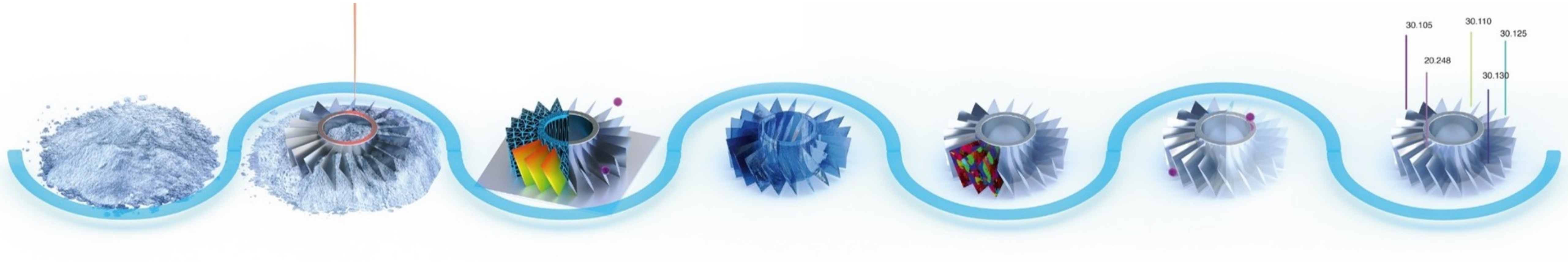
ZEISS Connected quality solutions:
Addressing the production-scale challenges using the laboratory-scale insights



Dr. Pradeep Bhattad (pradeep.bhattad@zeiss.com)

ZEISS AM Characterization Center, ORNL-MDF, Knoxville, TN

ZEISS Industrial Quality & Research

Portfolio
Shaping the Future - ZEISS Segments

Semiconductor Manufacturing Technology

Industrial Quality & Research

Medical Technology

Consumer Markets

Strategic Business Units

- Semiconductor Manufacturing Technology:
  - Semiconductor Manufacturing Optics
  - Semiconductor Manufacturing Mask Solutions
  - Process Control Solutions
- Industrial Quality & Research:
  - Industrial Quality Solutions
  - Research Microscopy Solutions
- Medical Technology:
  - Microsurgery
  - Ophthalmic Devices
- Consumer Markets:
  - Vision Care
  - Consumer Products

Facts

ZEISS Worldwide

Employees

31,260

Locations worldwide

100

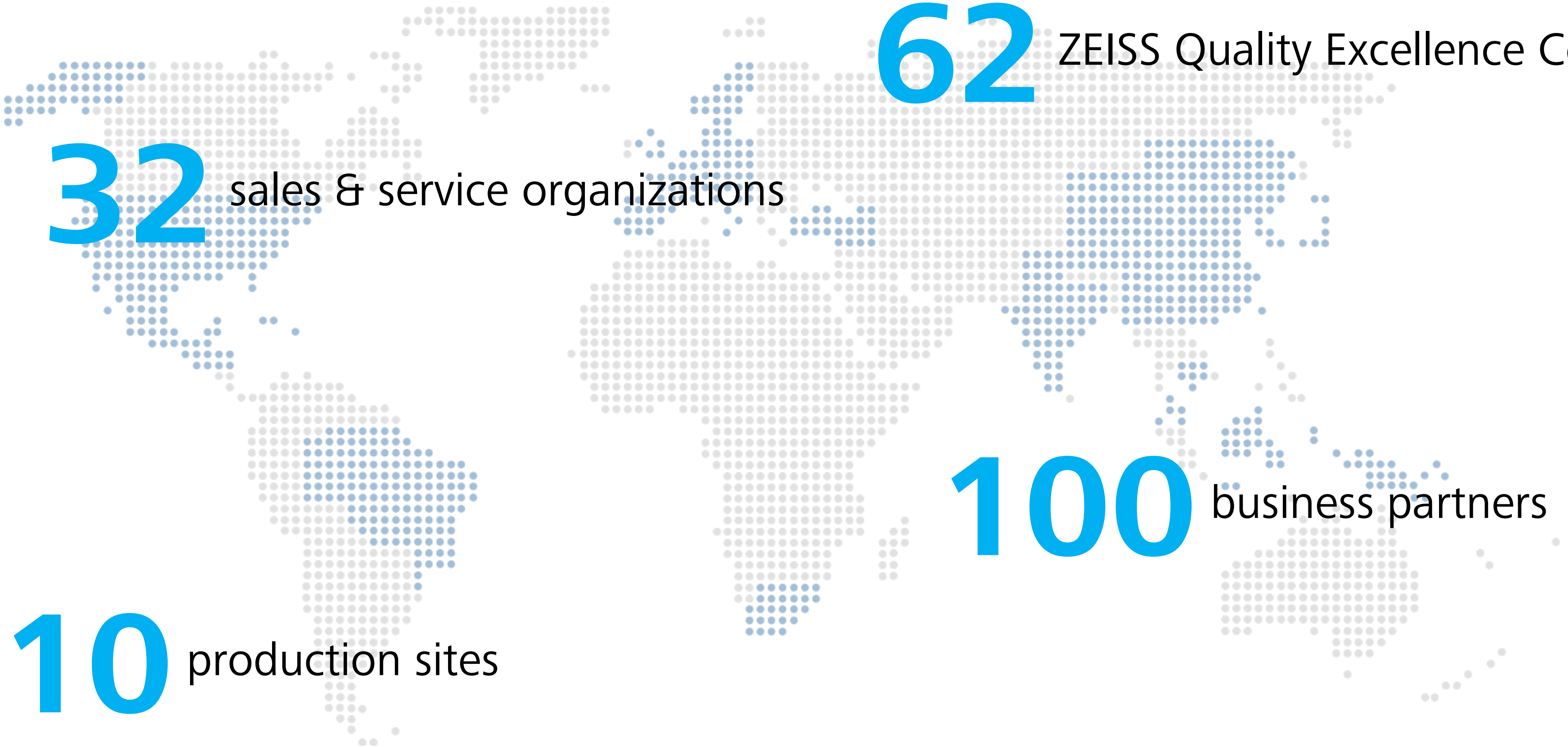
Countries

50

Headquarters:
Oberkochen, Germany

ZEISS – your global partner

Close to the customer – worldwide



62 ZEISS Quality Excellence Centers

32 sales & service organizations

100 business partners

10 production sites

ZEISS – Careers

https://www.zeiss.com/corporate/int/careers.html

We want you!

Your career – your future at ZEISS

You are a team player with an innovative spirit. An expert with real depth. You want to share your knowledge and gather as much experience as possible. You want to excel in your job and make your mark.

With your motivation and passion, you'll fit right in at ZEISS!

We're looking for people who are empathetic and passionate, who are committed to achieving their goals, and who get excited about challenging topics. People who deliver top performance and push the limits of what's possible. Who always strive to develop, accept responsibility, and take society into the future. As part of the global ZEISS team.

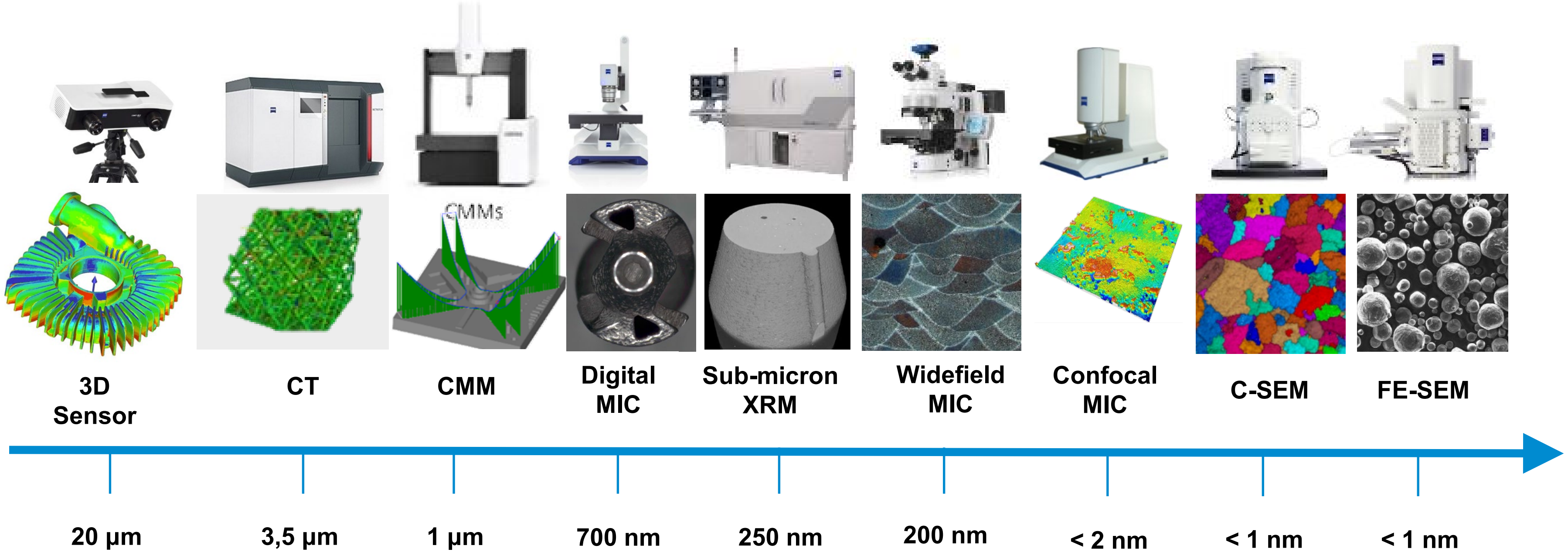
ZEISS Global Graduate Program

Setting things in motion as a team

Read more

ZEISS Solution Portfolio for AM

Industry Leading Quality Control Portfolio from µm to nm



Geometry

- Outer dimensions
- Inner dimensions
- Surface Roughness

→

Microstructure

- Cracks
- Pores
- Inclusions
- Grains

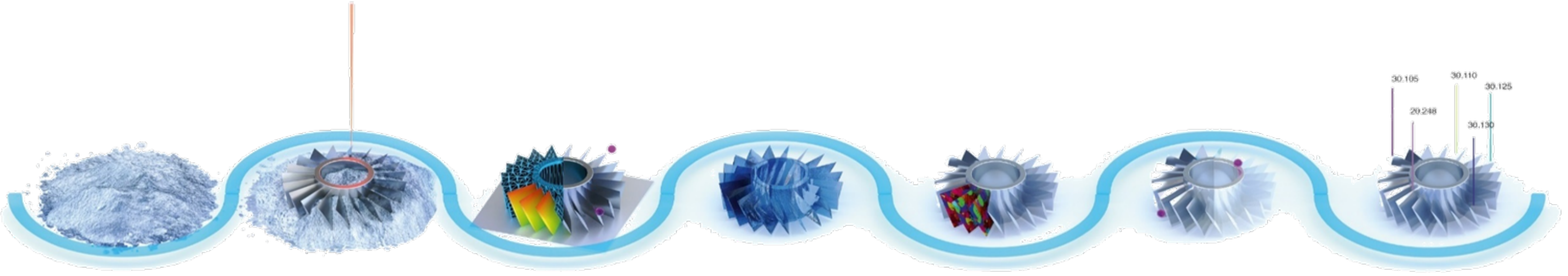
→

Material

- Defect Characterization
- Powder Quality

ZEISS Blue Line

The holistic integrated process for Additive Manufacturing



Process step	Methods
Powder and Material Characterization	SEM, LM, X-ray CT
In-Process Metrology and Data Analysis	Powder Bed Inspection
Post-Print Heat Treatment and Part Removal	CMM, 3D Scanning
Defect and Inner Structure Inspection	X-ray CT, LM
Post-Print Material Quality Inspection	SEM, LM, X-ray CT
Dimensional and Surface Quality Inspection	CMM, X-ray CT, 3D Scanning, LM
Process Data Statistics and Analytics	PiWeb, Analytics and Correlation Tools

Light Microscopy (LM)

Scanning electron microscopy (SEM)

In-process monitoring

Computer tomography & X-Ray microscopy

High precision measurement with CMM

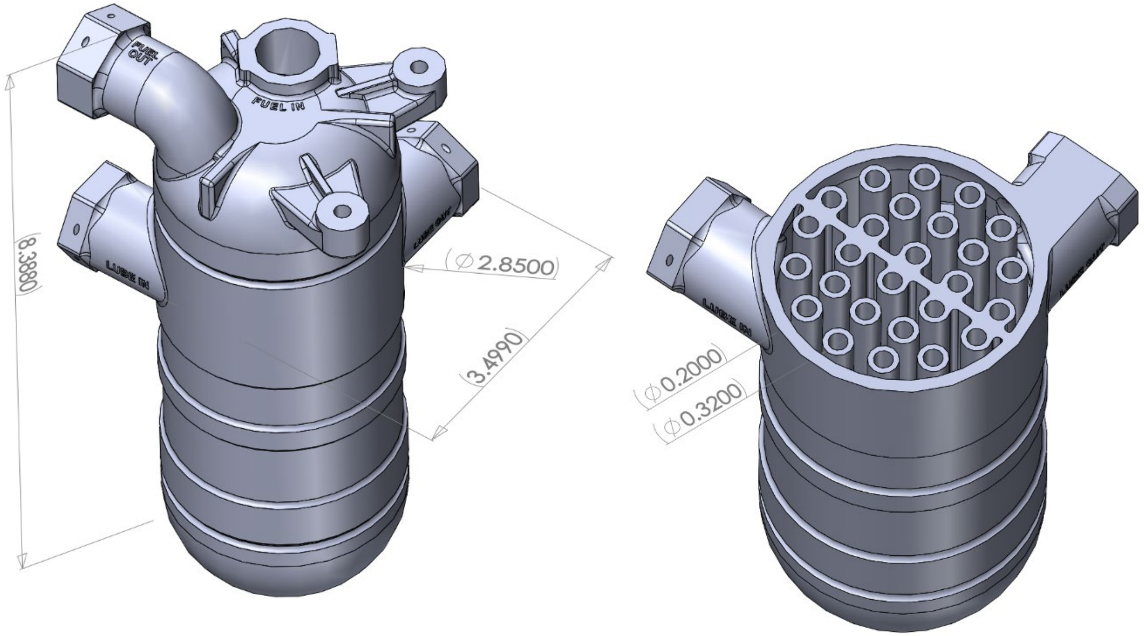
3D scanning

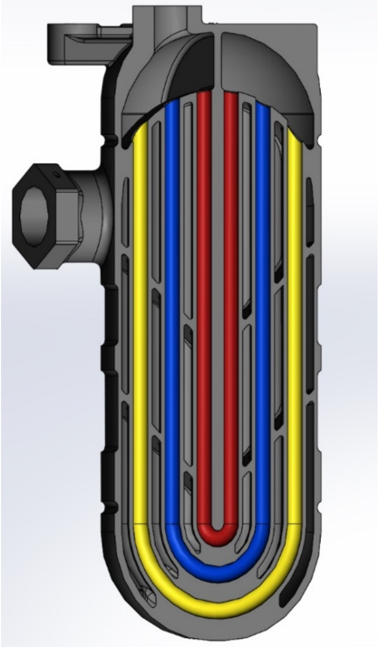
Metrology & analysis software

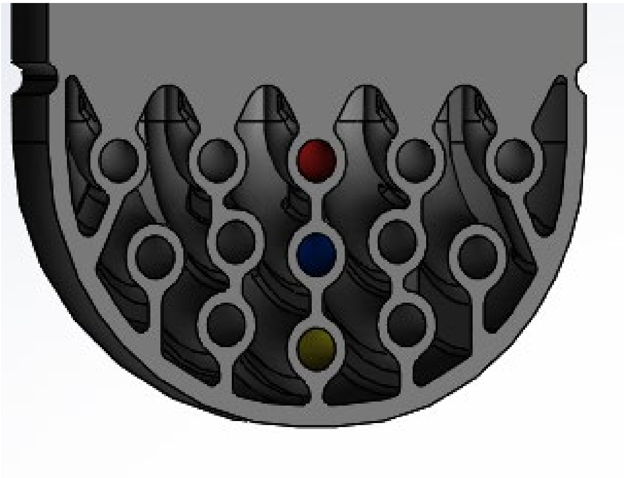
Case Study

AM Heat exchanger for Air Force Sustainment

- Fuel cooled oil coolers (FCOC) are utilized on nearly every powerplant in the DoD fleet for cooling of turbine oil and pre-heating fuel. These heat exchangers have become a sustainment problem due to high replacement part cost, long lead times, and ever- increasing replacement volume due to the number of aging powerplants.
- As part of an ongoing America Makes program UDRI and team are seeking to enable AM replacement of these oil coolers







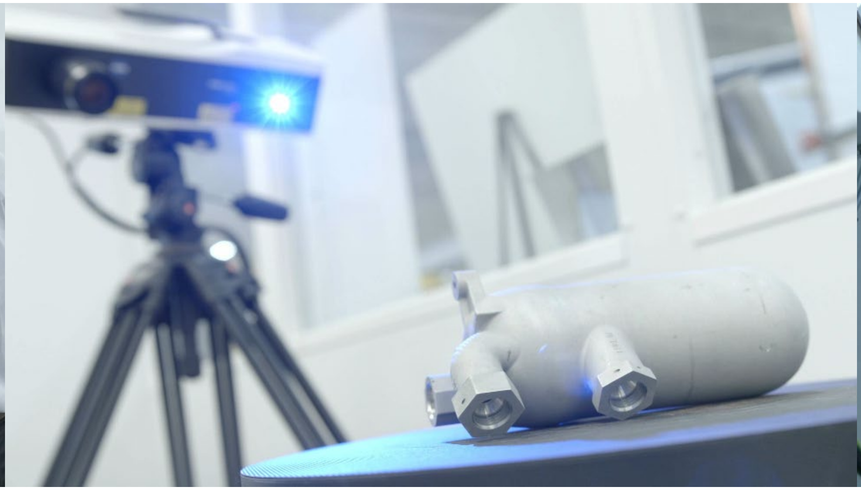
Fabrication

Correlative Measurement on Heat Exchanger

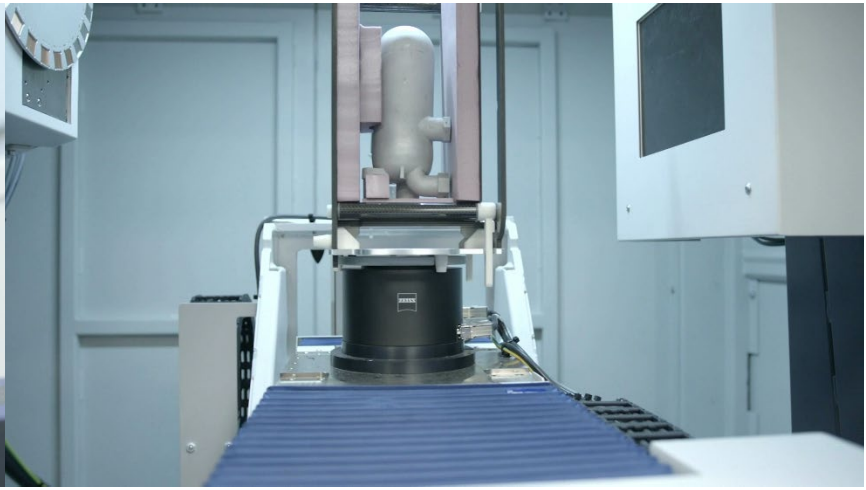
ZEISS AM Characterization Center

CMM (Duramax)

3D Scanner (GOM Scan1)



X-ray CT (Metrotom 800 HR)



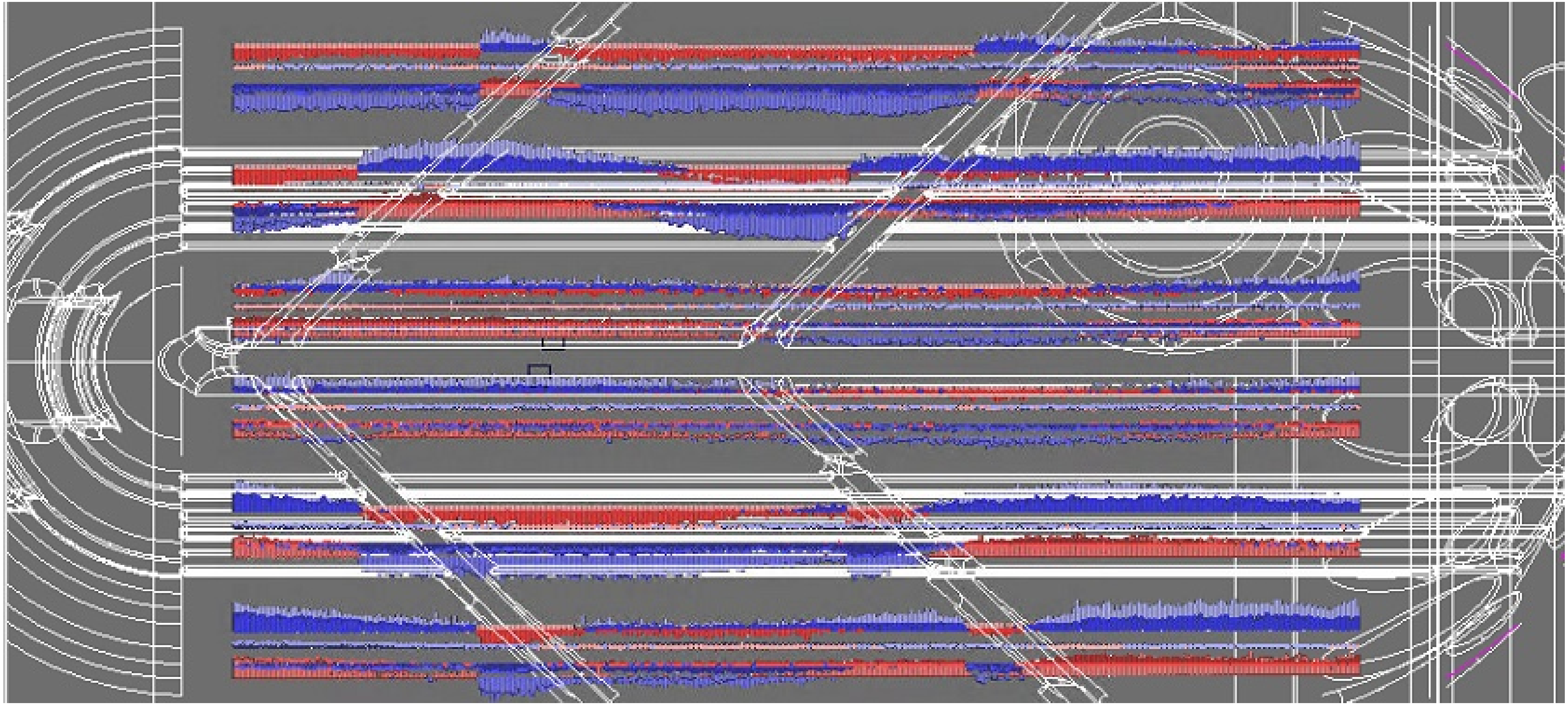
Micro-CT (Versa 620)

Light Microscope (Axio Imager & Smartproof)

SEM (Evo 15 & Crossbeam 550)

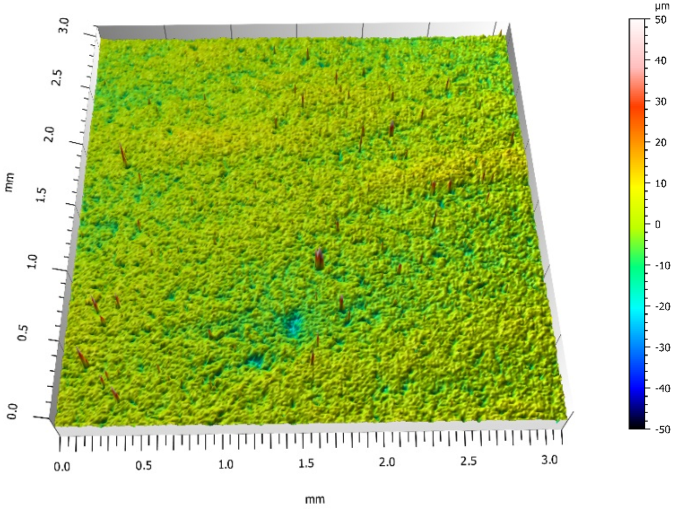

Deviation [mm]
0.2000
0.1600
0.1200
0.0800
0.0400
0.0000
-0.0400
-0.0800
-0.1200
-0.1600
-0.2000

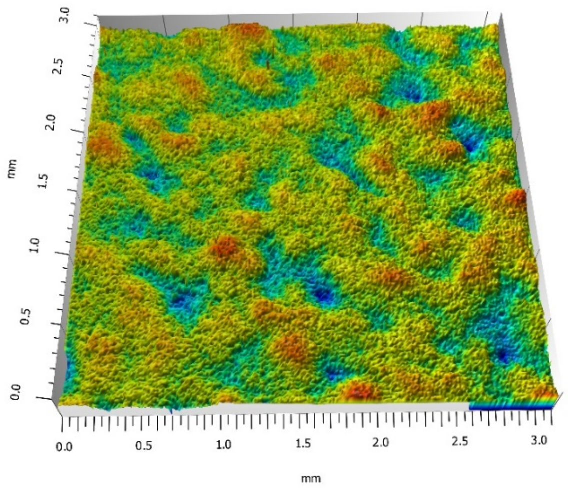
Actual vs Nominal Metrology Comparison
CT

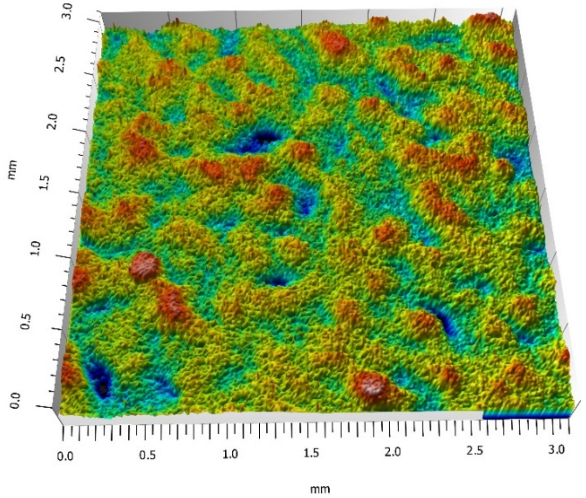


Non-destructive Surface Quality Measurement

Confocal (External) & X-ray (Internal) microscopy







ISO 4287		
Amplitude parameters ...		
Rp	5.184	µm
Rv	5.318	µm
Rz	10.50	µm
Rc	4.066	µm
Rt	17.05	µm
Ra	1.508	µm
Rq	1.933	µm
Rsk	-0.1913	
Rku	3.661	

ISO 25178		
Height Parameters		
Sq	4.627	µm
Ssk	-7.307	
Sku	331.6	
Sp	137.5	µm
Sv	286.5	µm
Sz	423.9	µm
Sa	2.790	µm

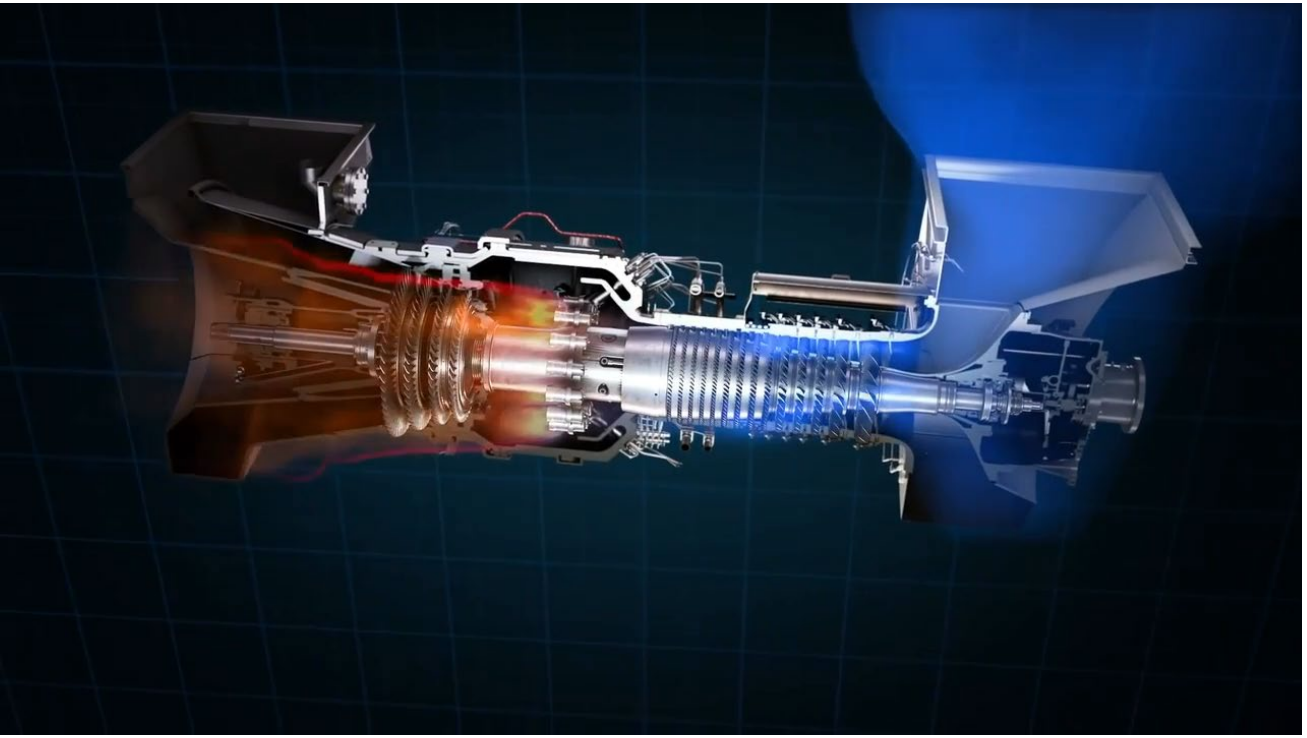
ISO 4287		
Amplitude parameters - R...		
Rp	10.50	µm
Rv	12.36	µm
Rz	22.86	µm
Rc	7.174	µm
Rt	30.63	µm
Ra	2.679	µm
Rq	3.475	µm
Rsk	-0.5899	
Rku	3.937	

ISO 25178		
Height Parameters		
Sq	10.38	µm
Ssk	-0.4719	
Sku	3.580	
Sp	75.60	µm
Sv	137.2	µm
Sz	212.8	µm
Sa	8.171	µm

ISO 4287		
Amplitude parameters ...		
Rp	14.20	µm
Rv	23.16	µm
Rz	37.36	µm
Rc	11.17	µm
Rt	68.30	µm
Ra	3.587	µm
Rq	4.874	µm
Rsk	-0.791	
Rku	7.408	

ISO 25178		
Height Parameters		
Sq	12.55	µm
Ssk	-0.2286	
Sku	4.008	
Sp	115.7	µm
Sv	143.4	µm
Sz	259.1	µm
Sa	9.773	µm

Improving Efficiency of Gas Turbine Using AM



Efficiency of most modern gas turbines for power generation is between 60–64%

Using AM, novel designs can be produced to improve efficiency beyond the 64% limit

<u>Advantage</u>: Design iteration time is fast, or the order of weeks/months compared to 2–3 years

<u>Disadvantage</u>: IN738 alloy used for gas turbine application is not weldable crack-prone, which makes the print AM parametereter development challenging

Collaboration partners to research and print, analyze for quality control, and test in real gas turbine

- Solar Turbines,
- MDF-ORNL and
- ZEISS

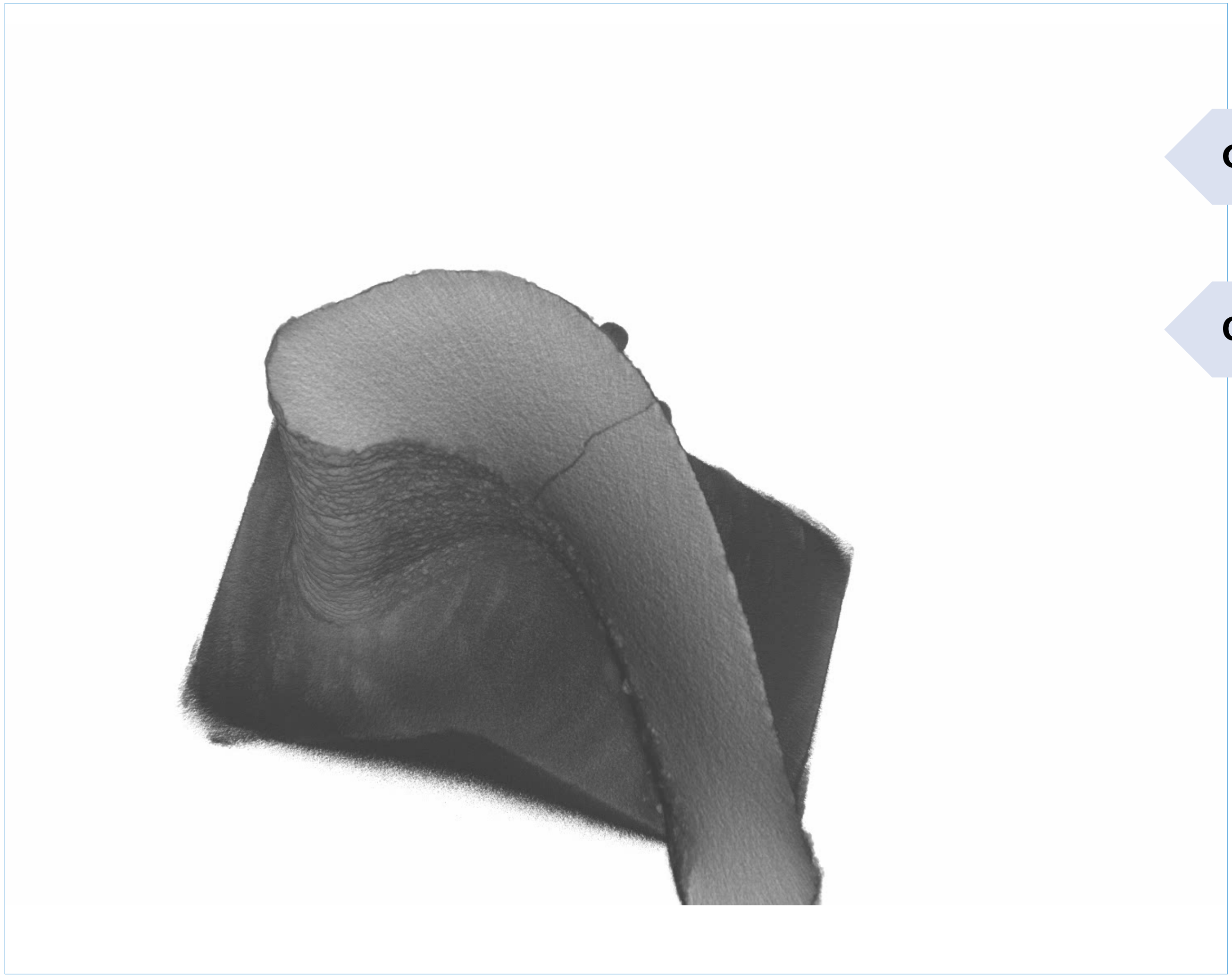
Inconel 738 Turbine Blades Inspection using ZEISS Blueline for AM

Correlative Multi-resolution Imaging (CT, XRM & SEM)

	Voxel size
Crack in blade detected in routine scan	[38µm]

Inconel 738 Turbine Blades Inspection using ZEISS Blueline for AM

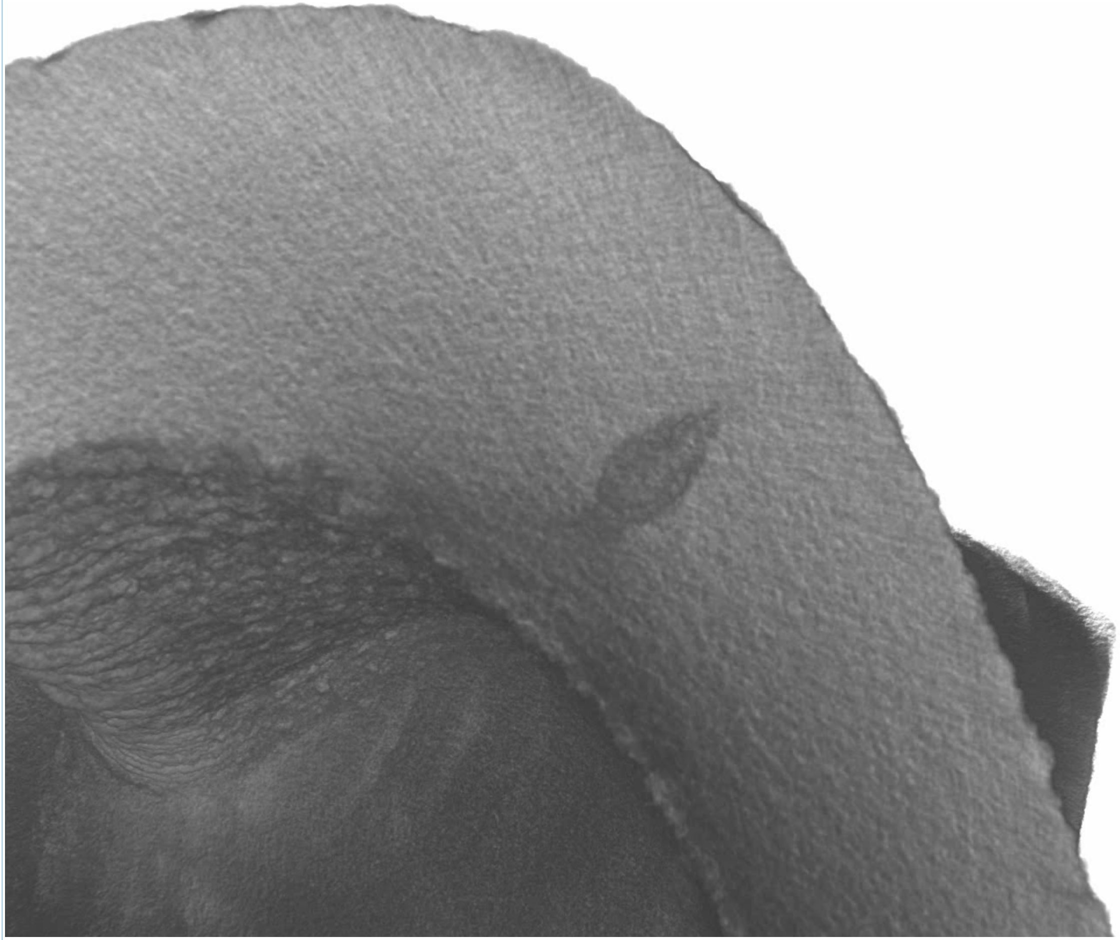
Correlative Multi-resolution Imaging (CT, XRM & SEM)



	Voxel size
Crack in blade detected in routine scan	**[38µm]**
Origin of the crack is a pocket in the material	**[18µm]**

Inconel 738 Turbine Blades Inspection using ZEISS Blueline for AM

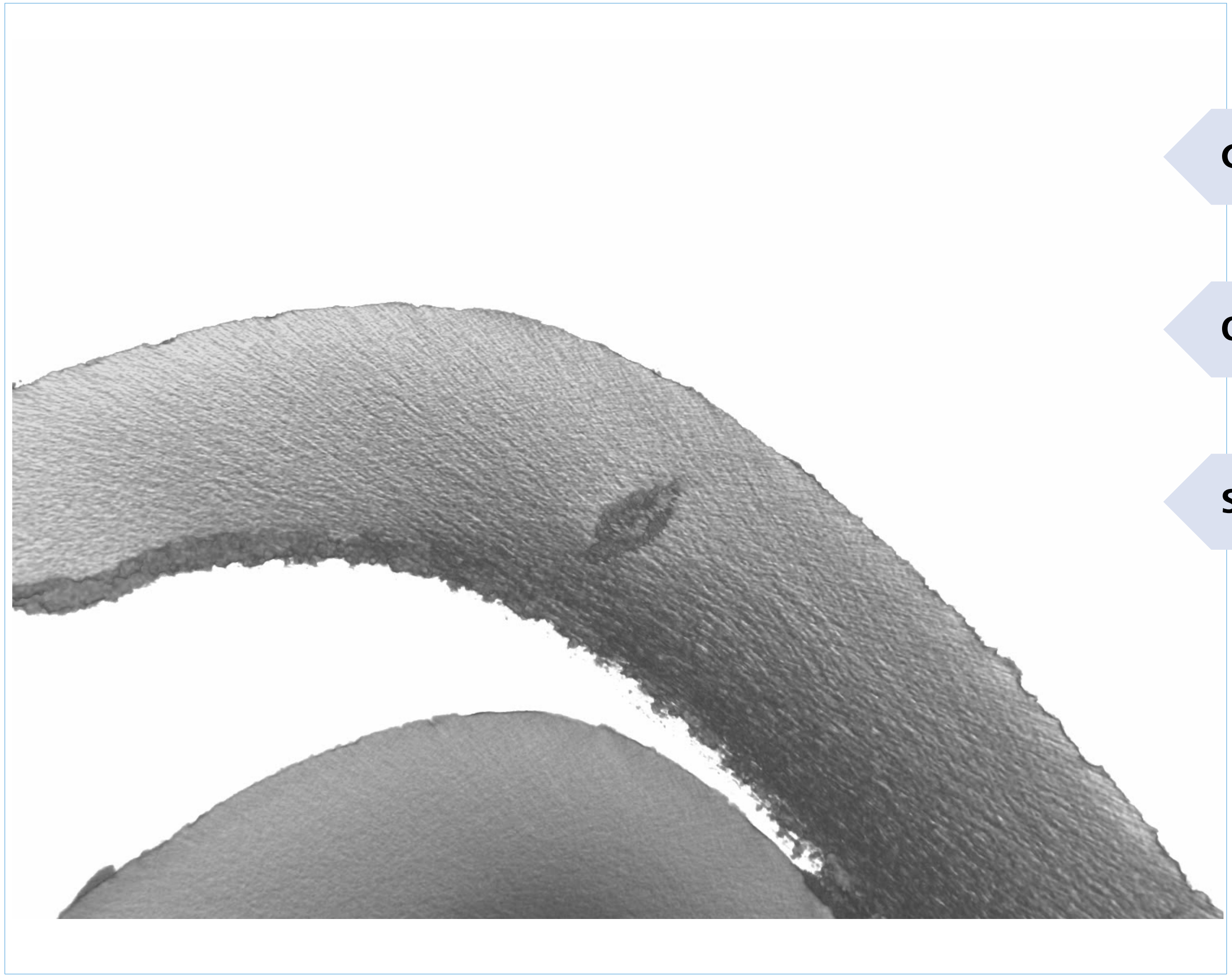
Correlative Multi-resolution Imaging (CT, XRM & SEM)



	Voxel size
Crack in blade detected in routine scan	[38µm]
Origin of the crack is a pocket in the material	[18µm]

Inconel 738 Turbine Blades Inspection using ZEISS Blueline for AM

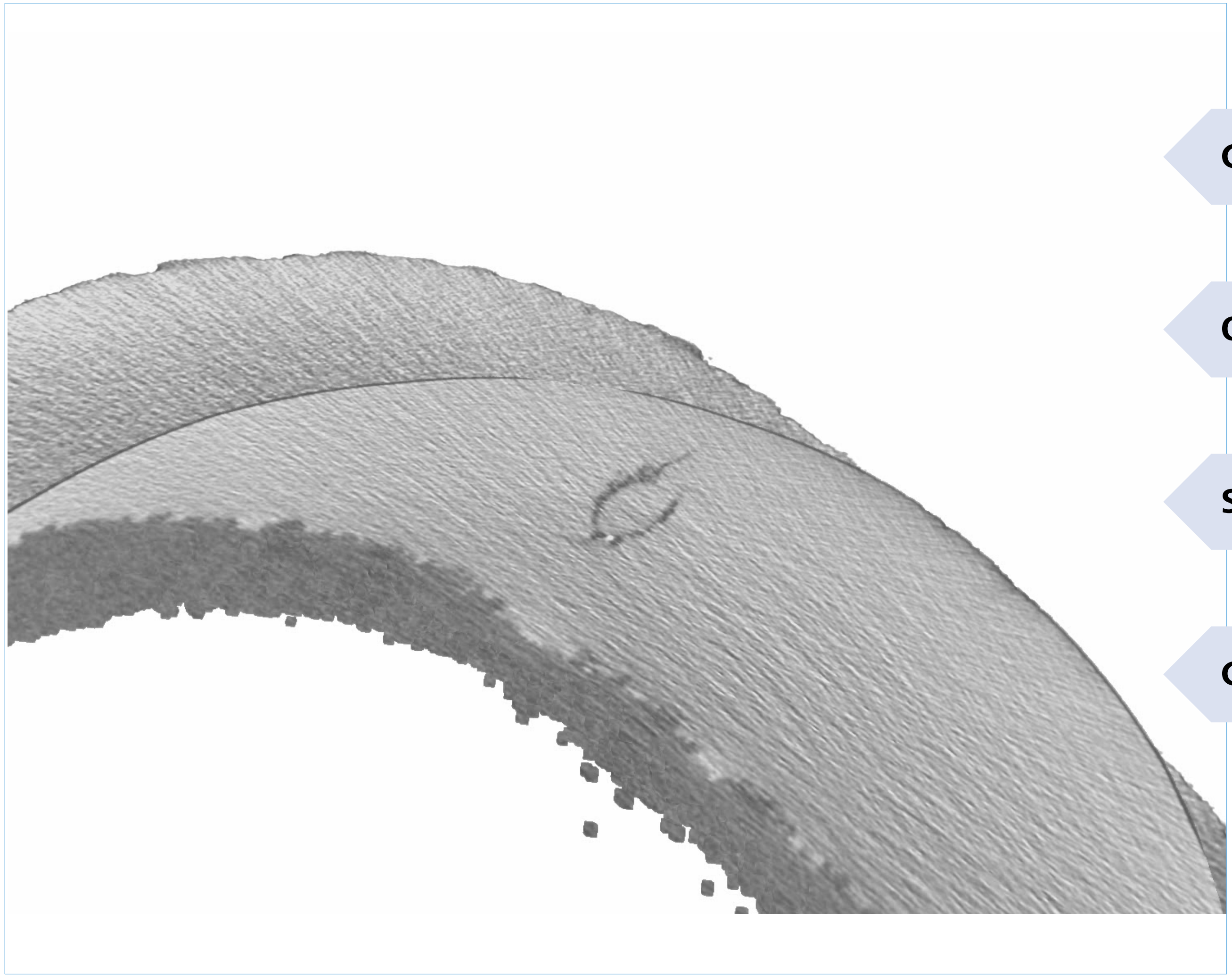
Correlative Multi-resolution Imaging (CT, XRM & SEM)



	Voxel size
Crack in blade detected in routine scan	[38µm]
Origin of the crack is a pocket in the material	[18µm]
Small area in the pocket with higher density spotted	[11µm]

Inconel 738 Turbine Blades Inspection using ZEISS Blueline for AM

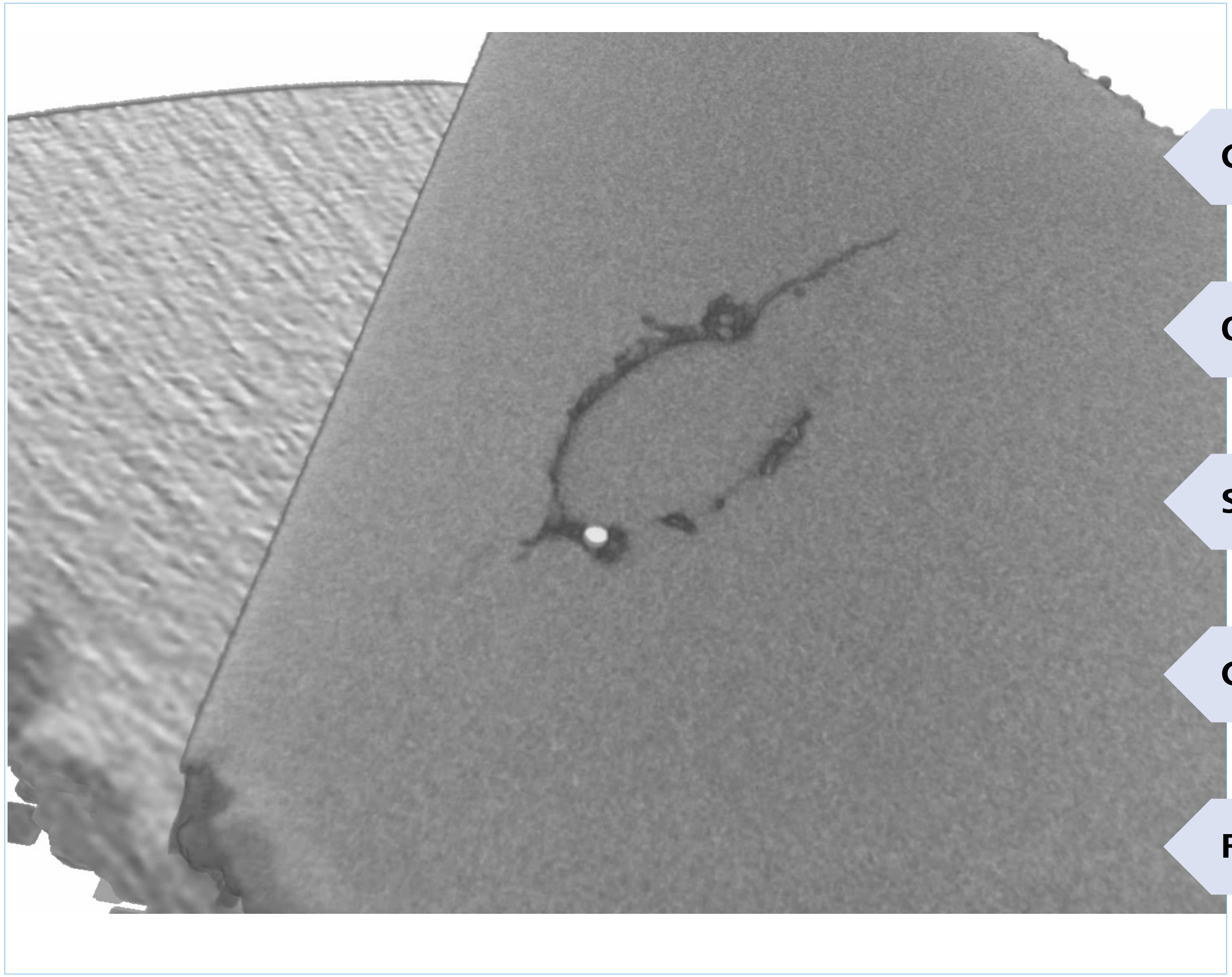
Correlative Multi-resolution Imaging (CT, XRM & SEM)



	Voxel size
Crack in blade detected in routine scan	[38µm]
Origin of the crack is a pocket in the material	[18µm]
Small area in the pocket with higher density spotted	[11µm]
Cutting and X-ray microscope scan	[11µm]

Inconel 738 Turbine Blades Inspection using ZEISS Blueline for AM

Correlative Multi-resolution Imaging (CT, XRM & SEM)



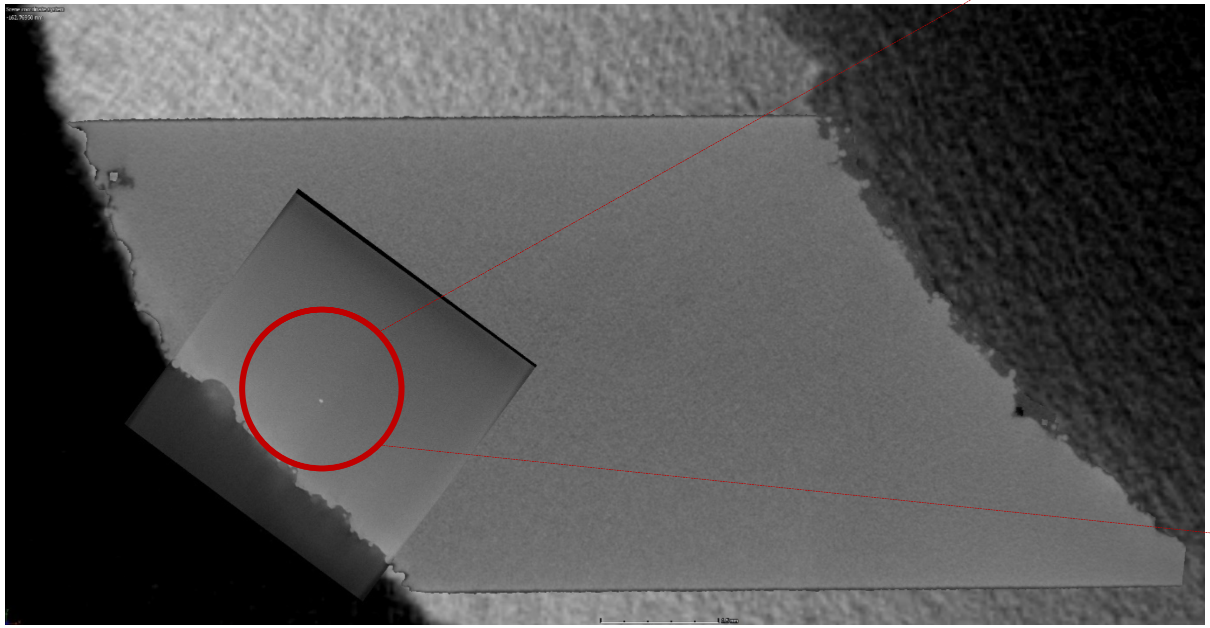
Step	Voxel size
Crack in blade detected in routine scan	**[38µm]**
Origin of the crack is a pocket in the material	**[18µm]**
Small area in the pocket with higher density spotted	**[11µm]**
Cutting and X-ray microscope scan	**[11µm]**
Final confirmation on contamination particle	**[1.8µm]**

Inconel 738 Turbine Blades Inspection using ZIESS Blueline for AM

Correlative Multi-resolution Imaging (CT, XRM & SEM)

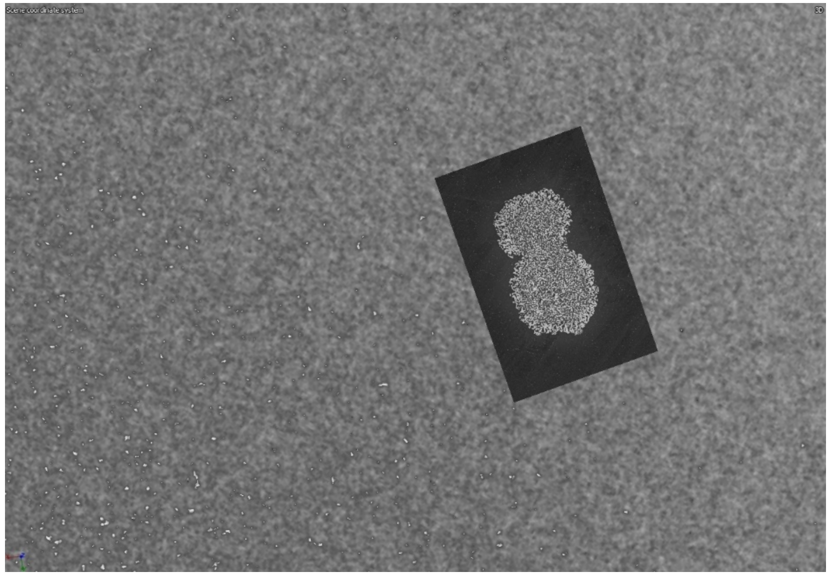
Navigation to ROI between several tools

X-ray microscope image



Assessment of identified contaminant

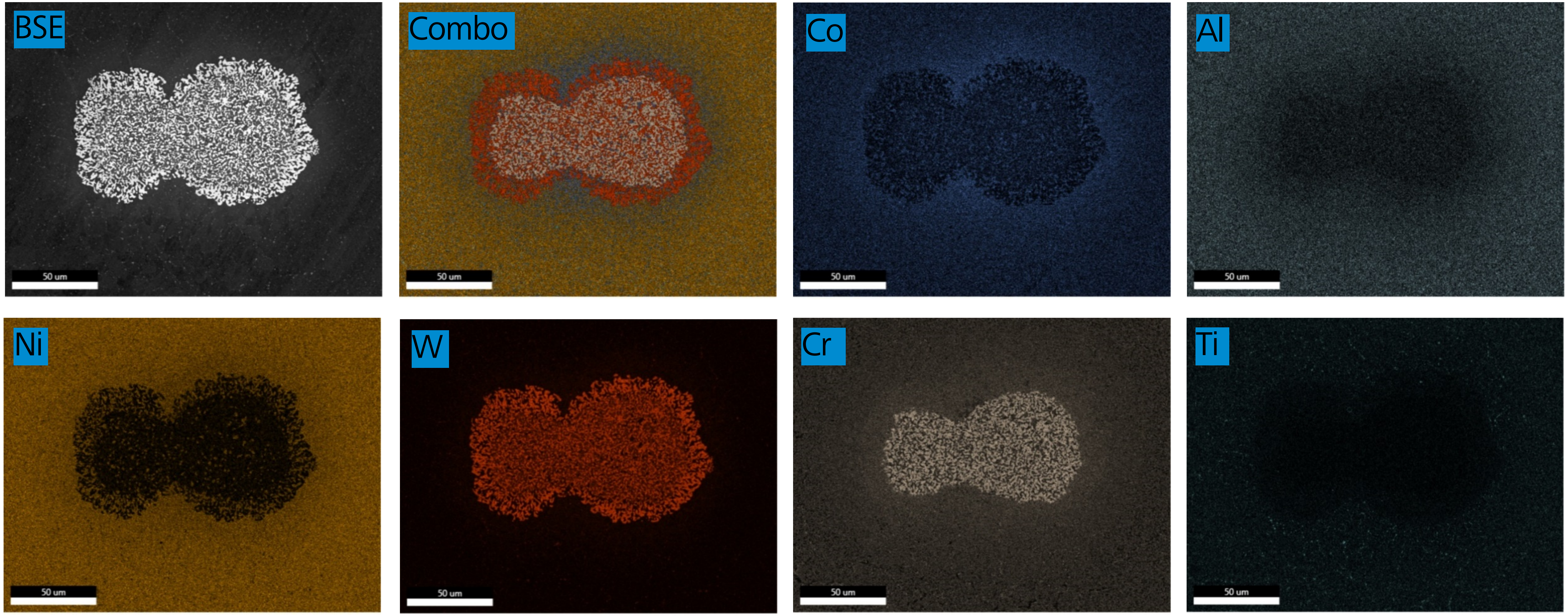
SEM Analysis



- BSE Image from ZEISS Crossbeam 550
- Similar to X-ray, dark areas are low density, bright areas are higher density

Inconel 738 Turbine Blades Inspection using ZIESS Blueline for AM

Correlative Multi-resolution Imaging (CT, XRM & SEM)

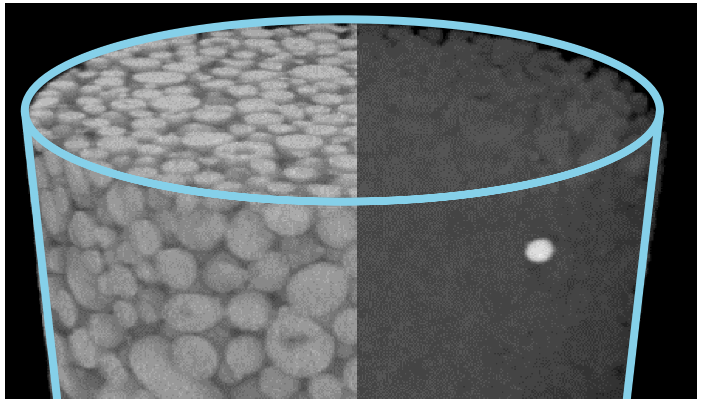


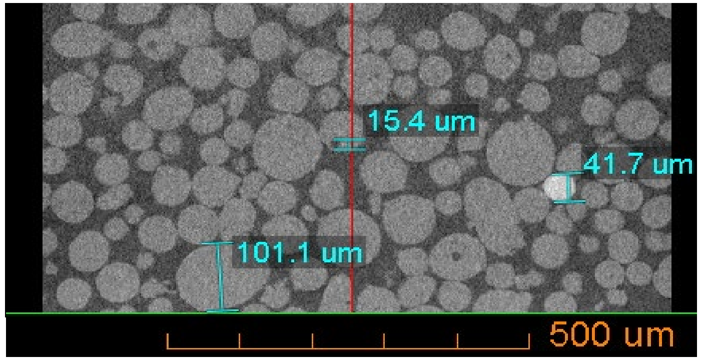
Contaminant particle is composed of Tungsten, Chromium

Inconel 738 Turbine Blades Inspection using ZIESS Blueline for AM

Correlative Multi-resolution Imaging (CT, XRM & SEM)

Surface Density

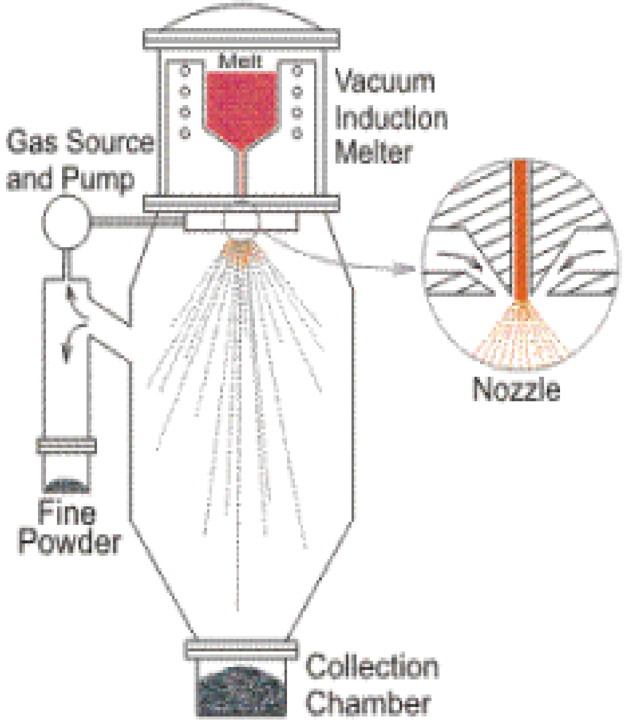




Cross-section

Atomization of powder can introduce contamination into the build. Nozzles, electrical filaments and other high stress components are generally made of Tungsten. This material can break off in aging equipment and deposit itself in the resulting powder.

We believe this to be the source of contamination in the final material.



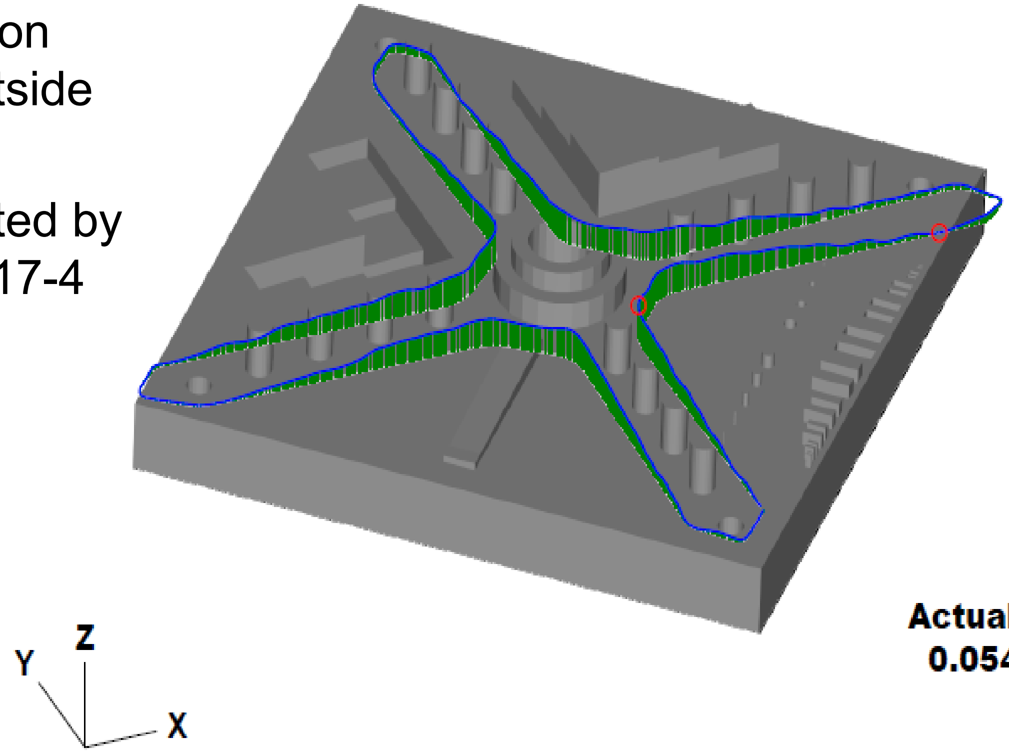
Vertical Gas Atomizer: Source "Powder Metallurgy Science" Second Edition, R.M. German, MPIF.

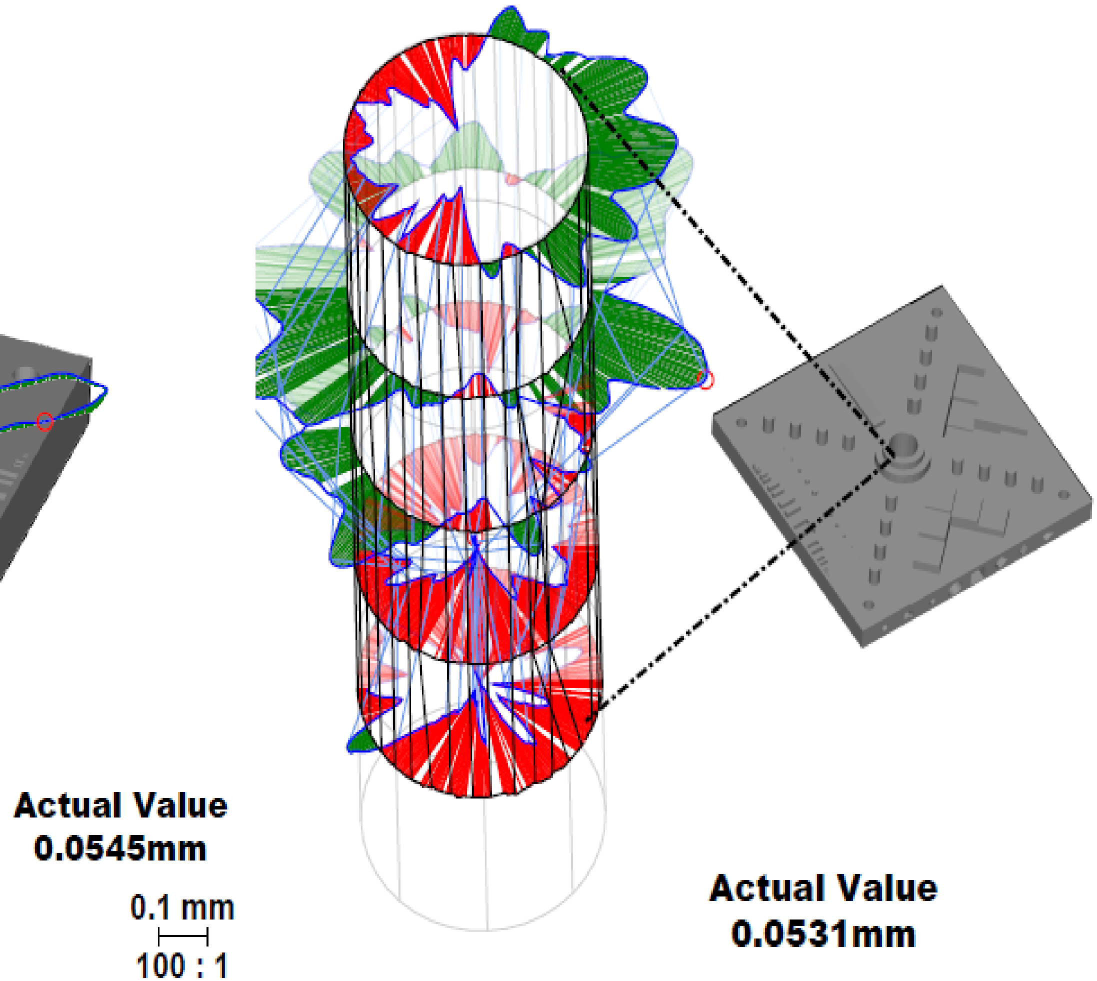
Heat Treatment effects — NIST Artefact

As Built (CMM + PiWeb)

Evaluation of flatness of the artifact right after build up

- Maximum deviation from inside to outside is 0.055 mm
- Artifact was created by EOS GP1 using 17-4 stainless steel



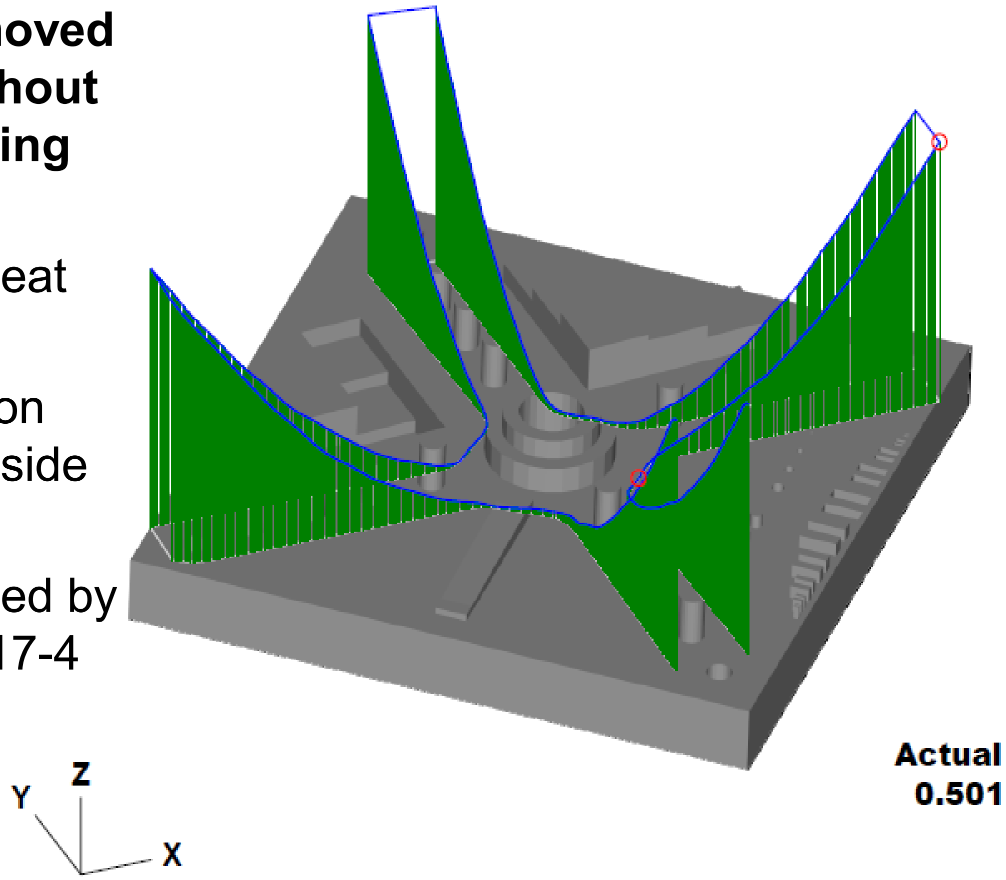


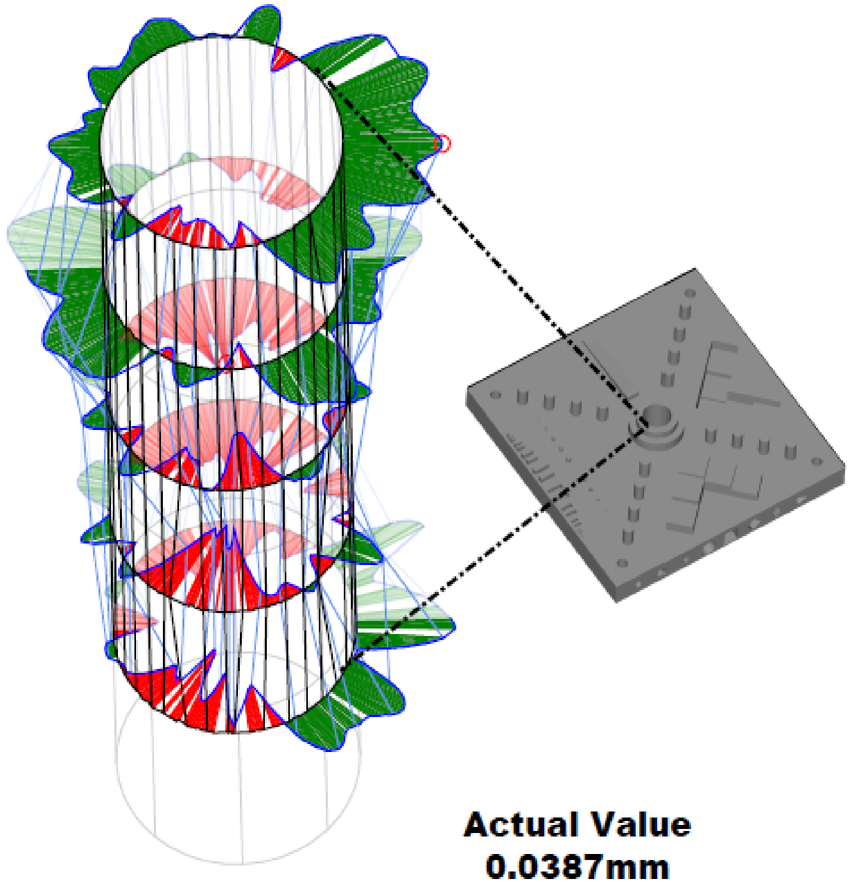
Heat Treatment effects — NIST Artefact

Before Heat Treatment and Removed from Build Plate (CMM + PiWeb)

Evaluation of flatness of the artifact removed from the base without heat treatment using WEDM

- Artifact was not heat treated
- Maximum deviation from inside to outside is 0.501 mm
- Artifact was created by EOS GP1 using 17-4 stainless steel

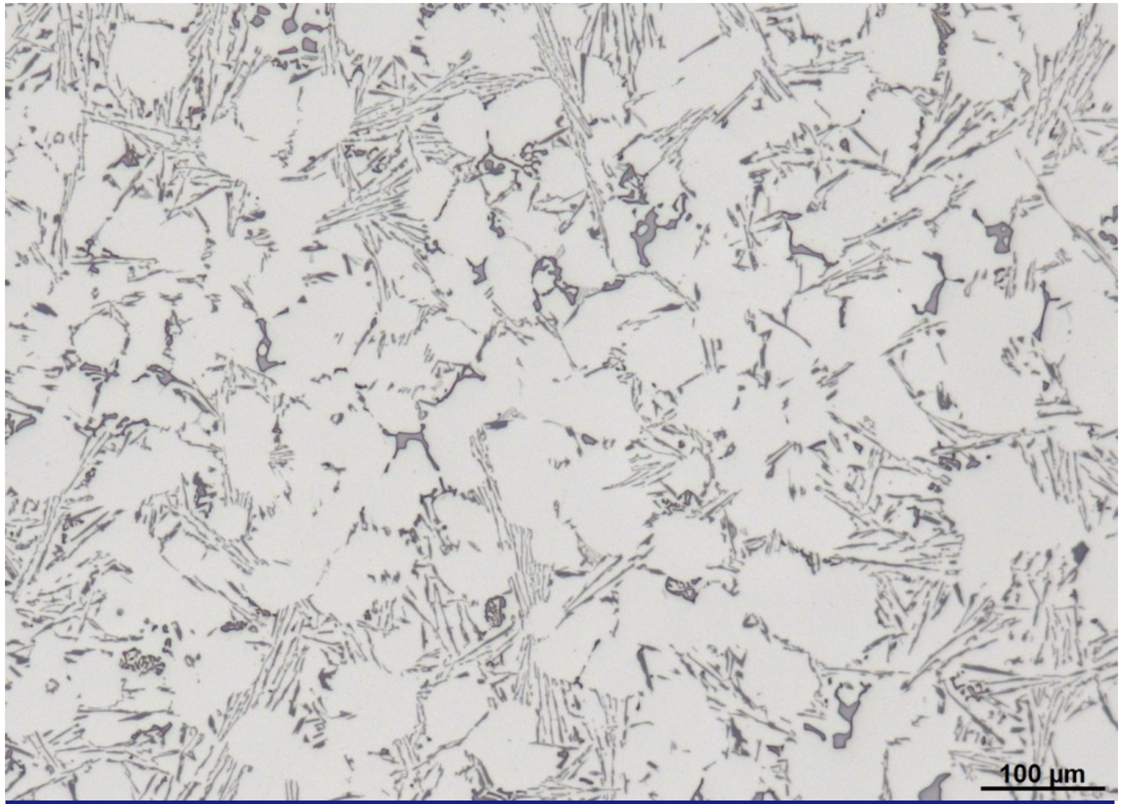




Analysis of Grain Structure

Comparison of Conventional and Additive (LM)

Conventional



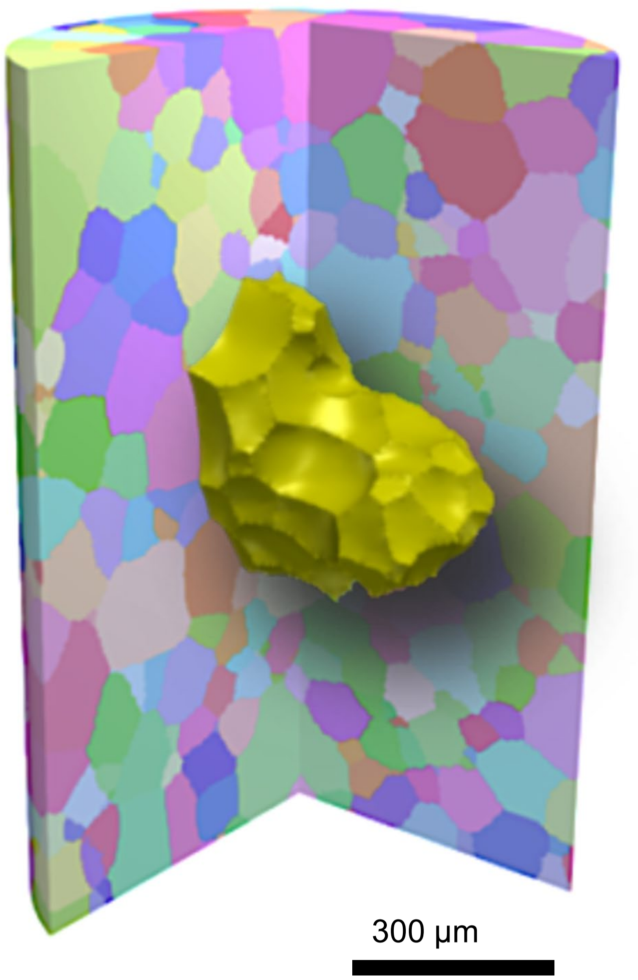
AlSi10Mg, conventional, polished
AxioImager.Z2m, BF, 100x

AM Printed

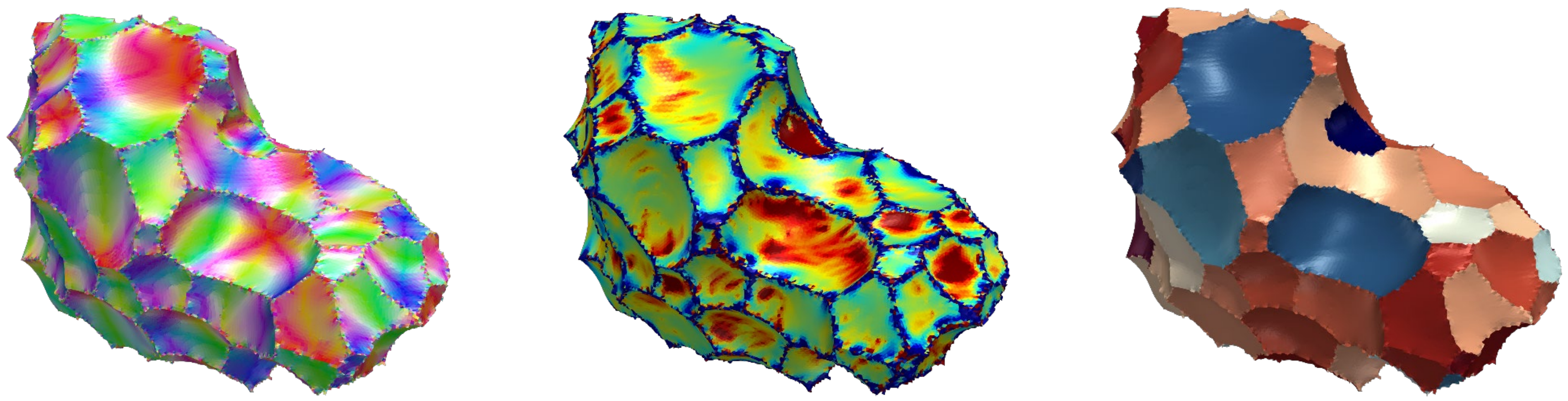
AlSi10Mg, SLM, polished, Si is dispersed.
AxioImager.Z2m, BF, 500x

Non-destructive Grain Structure Characterization

Annealing and Grain Growth (XRM, LabDCT)



- Abnormal grain growth can lead to anomalous properties
- Diffraction contrast tomography (LabDCT) measures morphology and crystallography of grain structures in 3D
- Grain boundary characterization (inclination, orientation, curvature) can be measured to understand grain growth behavior
- 4D analysis (3D + time) to observe evolution of grain structure through treatment

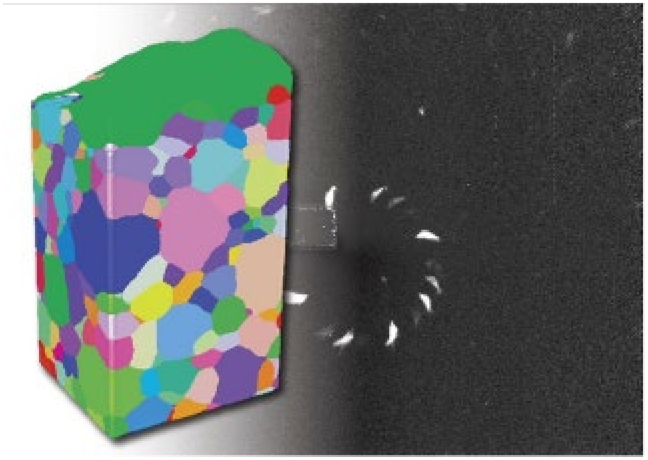


Prof. Burton R. Patterson, University of Florida

Application Examples

CrystalCT for a variety of sample sizes

$SrTiO_3$, 0.8x0.8x3.0 mm

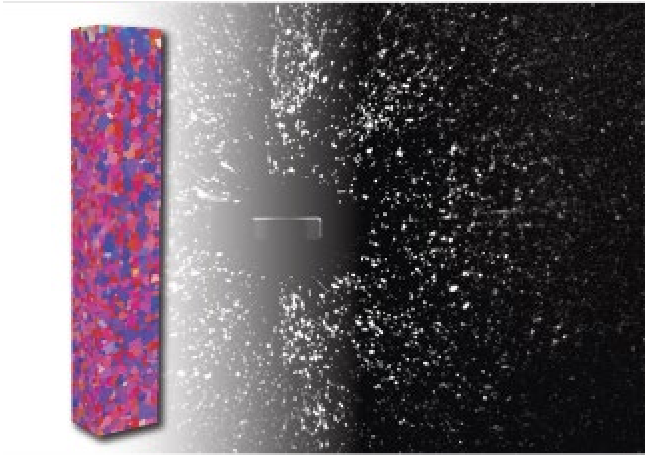


Courtesy of Prof. A. Krause, University of Florida, US

Armco iron, Ø=1.0 mm, h=3.1 mm

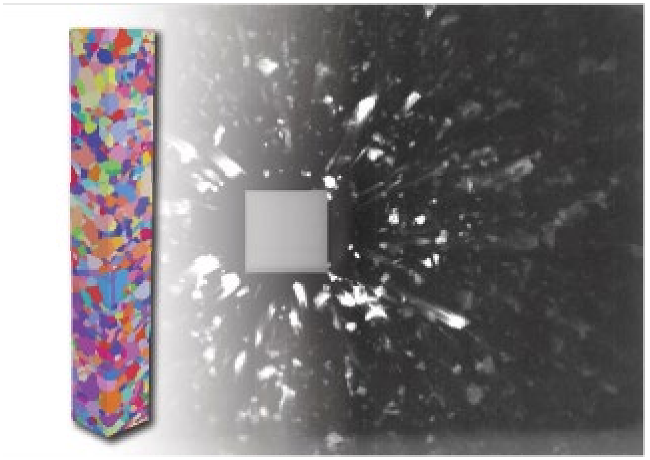
Courtesy of Prof. B.R. Patterson, University of Florida, US

β-Ti alloy, 1.0x1.0x3.2 mm



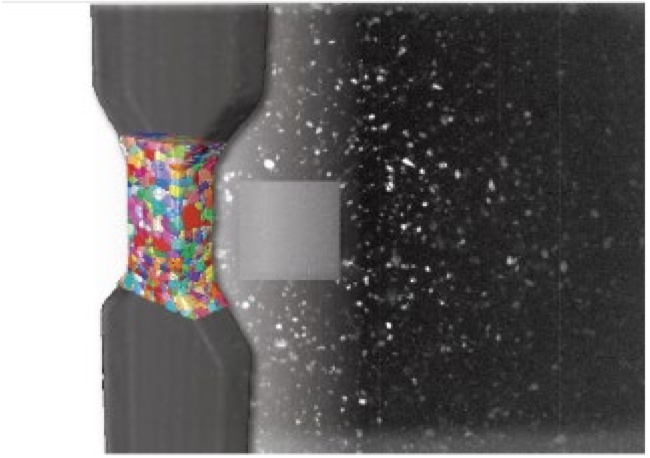
Courtesy of Prof. M. Kimura, KEK, Japan

Carbon steel, 0.4x0.4x2.0 mm



Courtesy of Prof. G. Winther, Technical University of Denmark

Stainless steel, 0.7x0.7x4.4 mm

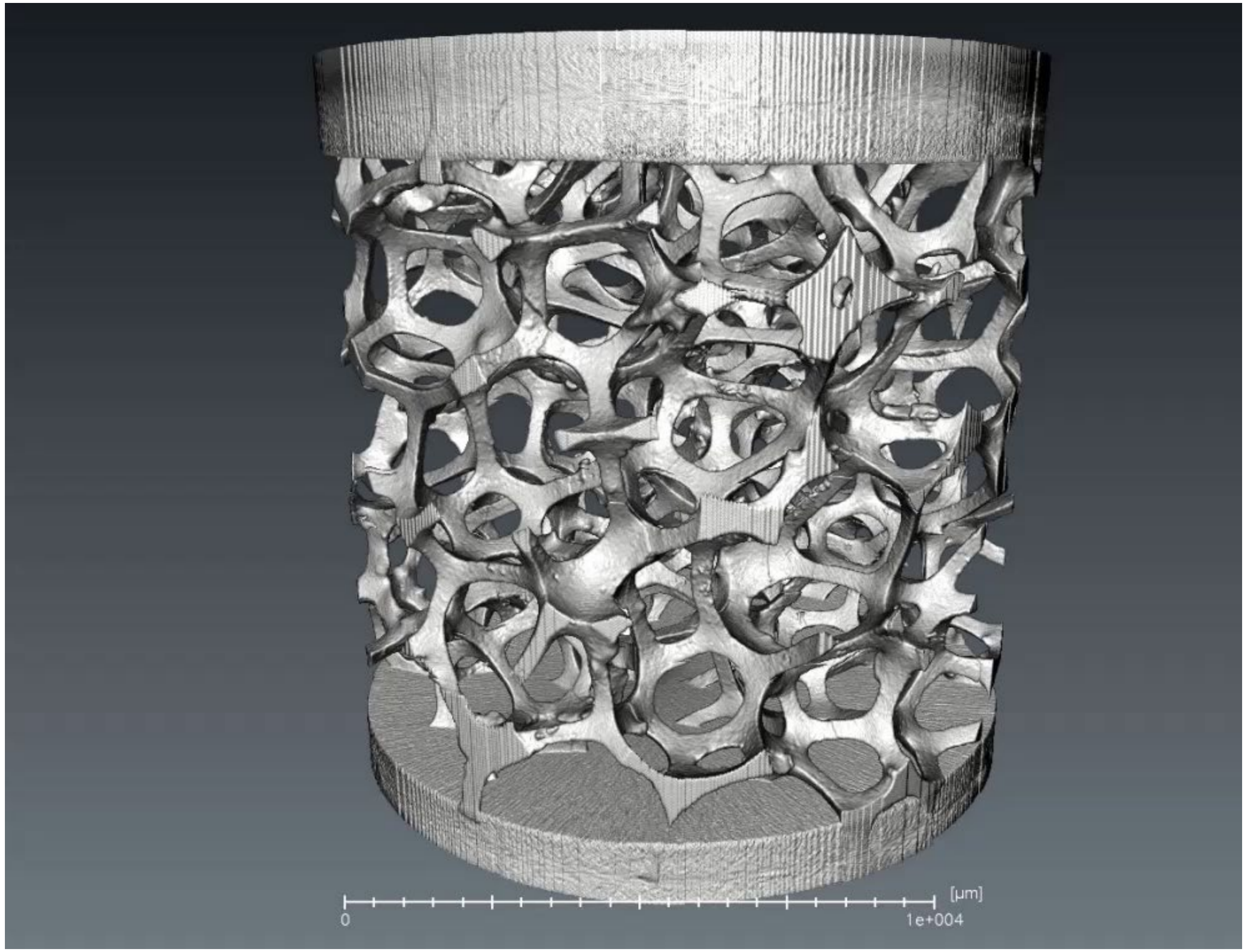


Courtesy of Prof. M. Kobayashi, Toyohashi Univ. of Techol., Japan

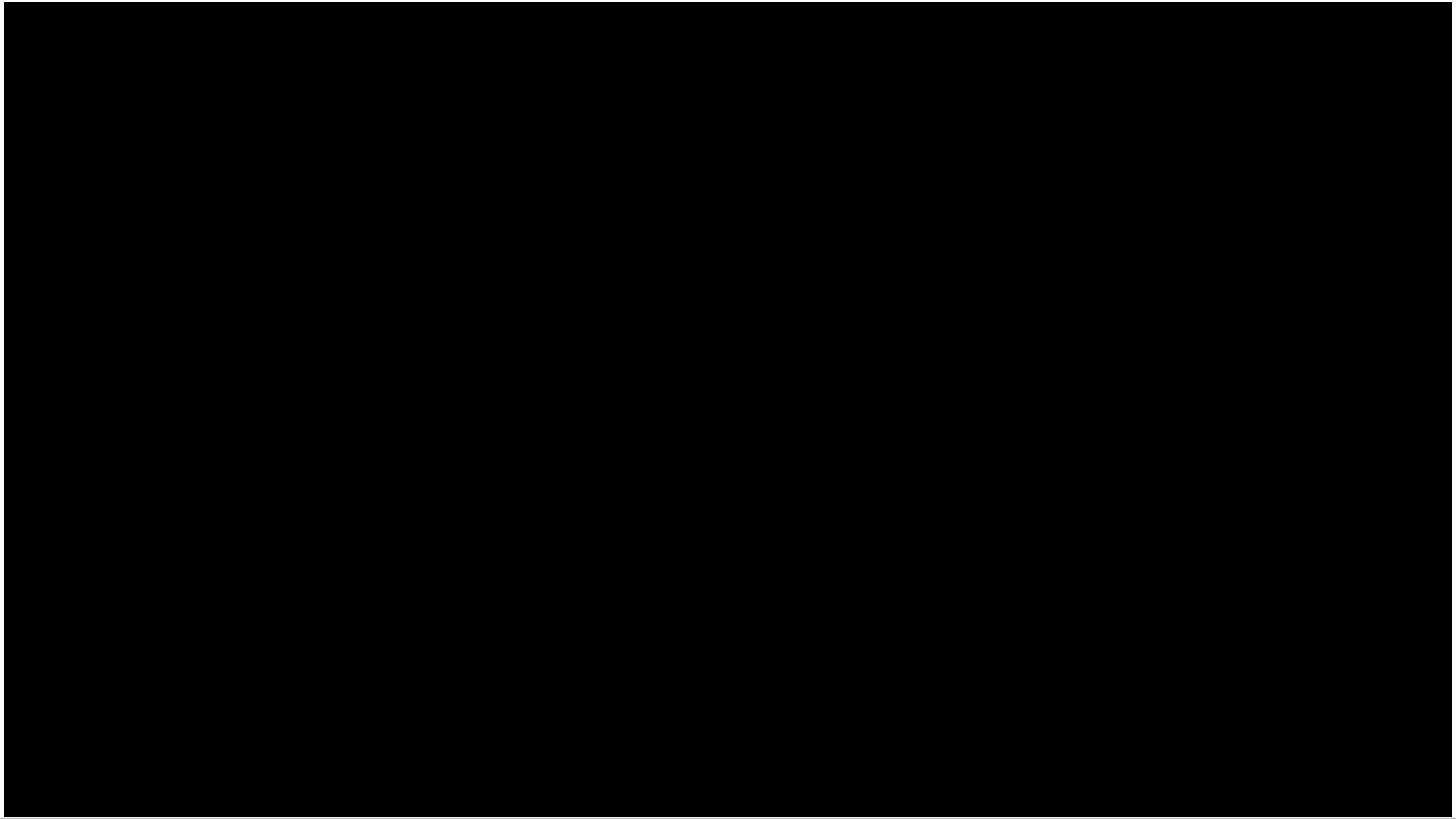
Al-4wt%Cu, 1.3x1.0x0.5 mm

In-Situ Compression Testing
4D Imaging of Metal Foam (XRM with RaaD)

Compression rig
Deben CT5000-TEC Load stage
Outer Diameter : **60mm**

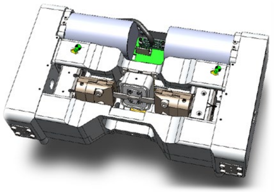


Material Testing
Measuring Surface Strain using GoM ARAMIS



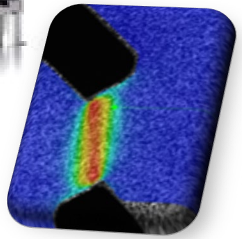
Integrated Nanoscale *In Situ* Microscopy

Using field emission SEM

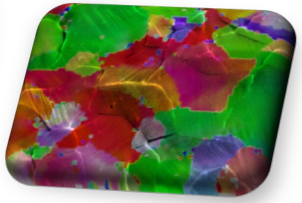


Heating and mechanical load

High Res Feature Tracking, Auto Focus & Alignment



Digital Image Correlation

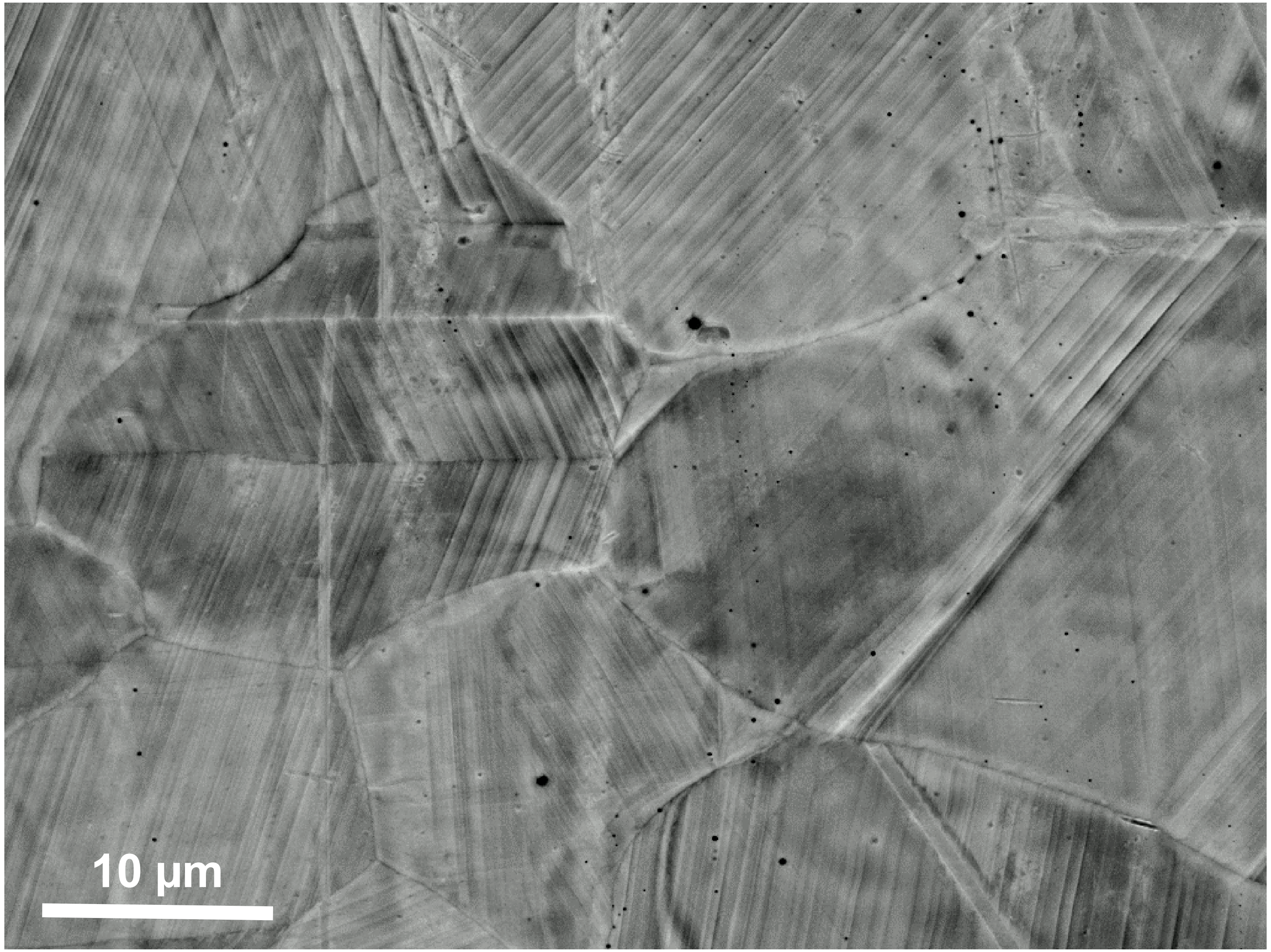


Automated Analytics

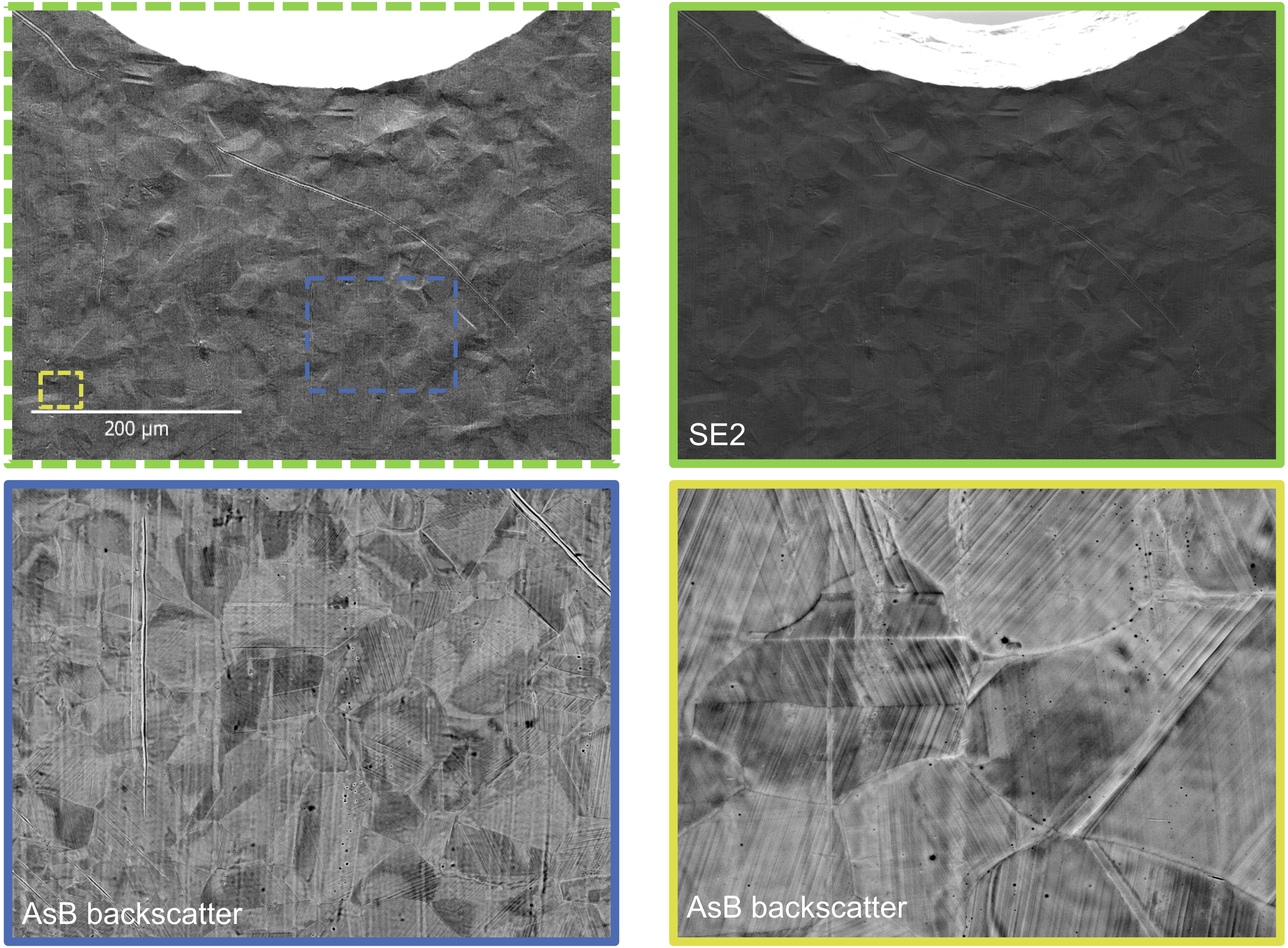
Complete sub-system integration

In Situ Deformation and Heating in ZEISS SEM

Imaging and tracking RoI's (automatically) at each deformation step

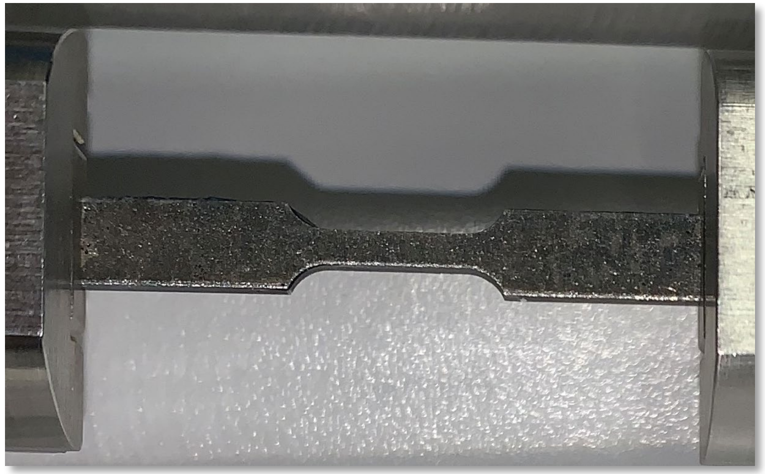


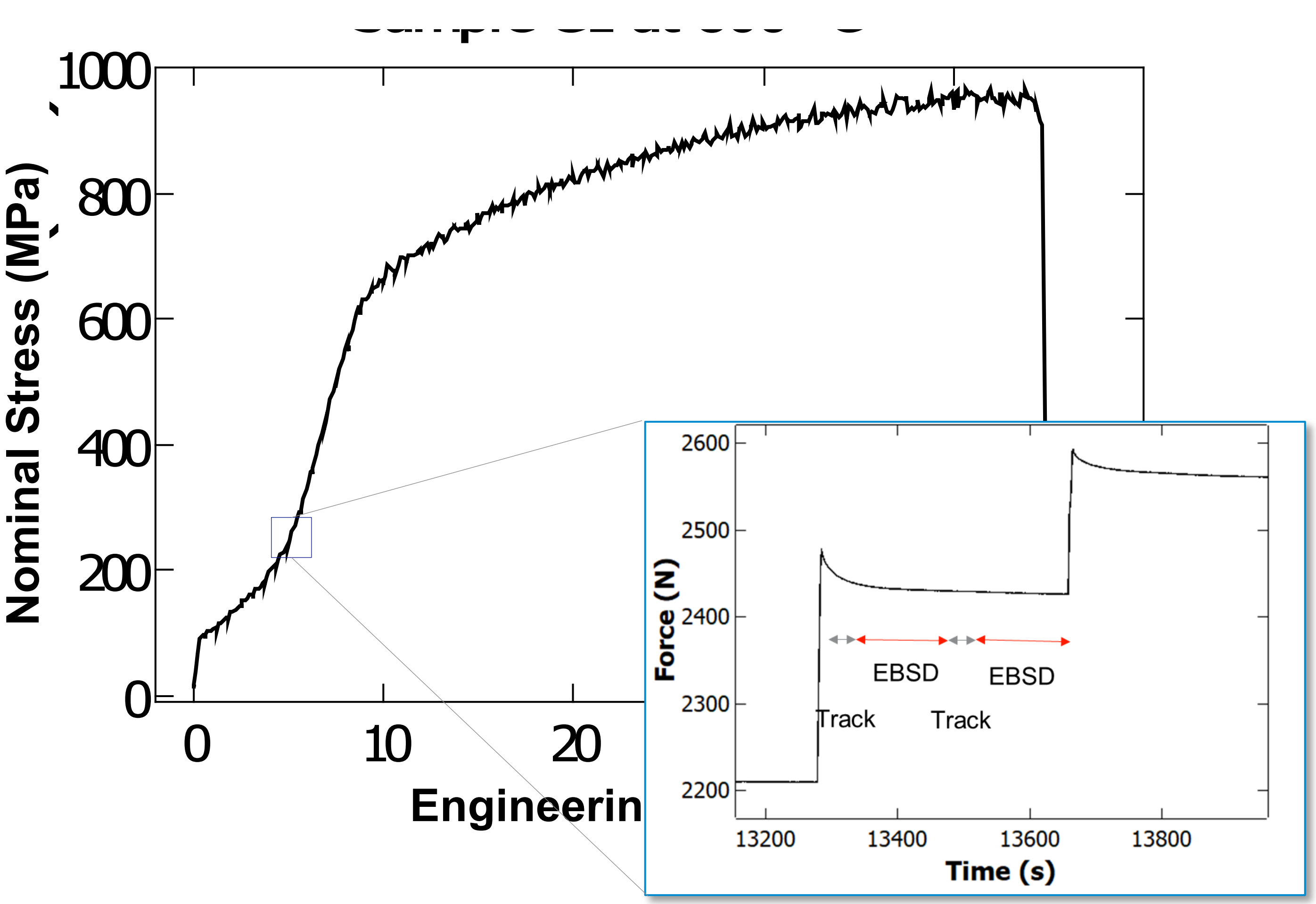
- Using automation and feature tracking it is possible to capture the material deformation at much smaller steps that are not practical to do manually.
- In this specific example, the development of material defects under deformation is imaged using BSE detector and channeling contrast.



Multiple ROI's can be tracked and imaged automatically during in situ experiments, each with their own location, beam conditions, magnification, and detector options

Haynes 282 Alloy
Tensile studies at elevated temperature





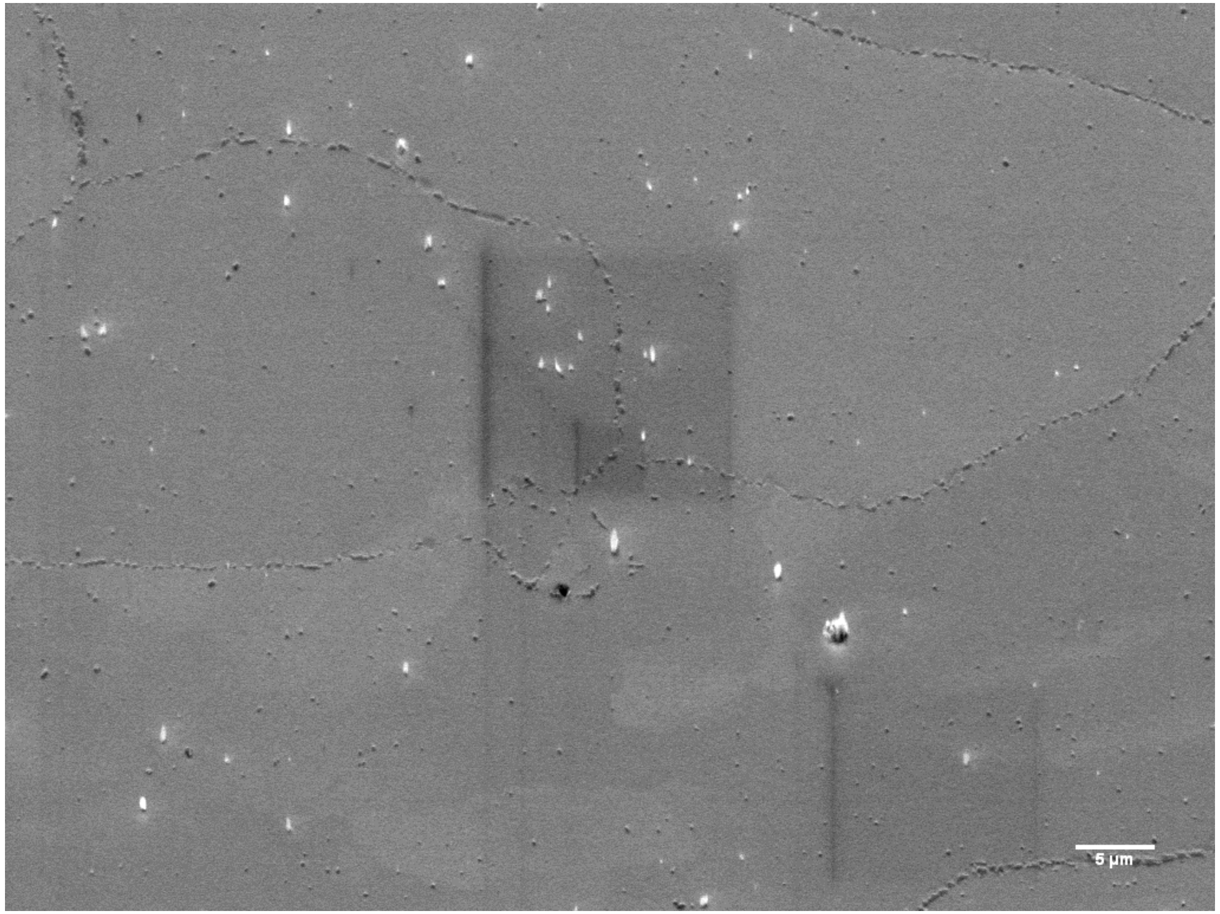
Two initial studies have been performed

1. Tensile loading at elevated temperature to failure
2. Creep relaxation under elevated temperature at constant stress

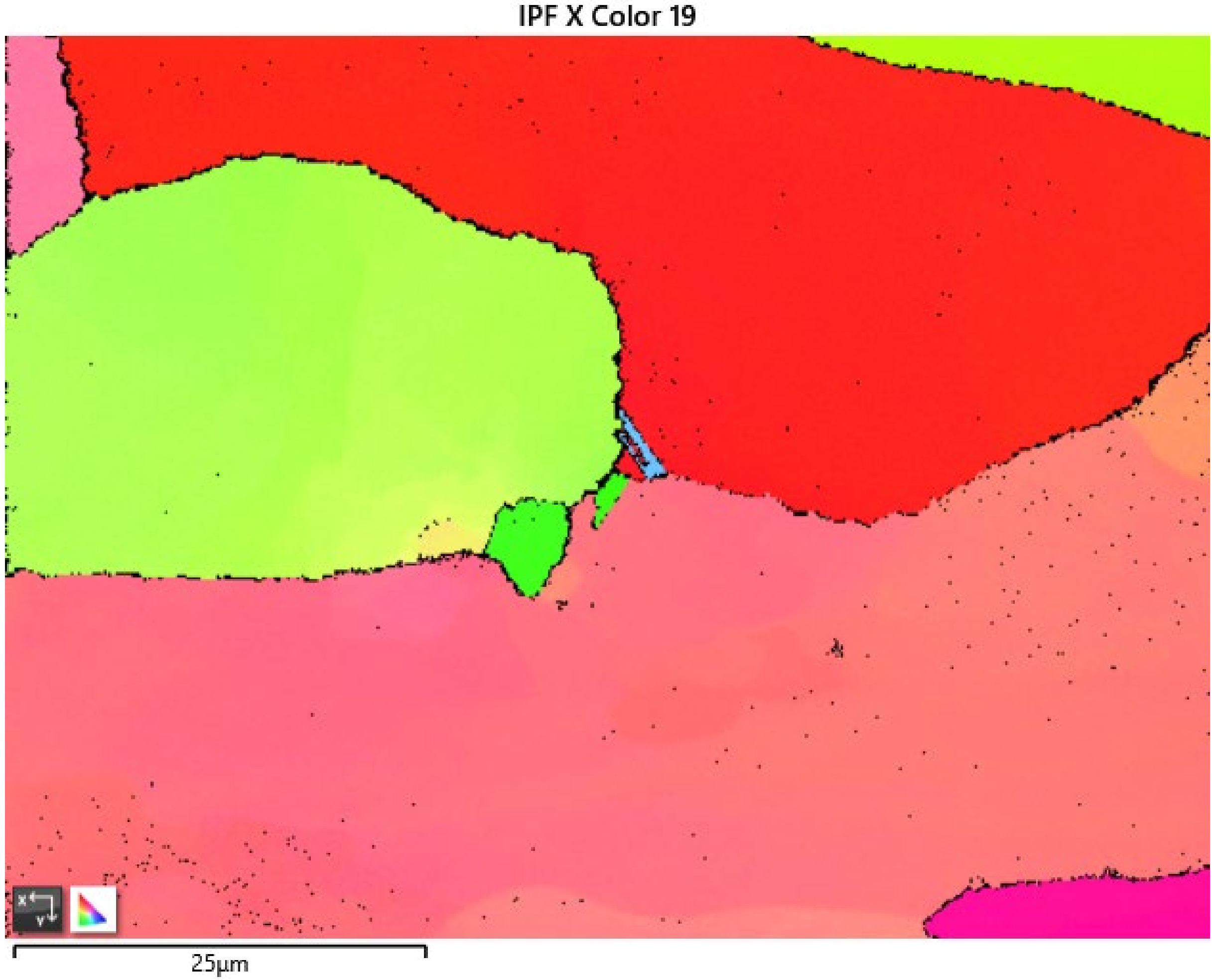
Temperature held at 800C, but due to surface roughness of sample creating imperfect contact with heater, actual sample temperature likely somewhat lower

Part 1: Tensile Load Under Elevated Temp

Backscatter electron image

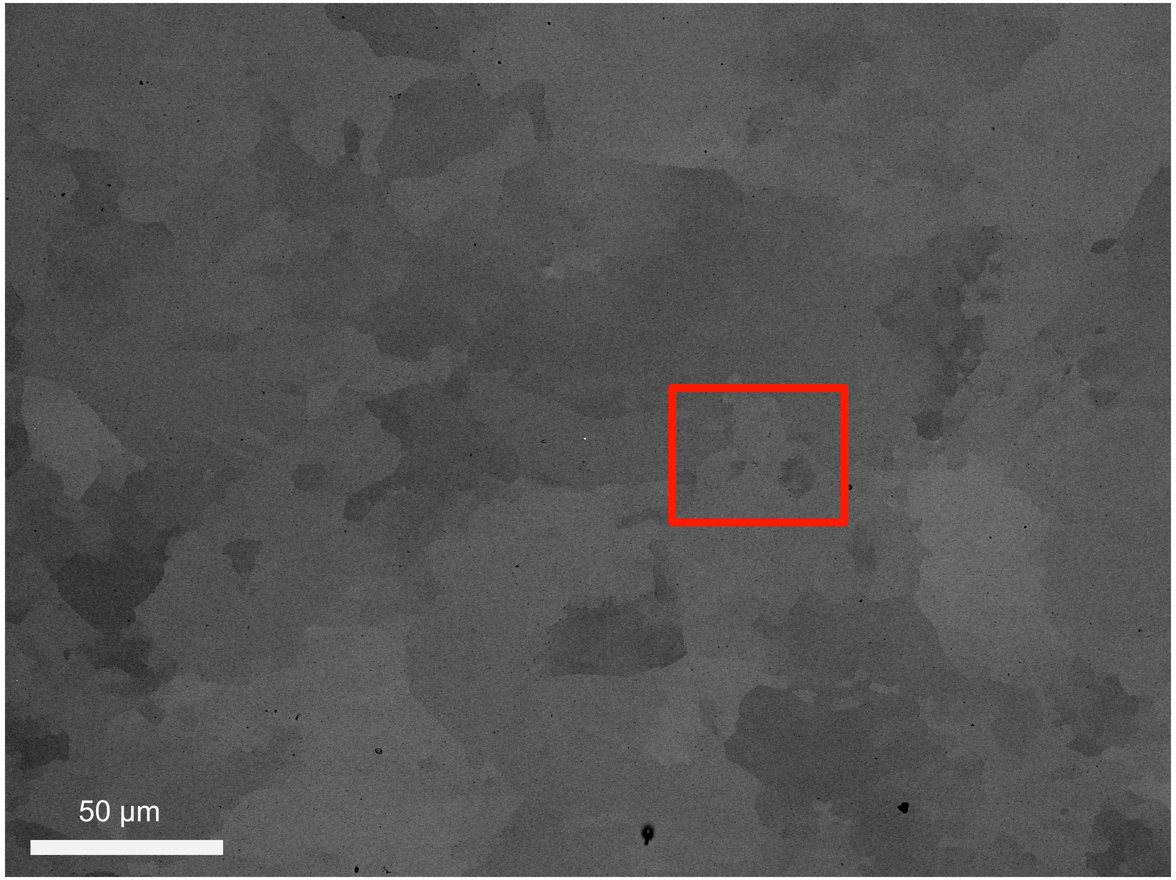


EBSD map

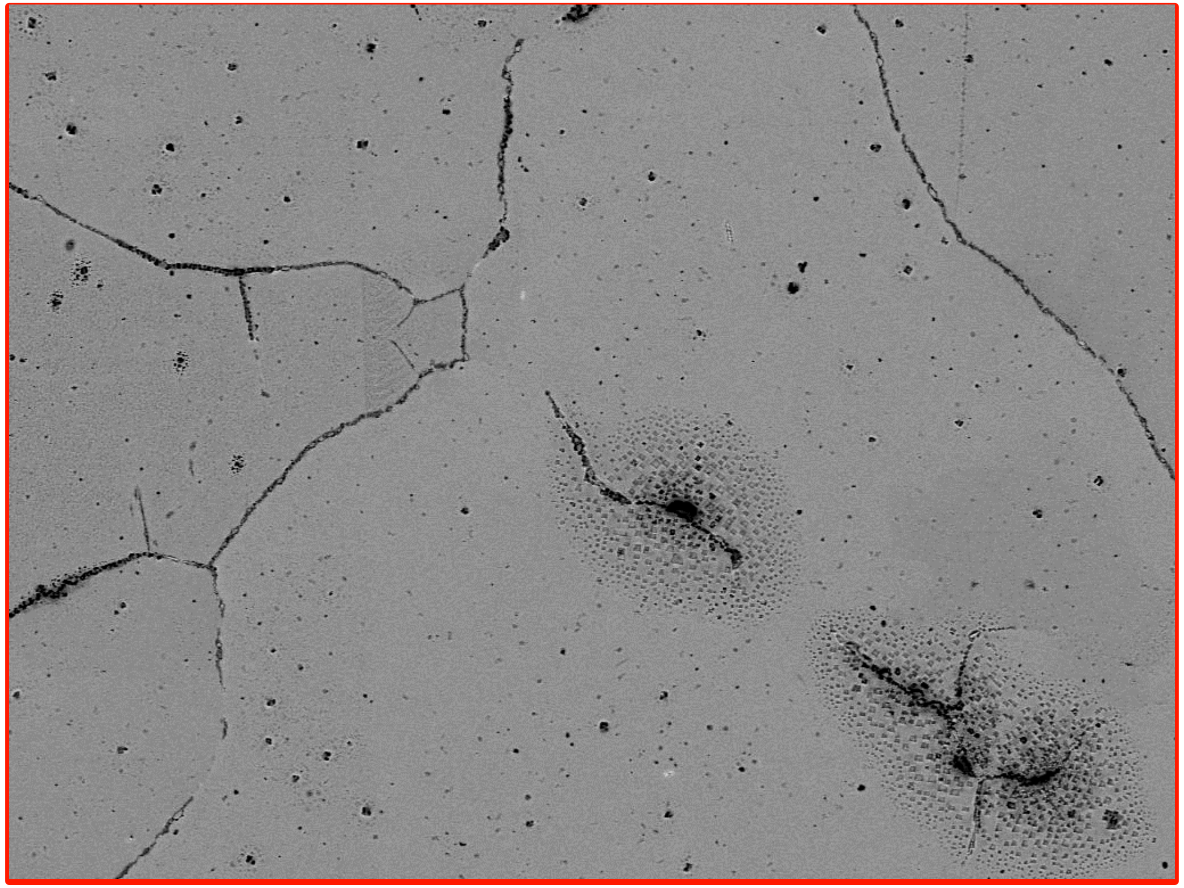


Part 2: Creep Relaxation Testing

Region of Interest 1

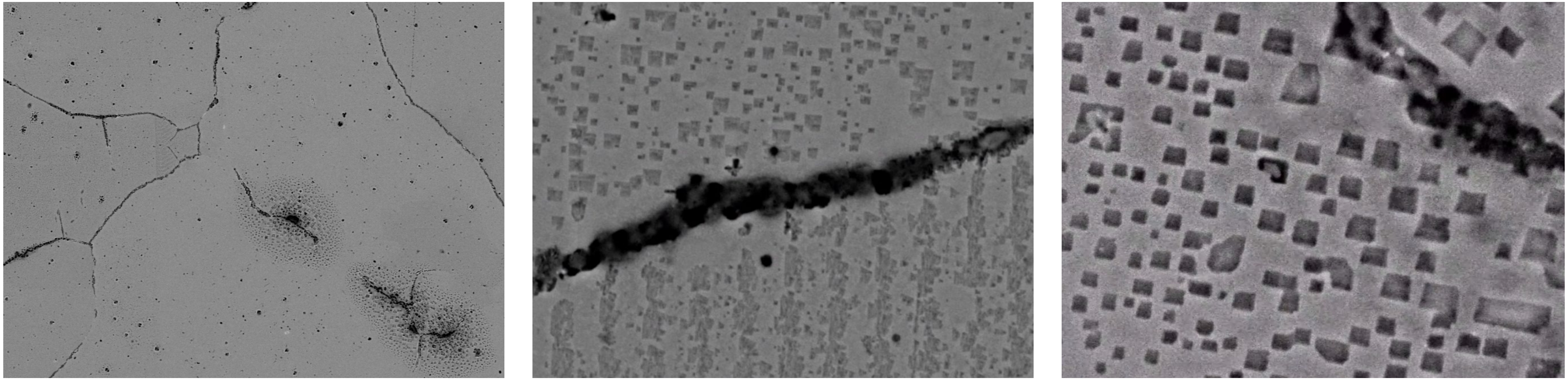


Region of Interest 2



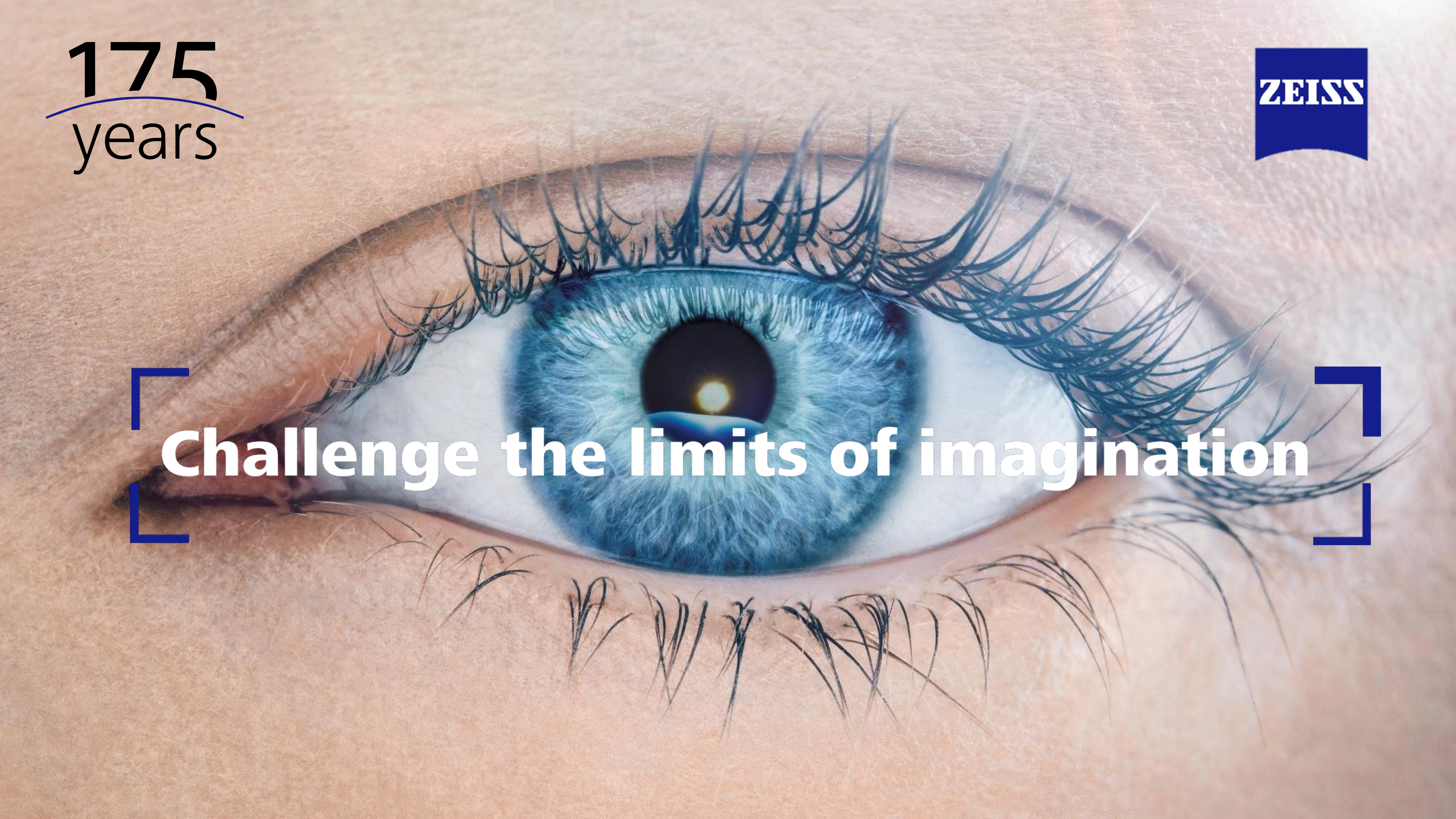
Automated experiment time of 48 hours

Part 2: Creep Relaxation Testing



Visibility of gamma prime phase during creep relaxation. Note deformation dependency of precipitates based on local stress environment

Holistic Correlative Analysis


175
years
ZEISS
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