
- Unzureichende Auswertung der anfallenden Daten-mengen
- Fehlende digitale Verfahren zur Zulassung, Zertifizierung und Normung

Motivation/Ziele

Entwicklung und Erprobung einer **digitalen Laufkarte** entlang der AM-Prozesskette

- konform zu ISO/ASTM 52920 und ASTM F3490 (CDEF – Common Data Exchange Format)

Entwicklung und Erprobung von Datenerhebungs- und Analyseverfahren

- Gesteigerte Automatisierung entlang der gesamten Prozesskette

Erprobung der digitalen Laufkarte im Rahmen einer digitalen Zertifizierung im Netzwerk **Quality-X**

- Datengrundlage für den Digitalen Produktpass (DPP)
- Verknüpfung Normungsaktivitäten (AM ←→ DPP)

Nutzen

- Bündelung aller QS-, zulassungs- und normungsrelevanten Daten
- Schnelle und digitale Qualitätsprüfung additiv gefertigter Komponenten

Entwicklung eines digitalen Produktpasses für AM-Komponenten

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Contact

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