X-ray Computed Tomography for Materials & Life Sciences series

Wed., November 13, 1 pm CDT

Presenter: Ted Huang | **Co-presenter:** Angela Criswell | **Host:** Viral Vaghela

- *You will be muted during the workshop*
- *You can ask questions using the Q&A tool.*
- *You should hear music if your sound is working*

X-ray Computed Tomography for Materials & Life Sciences series

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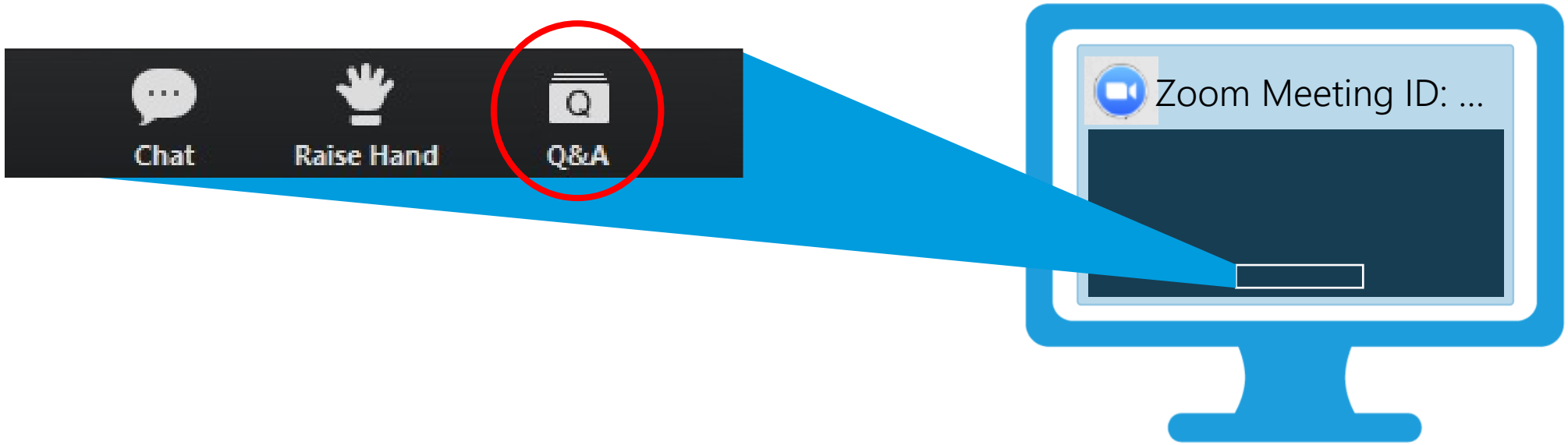
We are starting now…

Presenter: **Ted Huang** | X-ray Imaging Application Scientist

Co-presenter: **Angela Criswell** | Director of X-ray Imaging

Host: **Viral Vaghela** | X-ray Imaging Account Manager



You can ask questions during the presentation.
Please use the Q&A to ask questions.

Recording will be available tomorrow.

ADDITIVE MANUFACTURING IN X-RAY COMPUTED TOMOGRAPHY

Presenter: **Ted Huang** | X-ray Imaging Application Scientist
Co-presenter: **Angela Criswell** | Director of X-ray Imaging
Host: **Viral Vaghela** | X-ray Imaging Account Manager

Rigaku
POWERING NEW PERSPECTIVES

You will learn

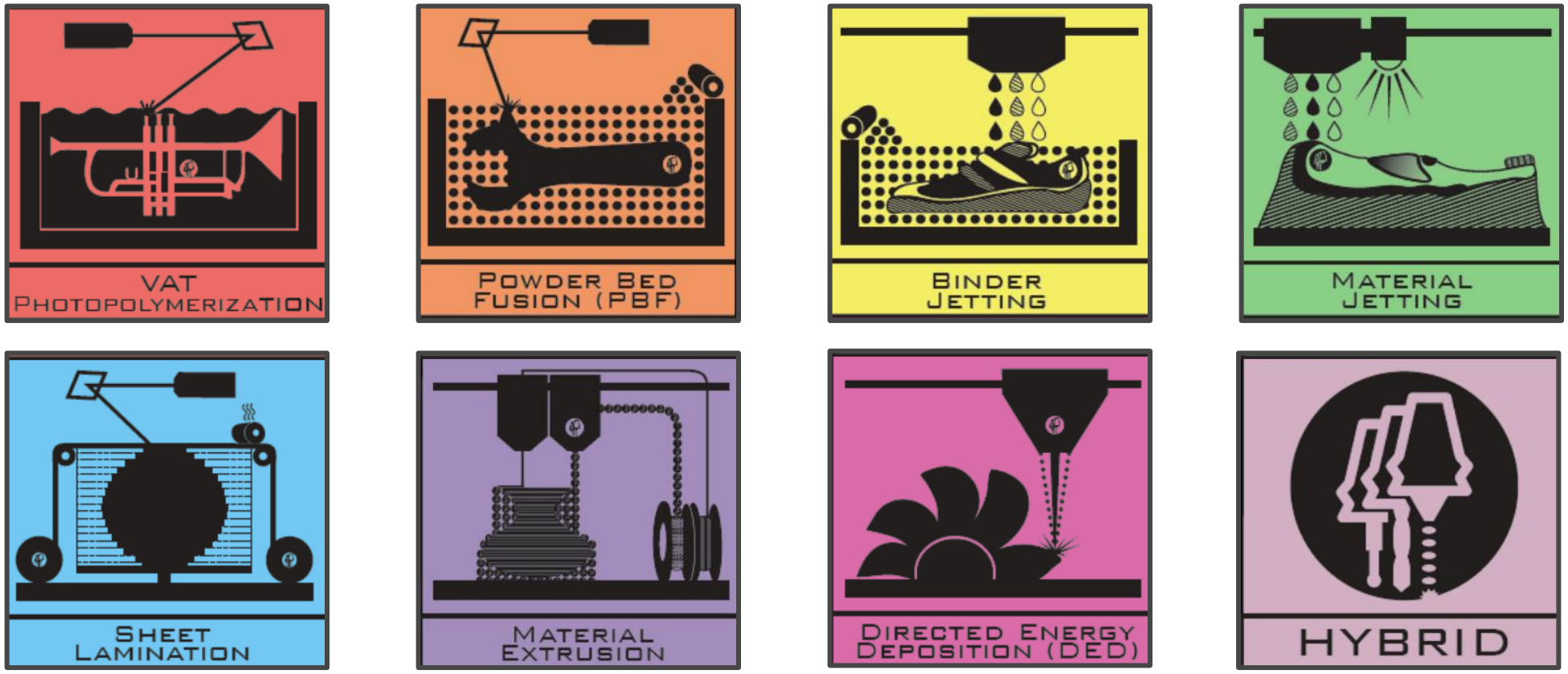
- What is additive manufacturing (AM)
- Why structure analysis is vital to AM
- What is x-ray CT
- How x-ray CT helps you throughout AM

What is additive manufacturing?

A product model generated using CAD to be fabricated directly without excessive process planning.

— *Additive Manufacturing Technologies: 3D Printing, Rapid Prototyping, and Direct Digital Manufacturing*
by Ian Gibson, David Rosen, Brent Stucker

Types of additive manufacturing



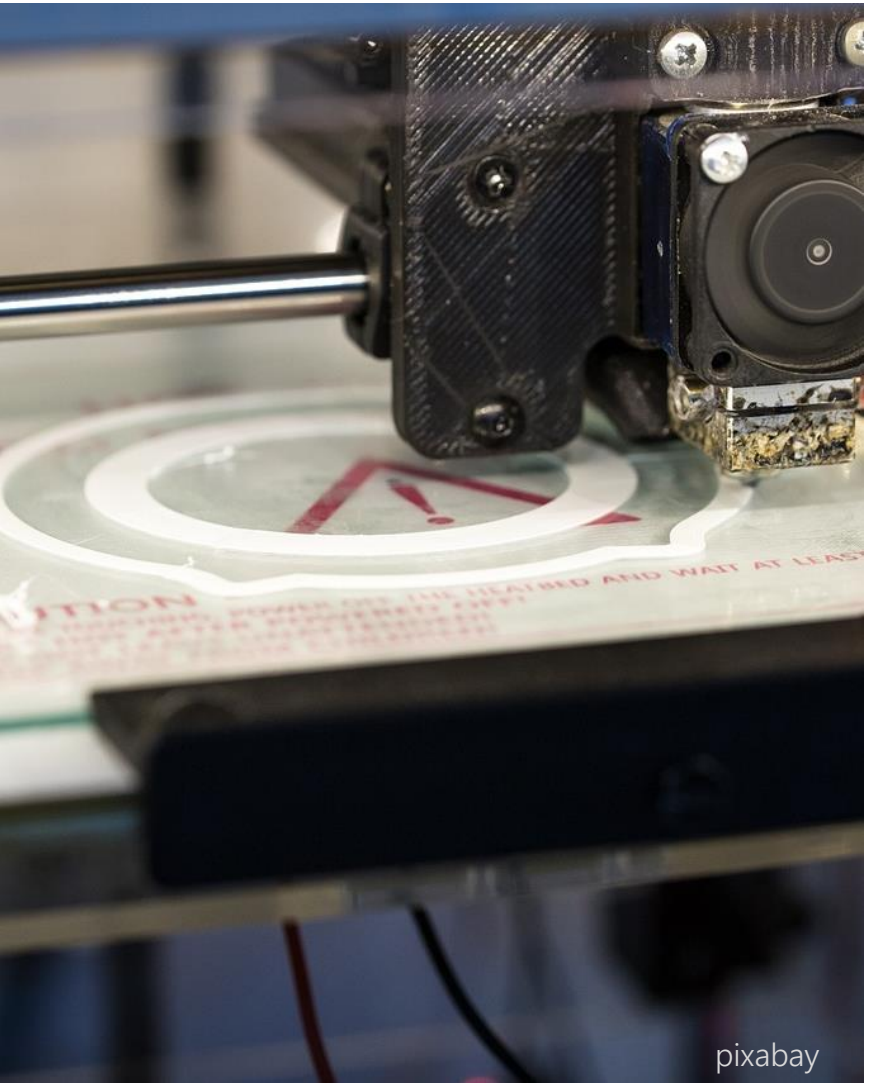
® KPTrumble

Why use additive manufacturing ?

- Fast
  - Design to product time
  - Iteration cycle
- Form
  - Shapes conventionally impractical
  - Vast amount of material choice

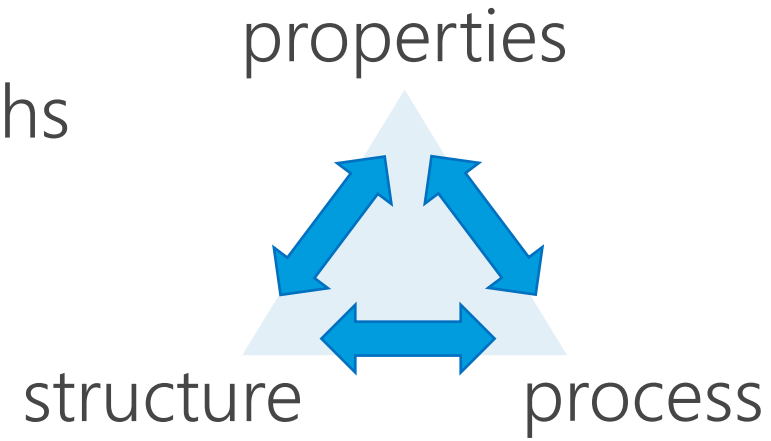
Polling Question #1

Microsoft Stock



Motivation for AM studies

- Improve overall properties
- Improve structure reliability
- Improve process precision
- Achieve breakthroughs



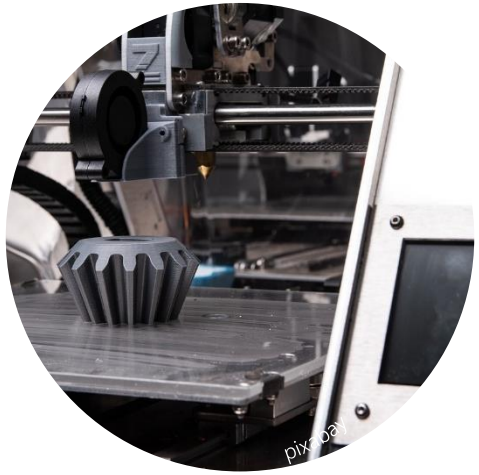
Process of additive manufacturing

Design

Virtual to physical

Physical to virtual

Build



Build quality

Quality improvement

Processing

Processing result

Process modification

Product

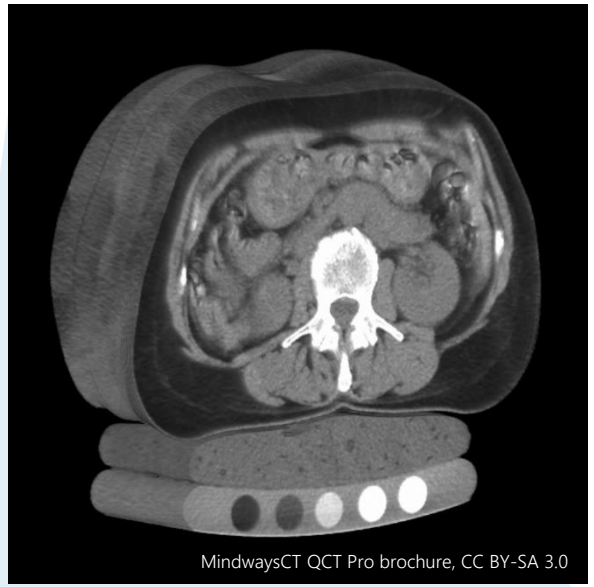
Final inspection

New iteration inspection

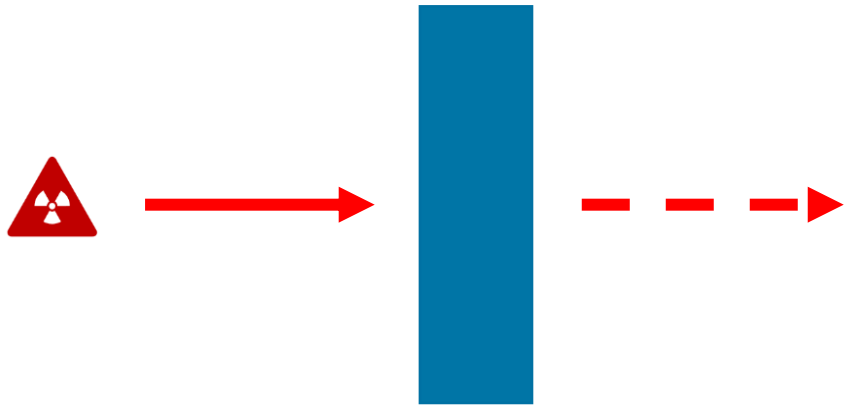
Structure

What is x-ray CT?

What is CT (Computed Tomography)



How do x-rays generate contrast?



Things absorb x-rays.

Object thickness

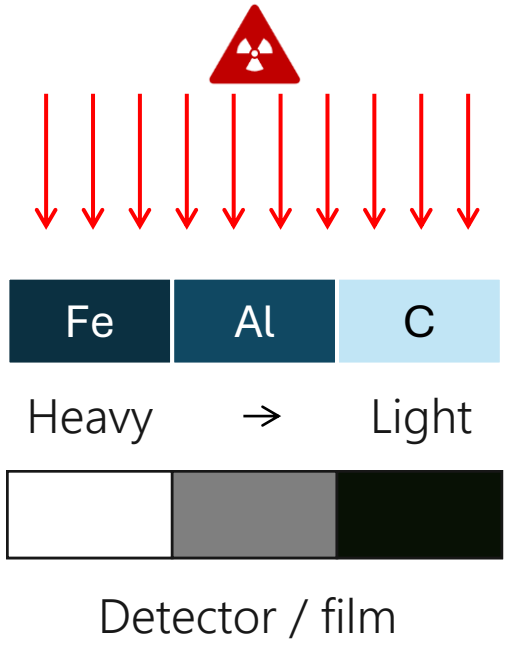
$$I_{measured} = I_{incident}\, e^{-\mu t}$$

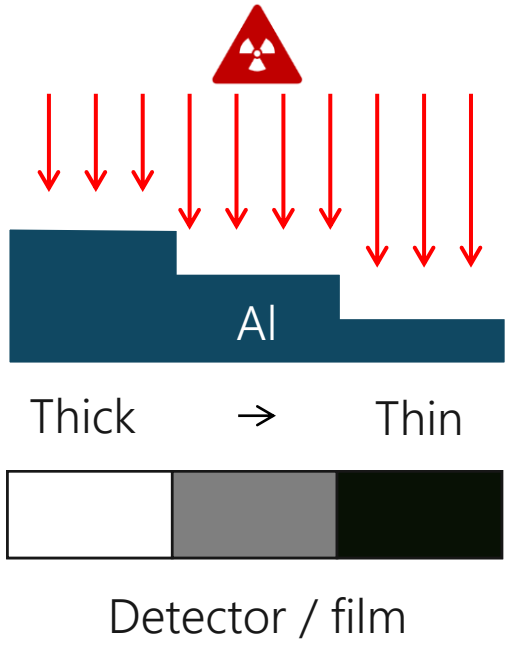
Attenuation coefficient

$$\mu \propto \frac{\rho A Z^4}{E^3}$$

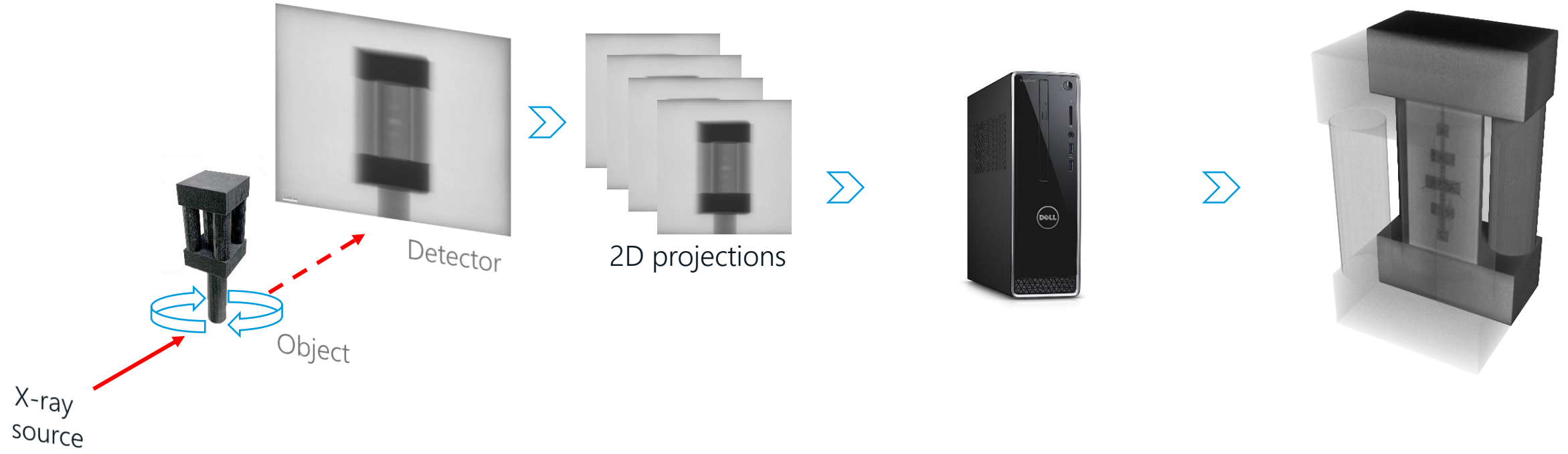
- $\propto$ Density (ρ)
- $\propto$ Atomic number (Z)
- $\propto$ Atomic mass (A)
- $\propto \frac{1}{\text{X-ray energy } (E)}$

How do x-rays generate contrast?





How does X-ray CT acquire 3D structural data?

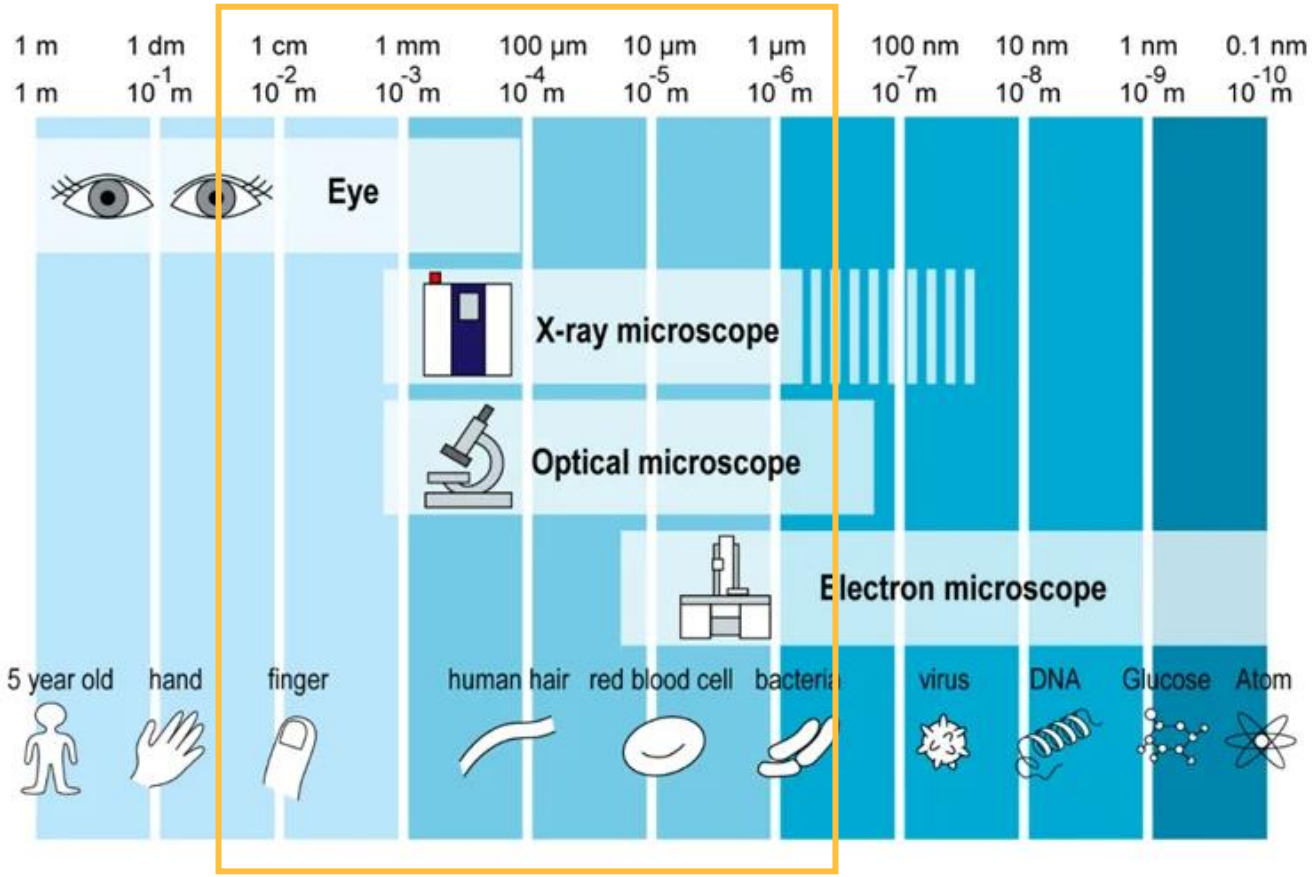


Common structure analysis methods

Common structure analysis methods

- Specific feature analysis
  - Archimedes density testing
  - Ultrasonic detection
  - Coordinate measuring machine (CMM)
- Image based inspection
  - Microscopy (optical, SEM)
  - X-ray radiography
  - X-ray CT

Structural features scale

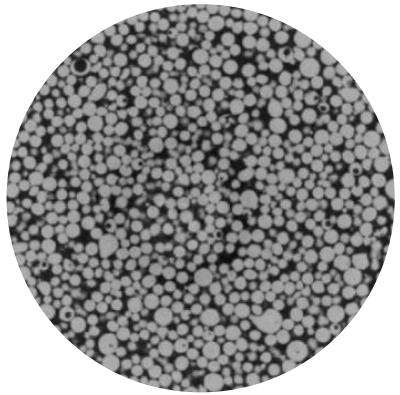


Size range of common AM features of interest

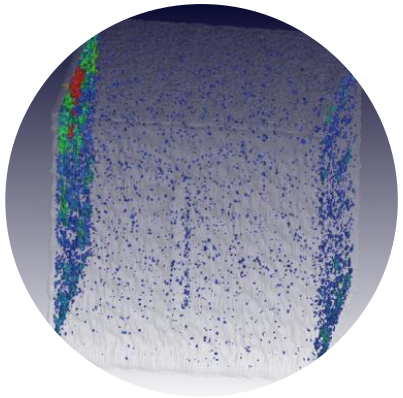
What are structural features of interest ?

Key structural features of interest for AM

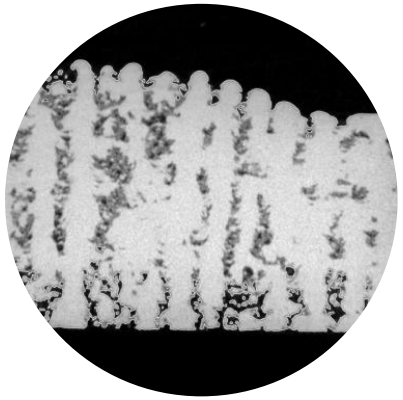
Powder analysis



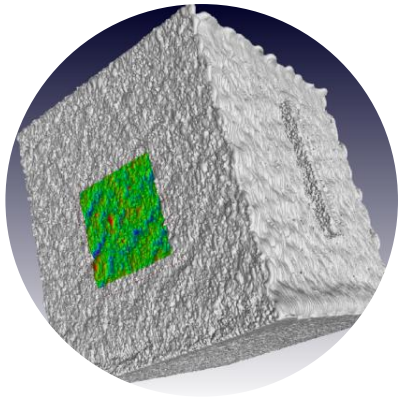
Porosity



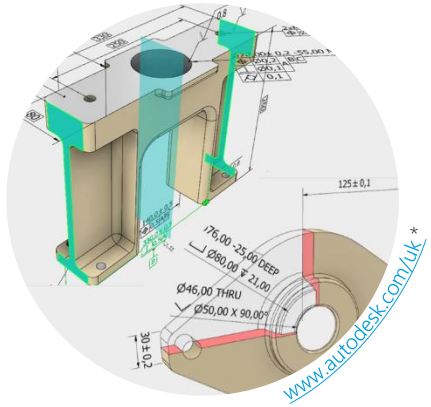
Density



Surface roughness



Dimensioning



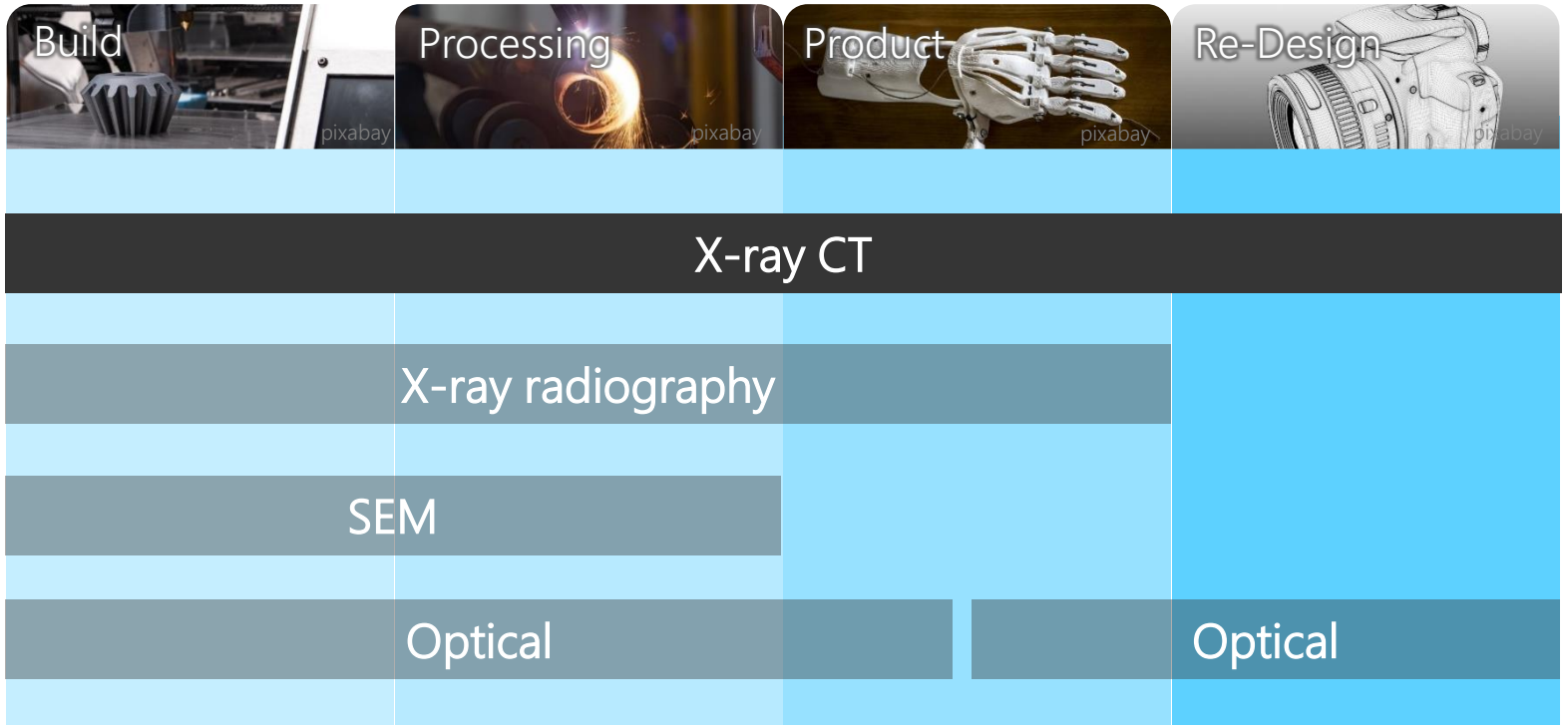
Morphology
Size distribution

Tolerance variation
Actual to nominal

Du Plessis, Anton, et al. "*Standard method for microCT-based additive manufacturing quality control 1-4*" MethodsX 5 (2018)

Powder analysis article link Porosity article link Density article link Surface roughness article link

Why choose x-ray CT?



Objective advantages:

Internal structure
Non-destructive
Spatial 3D data

Polling Question #2

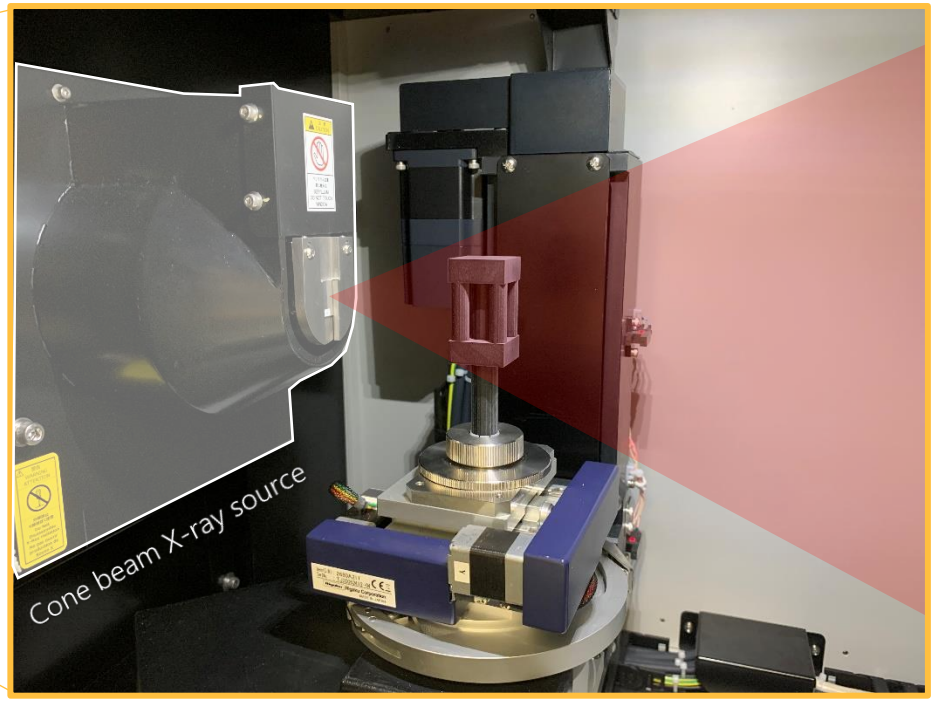
Microsoft Stock

Structure analysis x-ray CT examples

Photopolymer

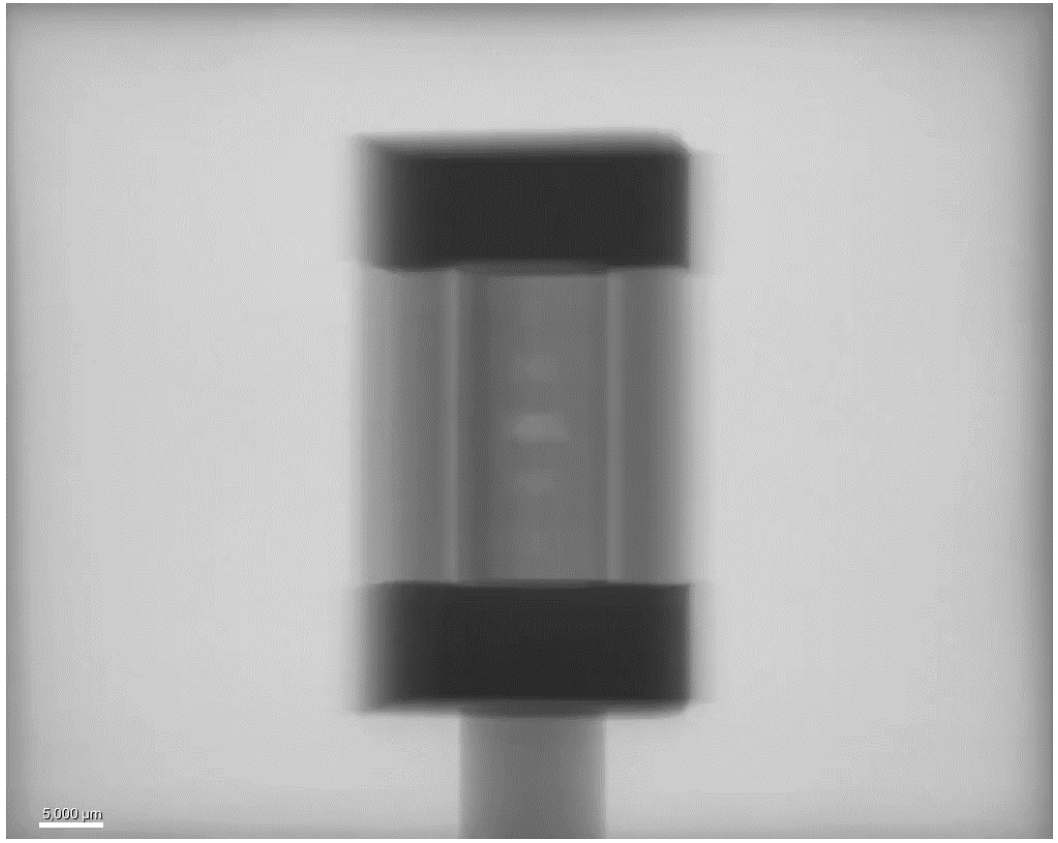
(Vat polymerization)

Photopolymer- CT scan process



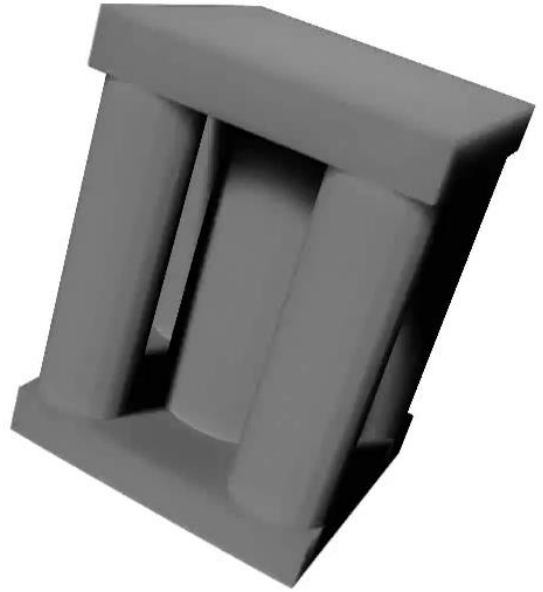
Finest voxel resolution 2.1 μm

Photopolymer- CT scan process



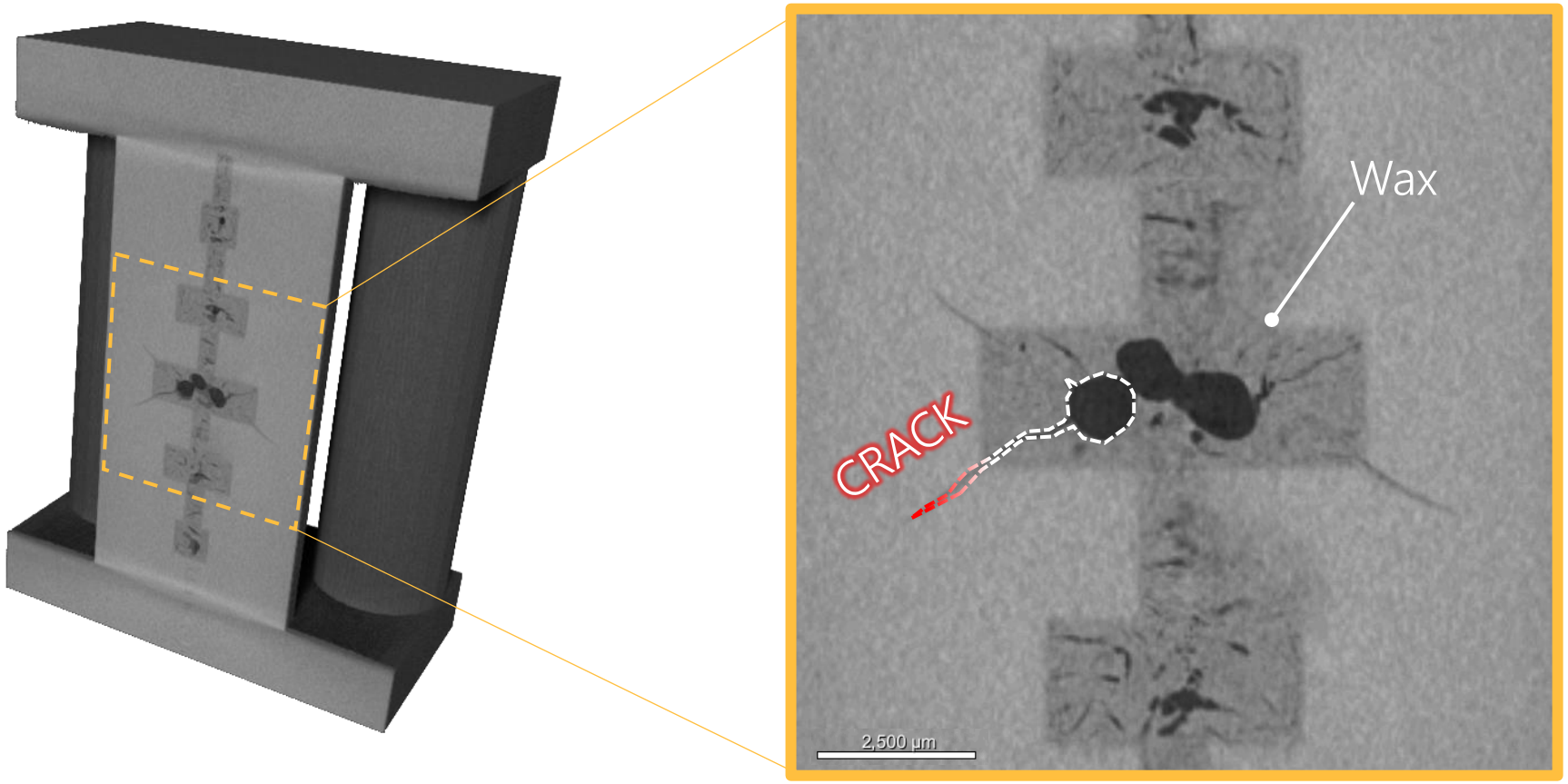
2D Radiograph

3D Reconstruction



dragonfly 3D World

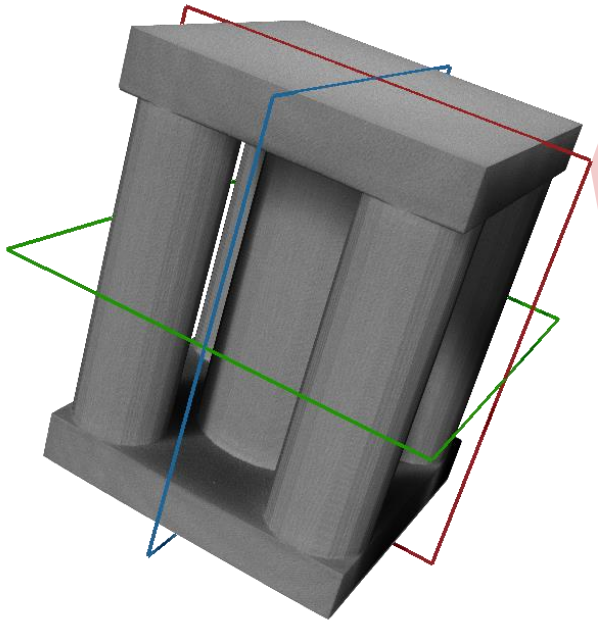
Photopolymer- 2D inspection

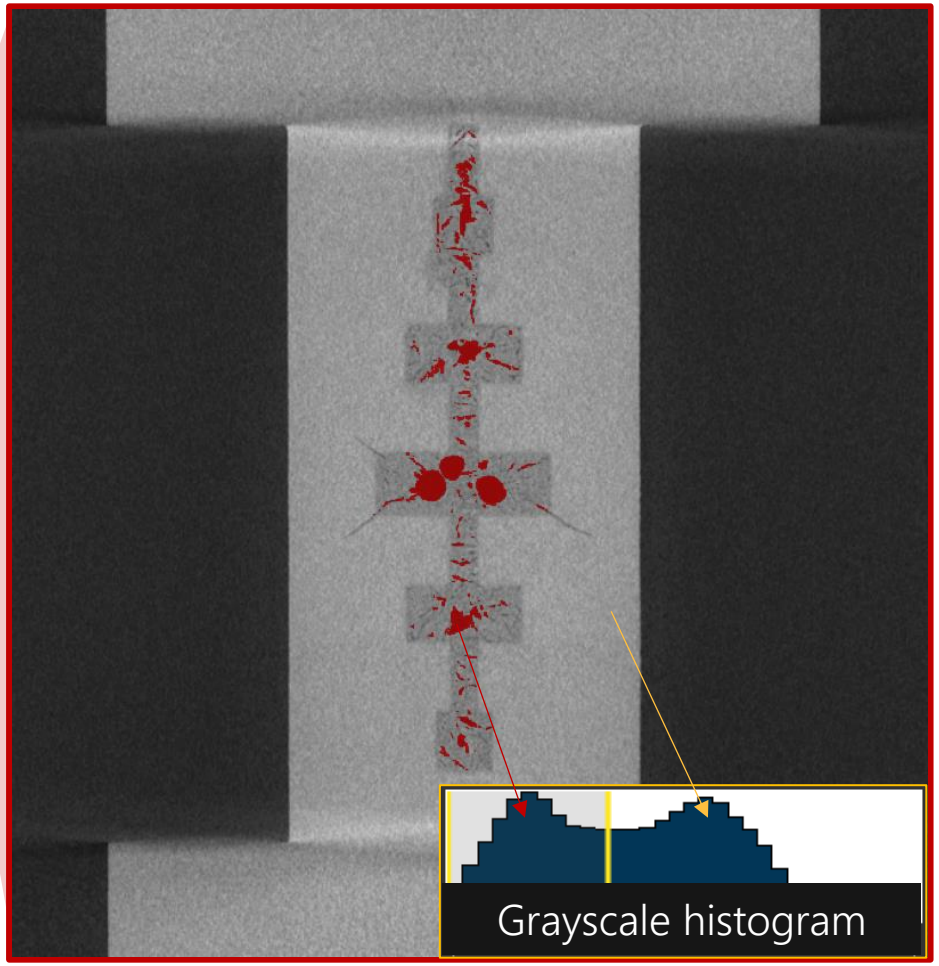


Crack grew into printed material

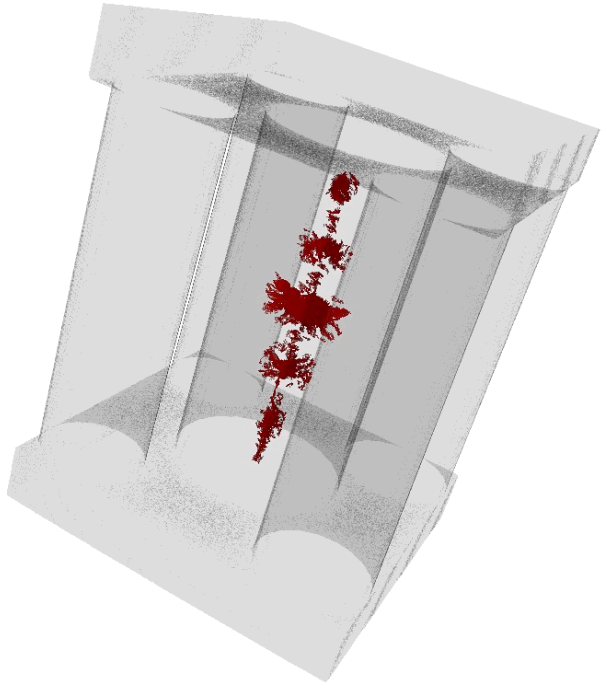
dragonfly 3D World

Photopolymer- 3D inspection





- 3D visualization
- Quantification



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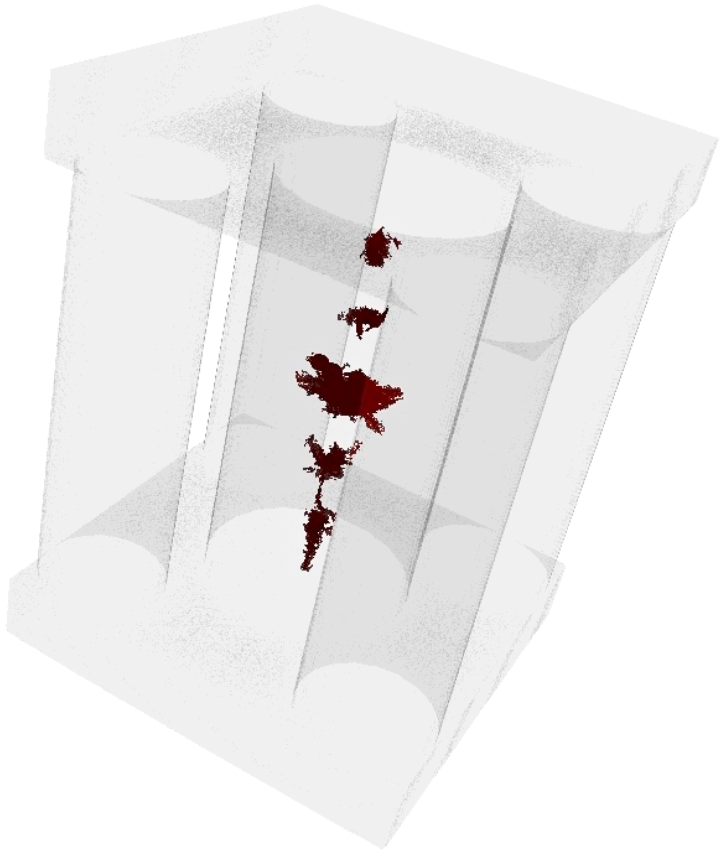
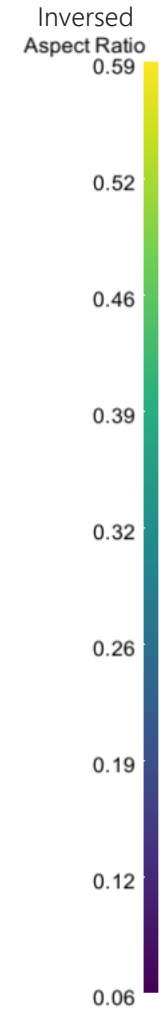
Photopolymer- Void analysis



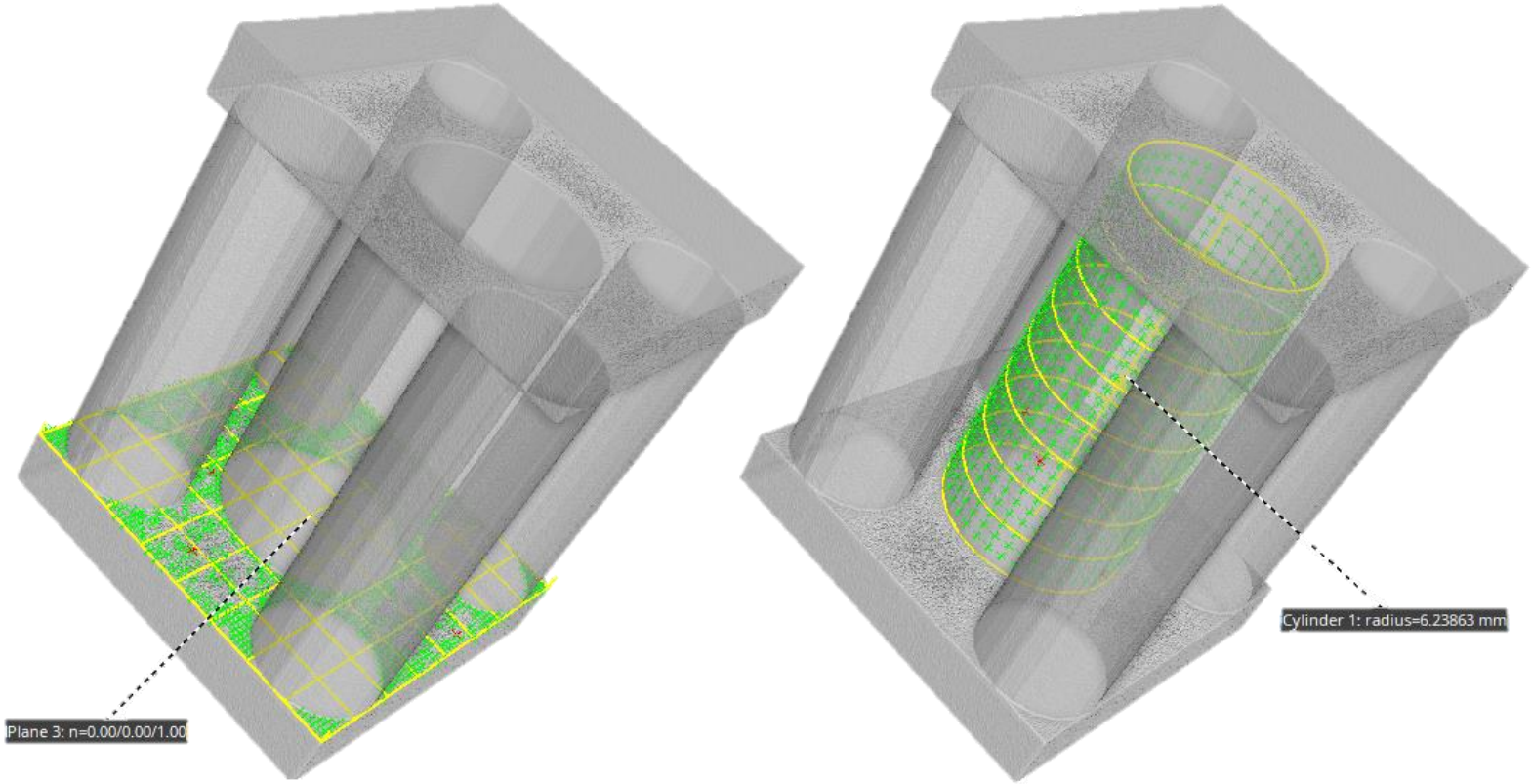
Larger voids

Small pores



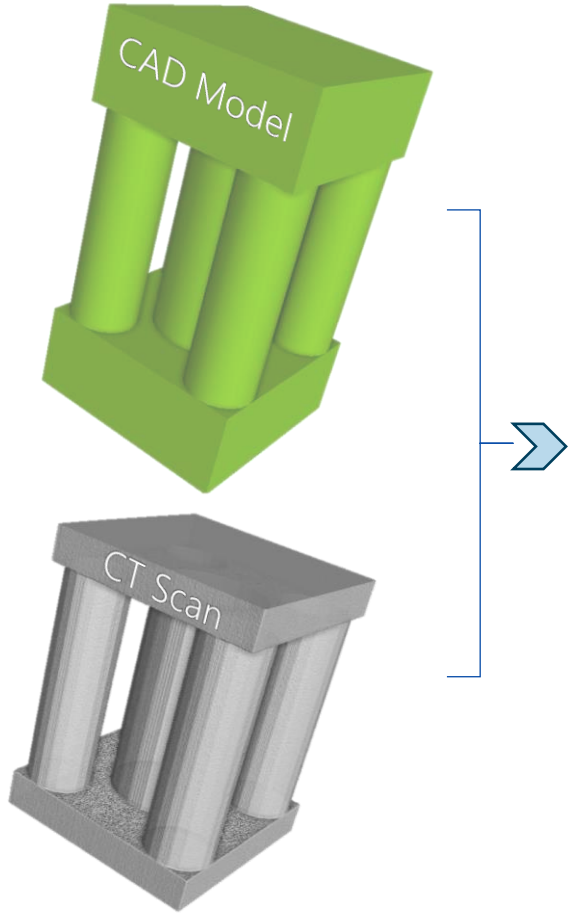
dragonfly
3D World

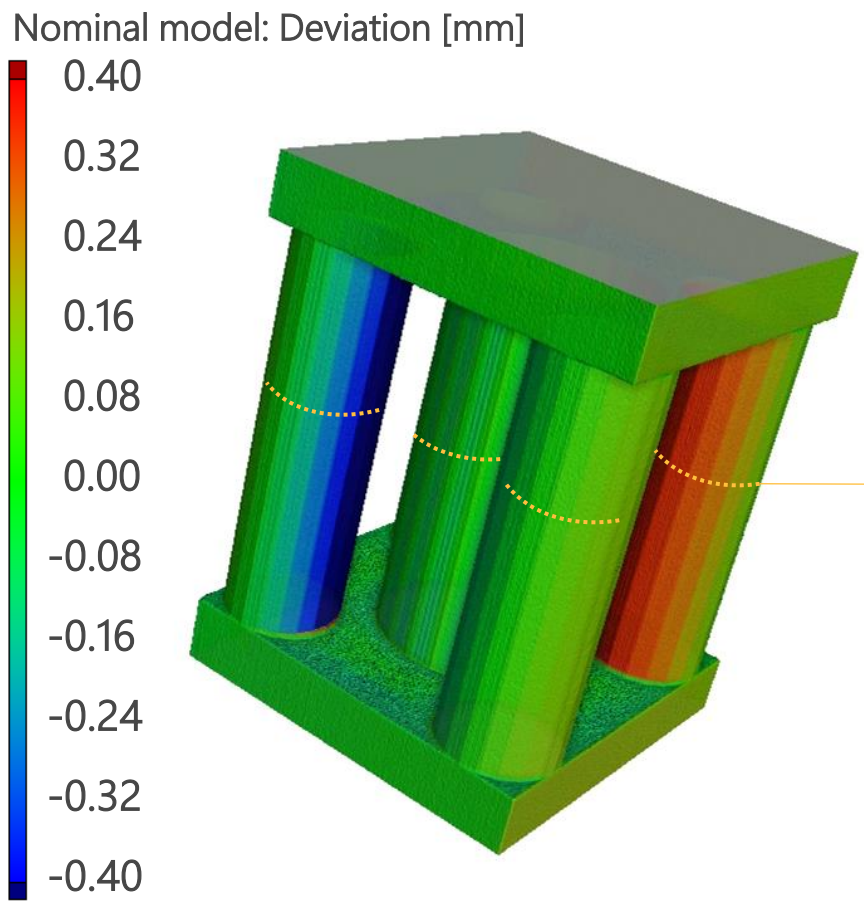
Photopolymer- 3D dimensioning

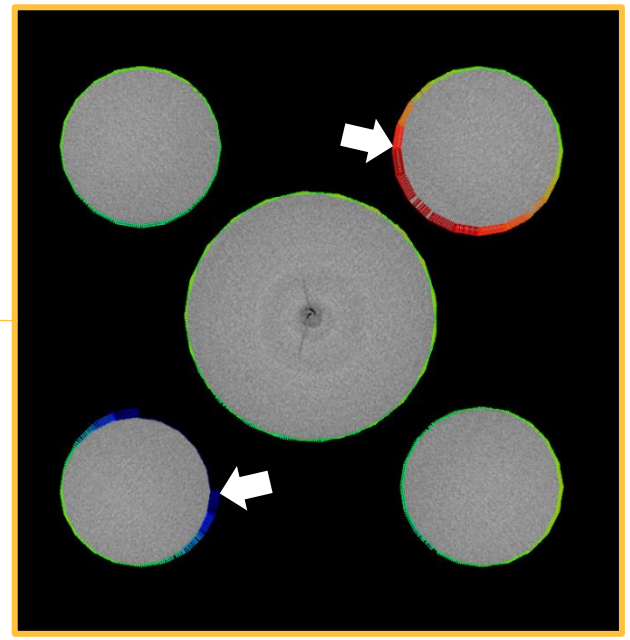


- Volume visualization
- Nominal to actual

Photopolymer- Nominal to actual comparison







Metal powder

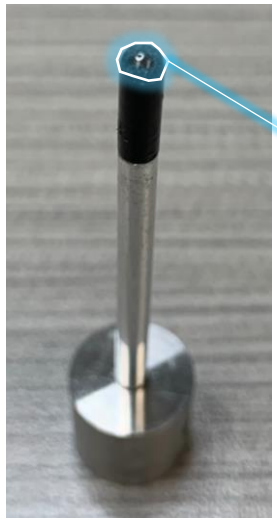
(For PBF & DED)

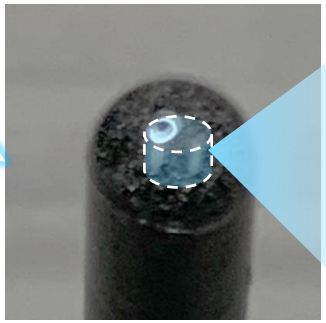
Metal powder- CT scan process

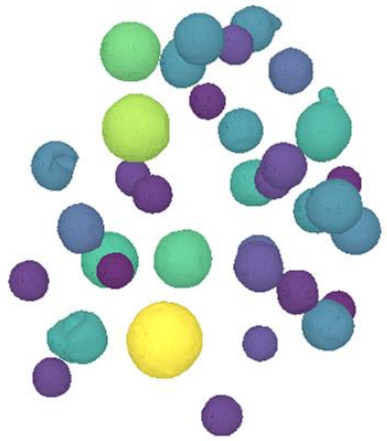
Finest voxel resolution 325 nm

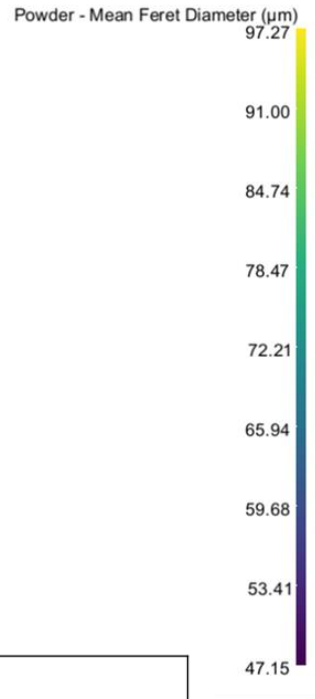
Metal powder- Morphology analysis

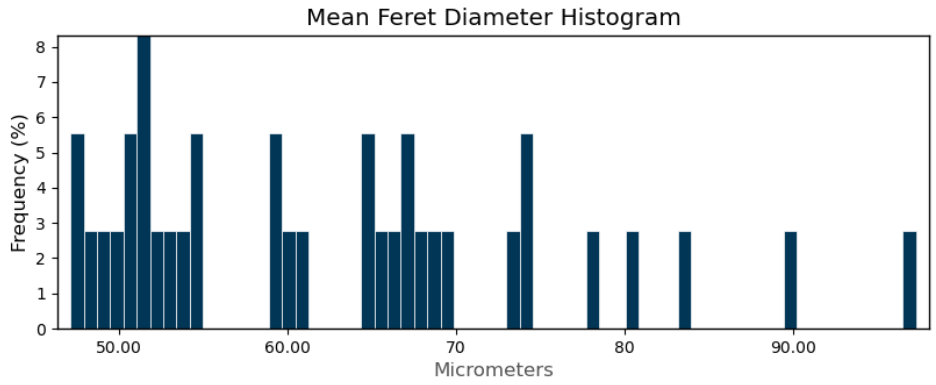
Titanium alloy powder











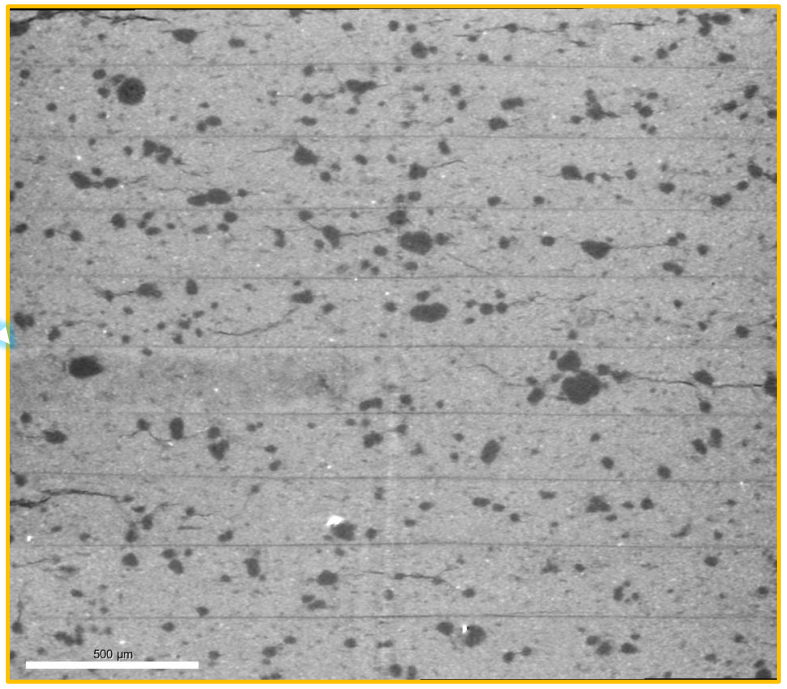
dragonfly 3D World

Ceramic

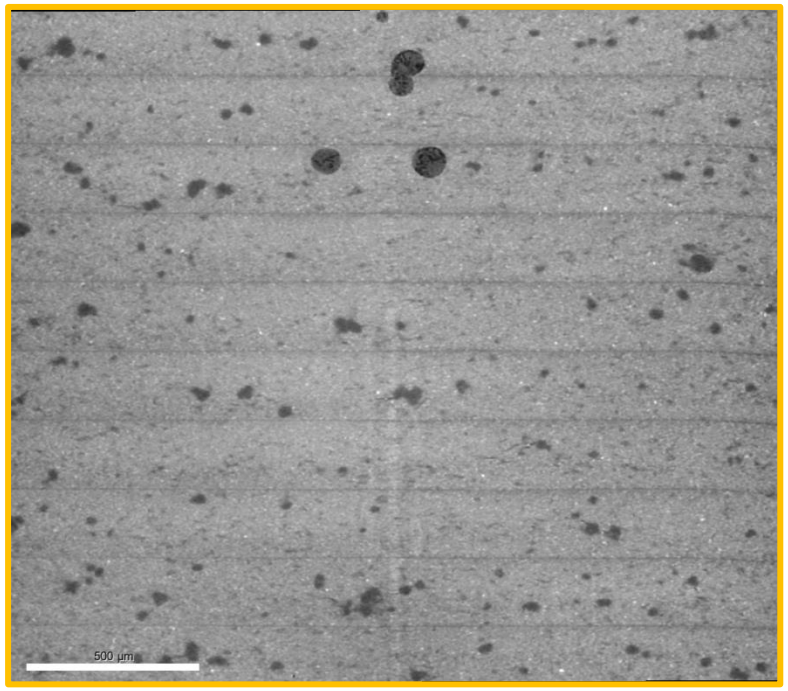
(Sheet lamination)

Ceramic- 2D inspection

Green body
Sample A

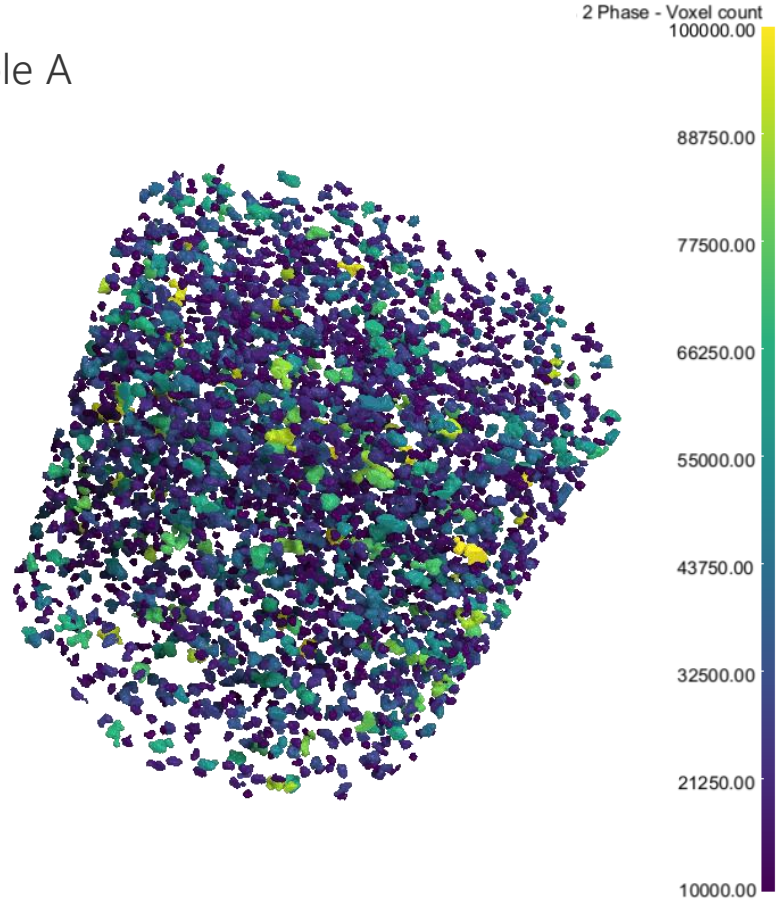


Green body
Sample B

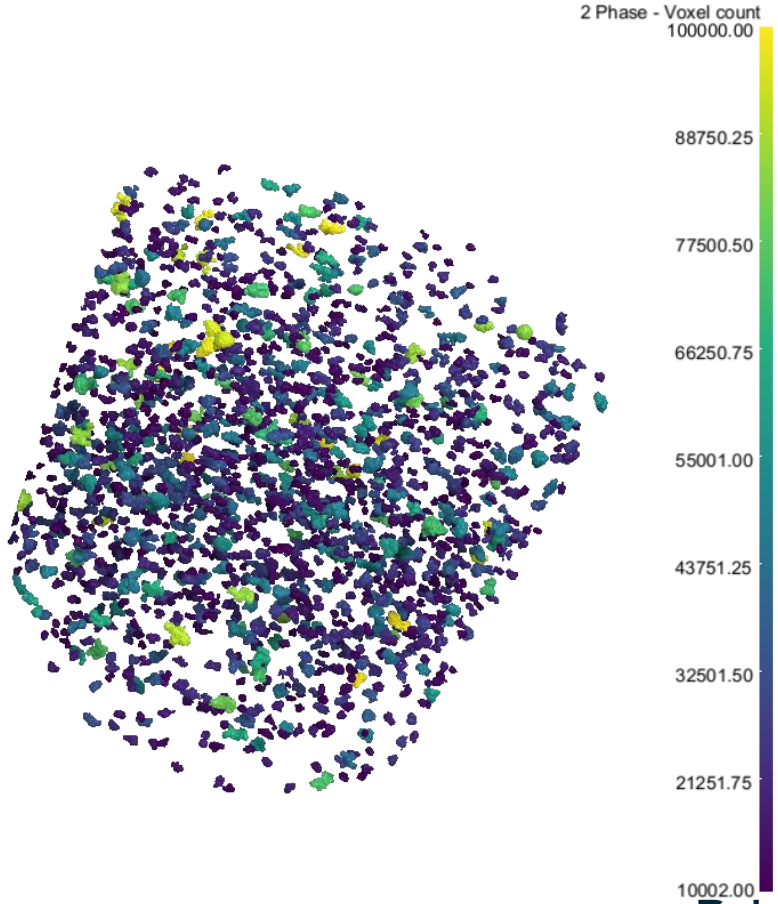


Ceramic- 3D inspection

Sample A



Sample B



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Ceramic- 2D inspection

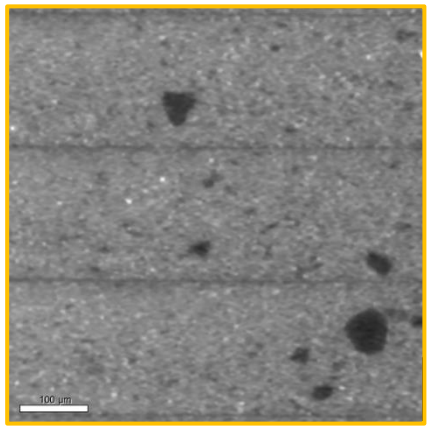
Green body

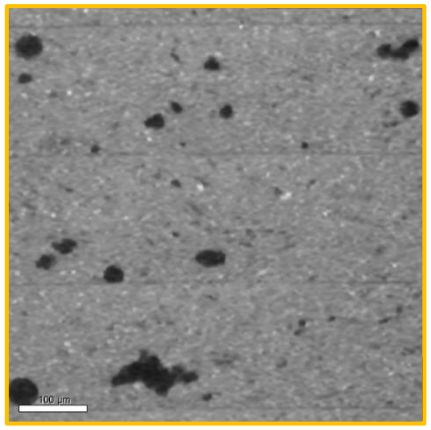
Pre-baking

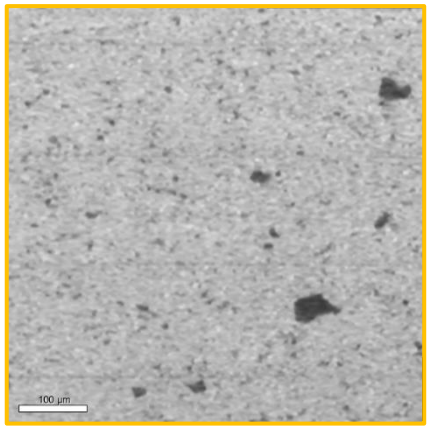
Brown body

Major Sintering

Sintered body

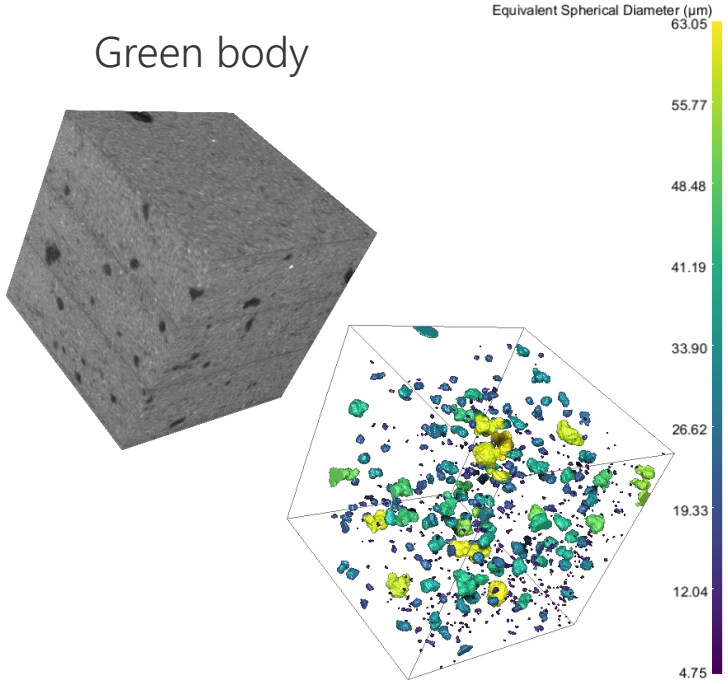






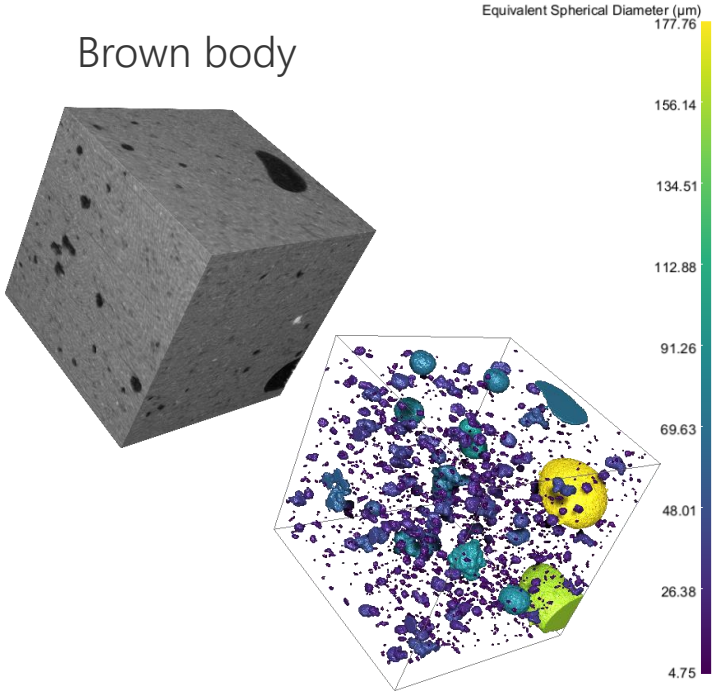
Ceramic- Potential time resolved analysis

Green body



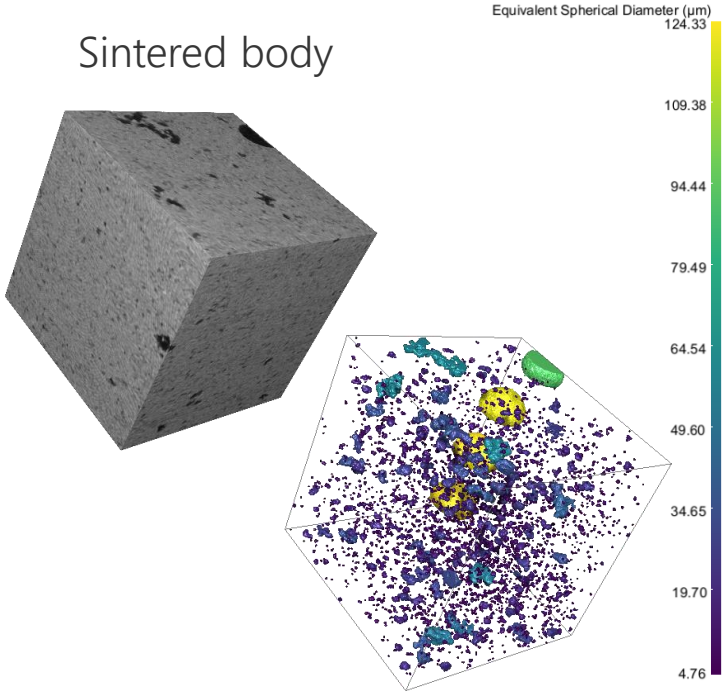
Mean Equivalent Spherical Diameter:
13.05 µm

Brown body



Mean Equivalent Spherical Diameter:
11.11 µm

Sintered body



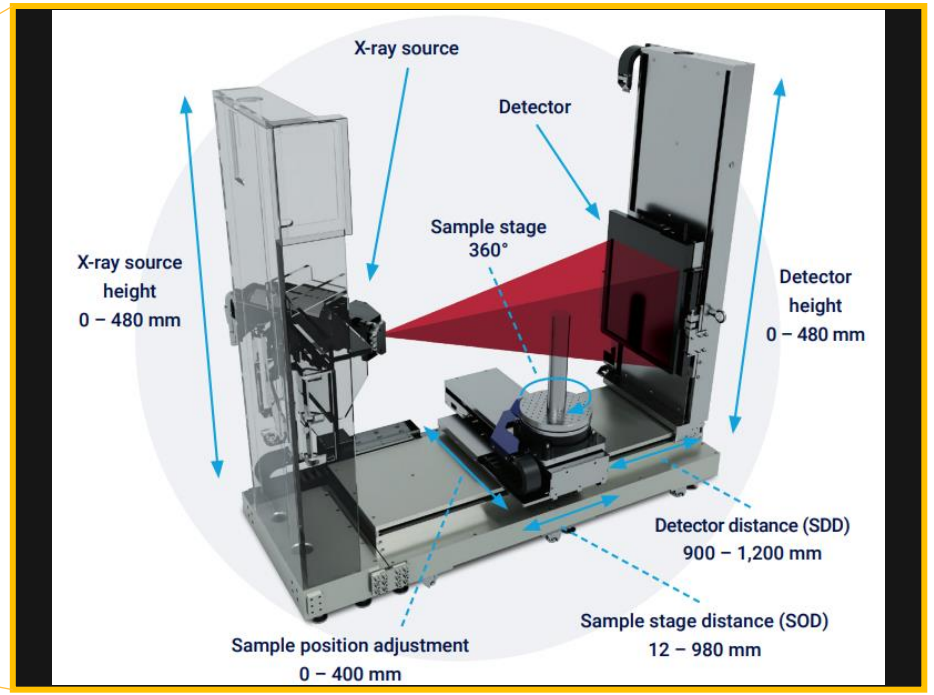
Mean Equivalent Spherical Diameter:
8.45 µm

dragonfly 3D World

Titanium alloy rods

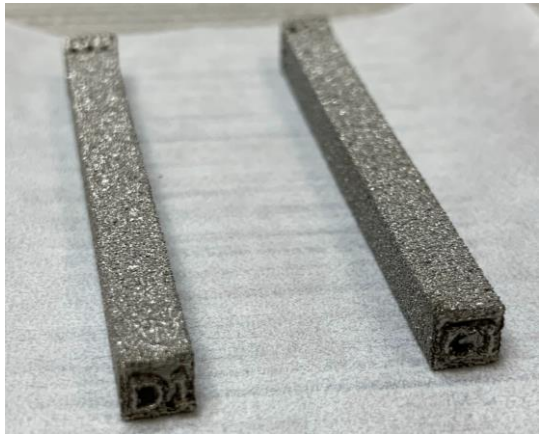
(PBF)

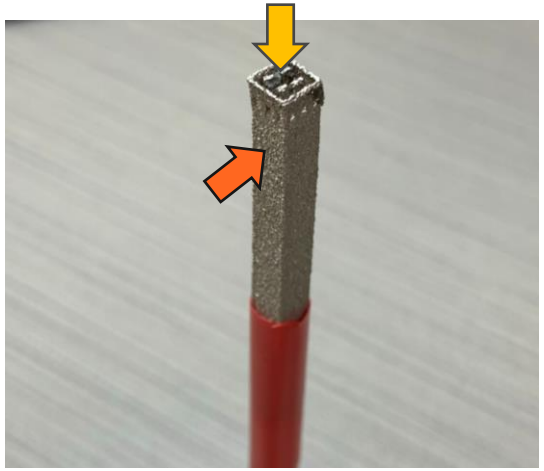
Titanium alloy rods- CT scan process

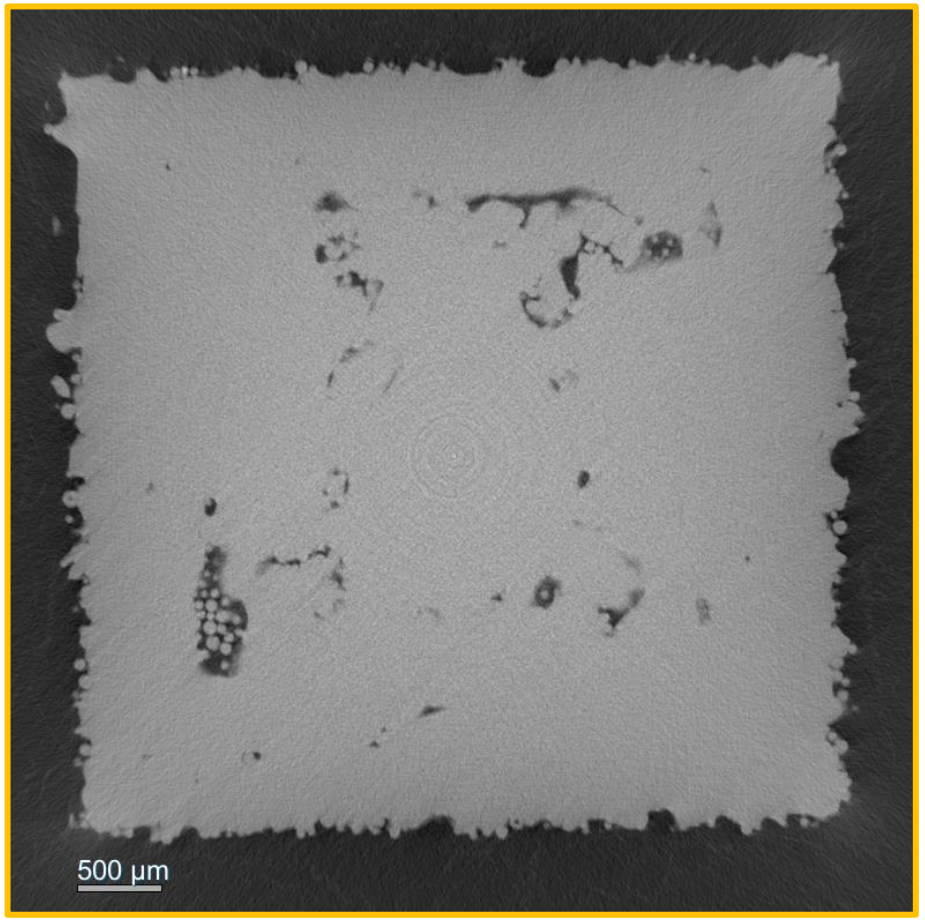


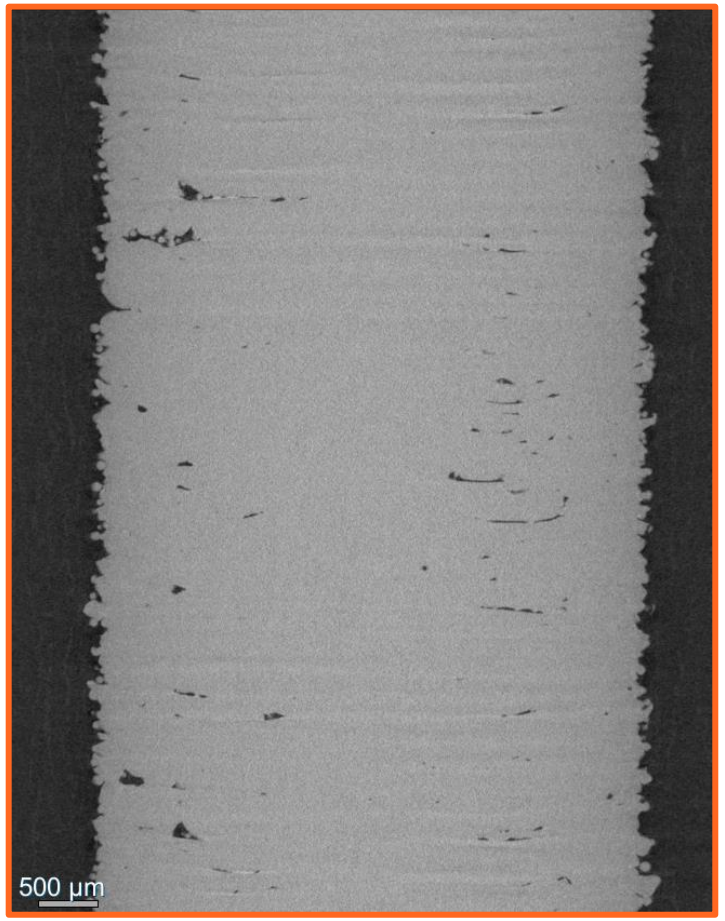
Finest voxel resolution 1.5 µm

Titanium alloy rods- 2D inspection



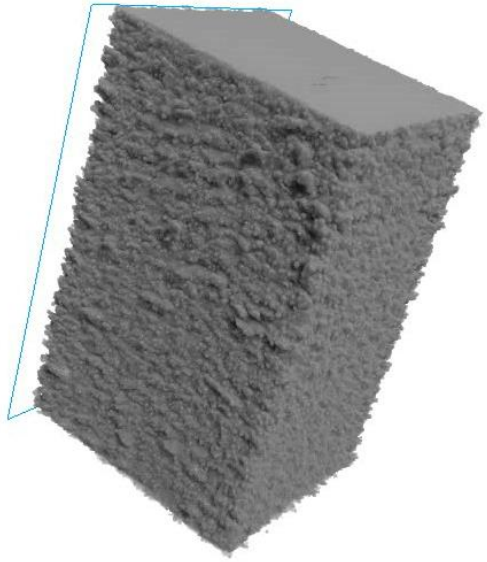




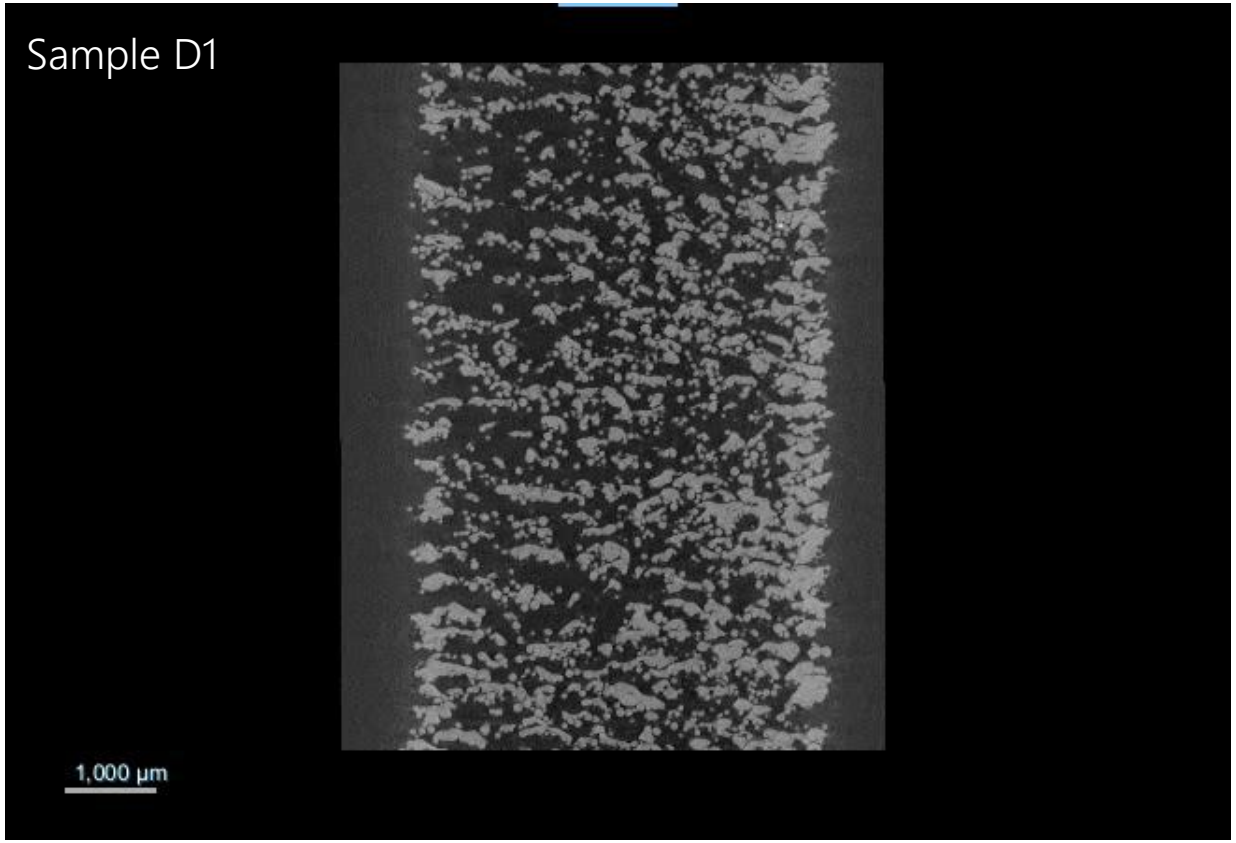


Titanium alloy rods- 2D inspection

Sample D1



3D slice location



2D slices

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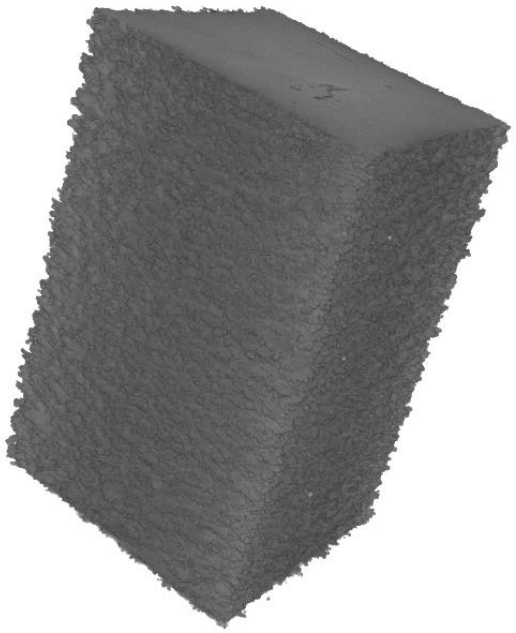
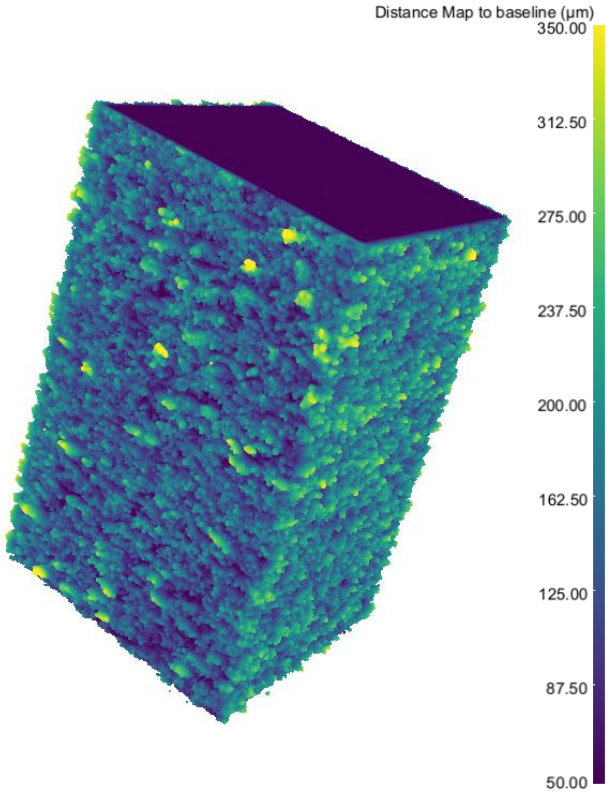
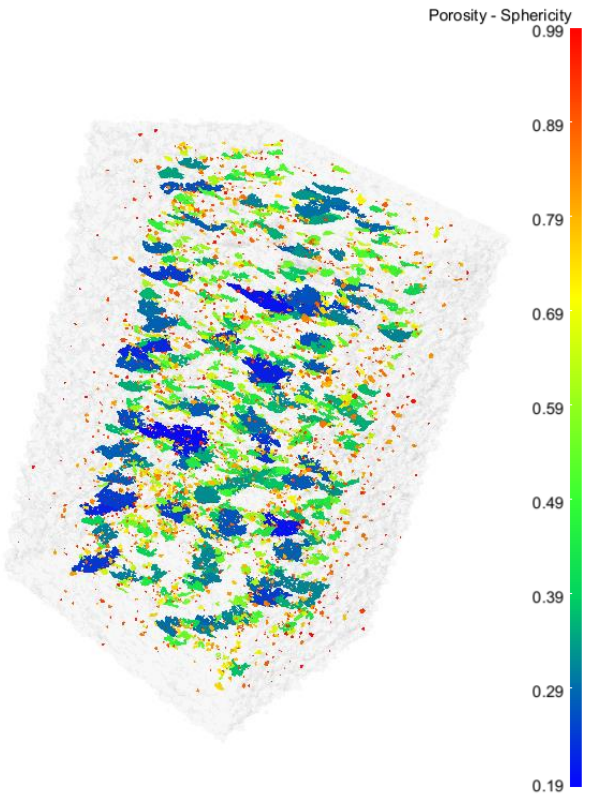
Titanium alloy rods- 3D inspection

Sample D1







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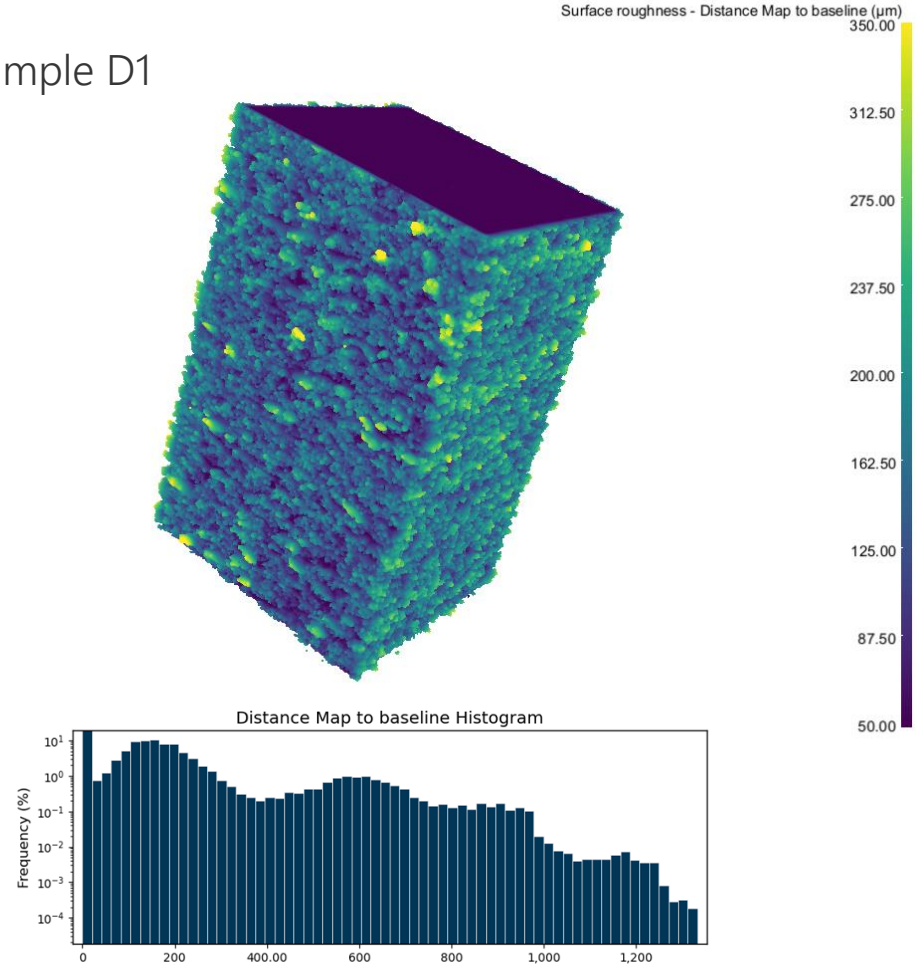
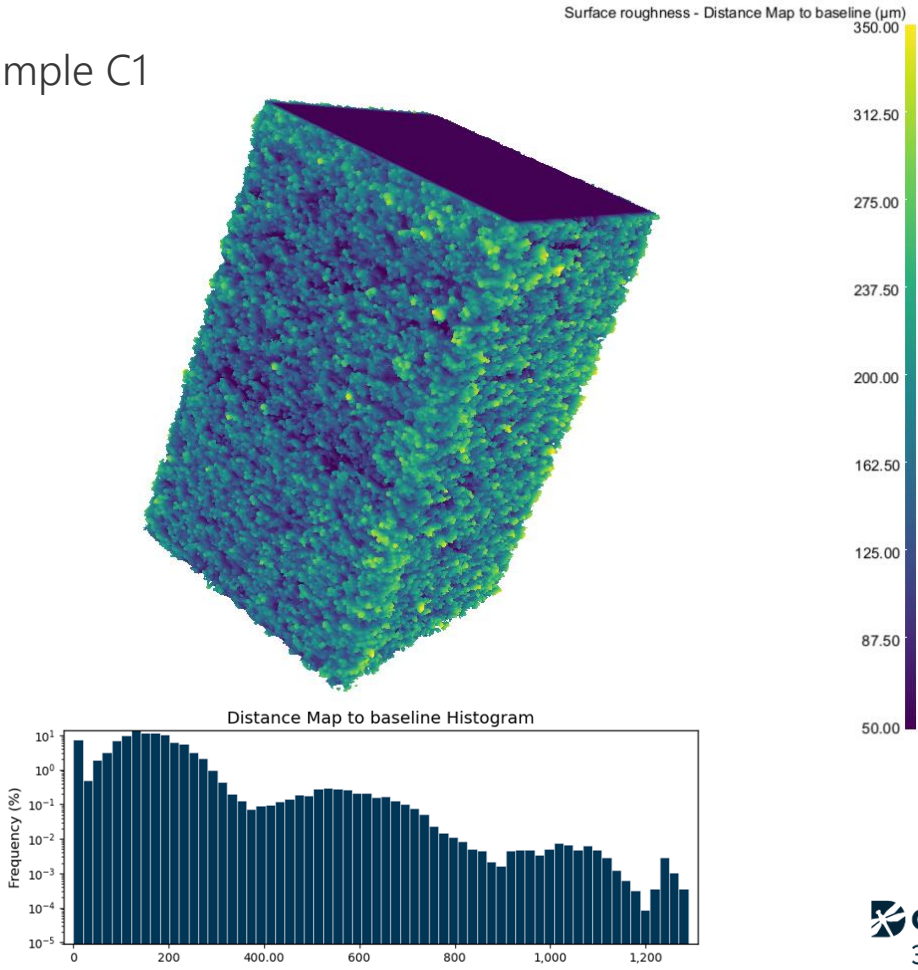
Titanium alloy rods- Surface roughness

Sample D1



Sample C1



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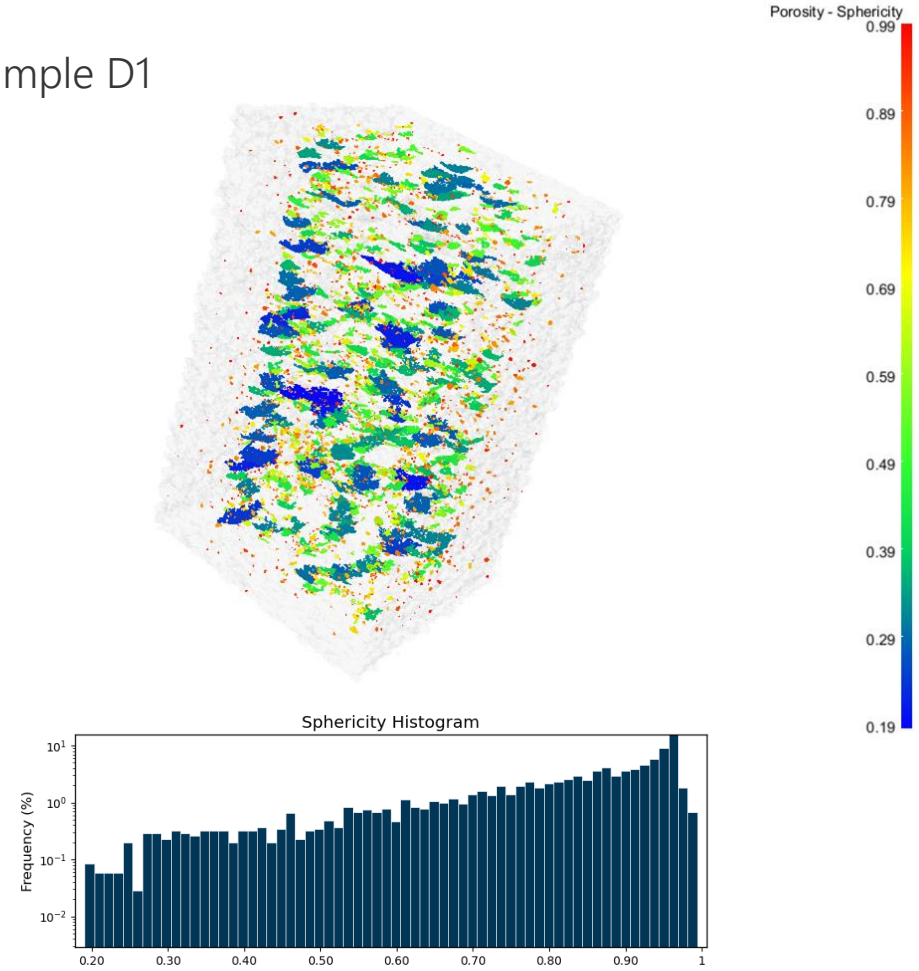
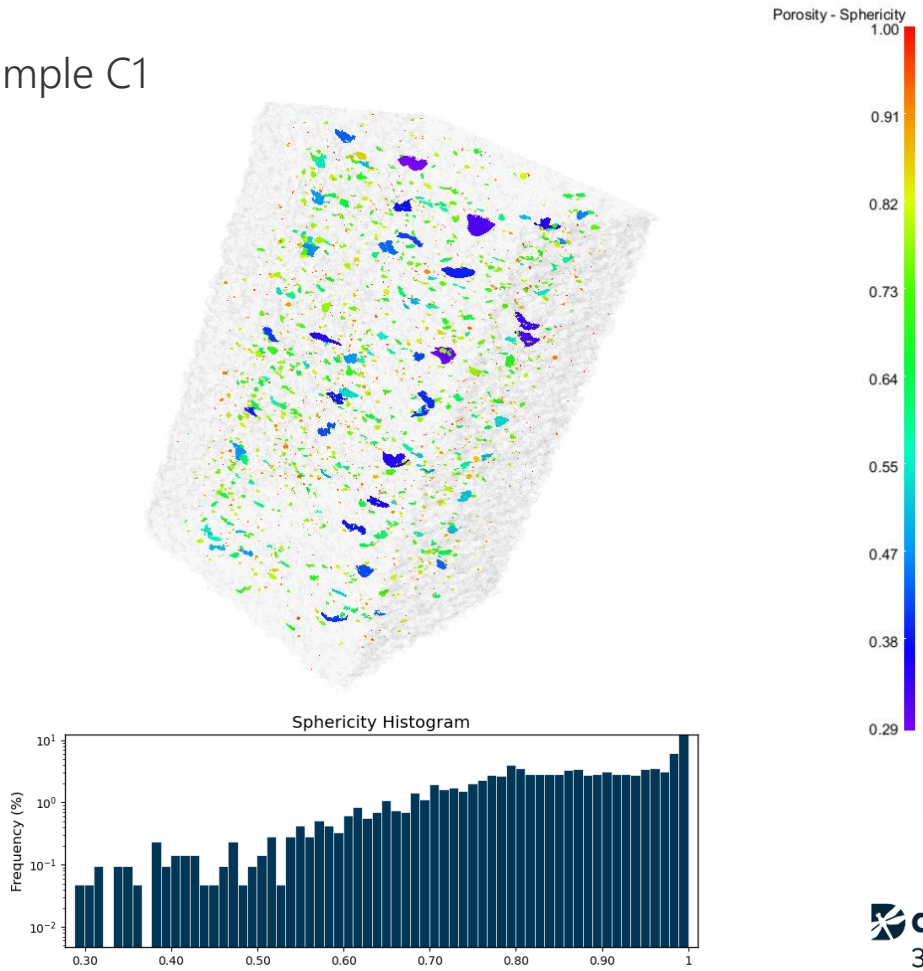
Titanium alloy rods- Void analysis

Sample D1



Sample C1



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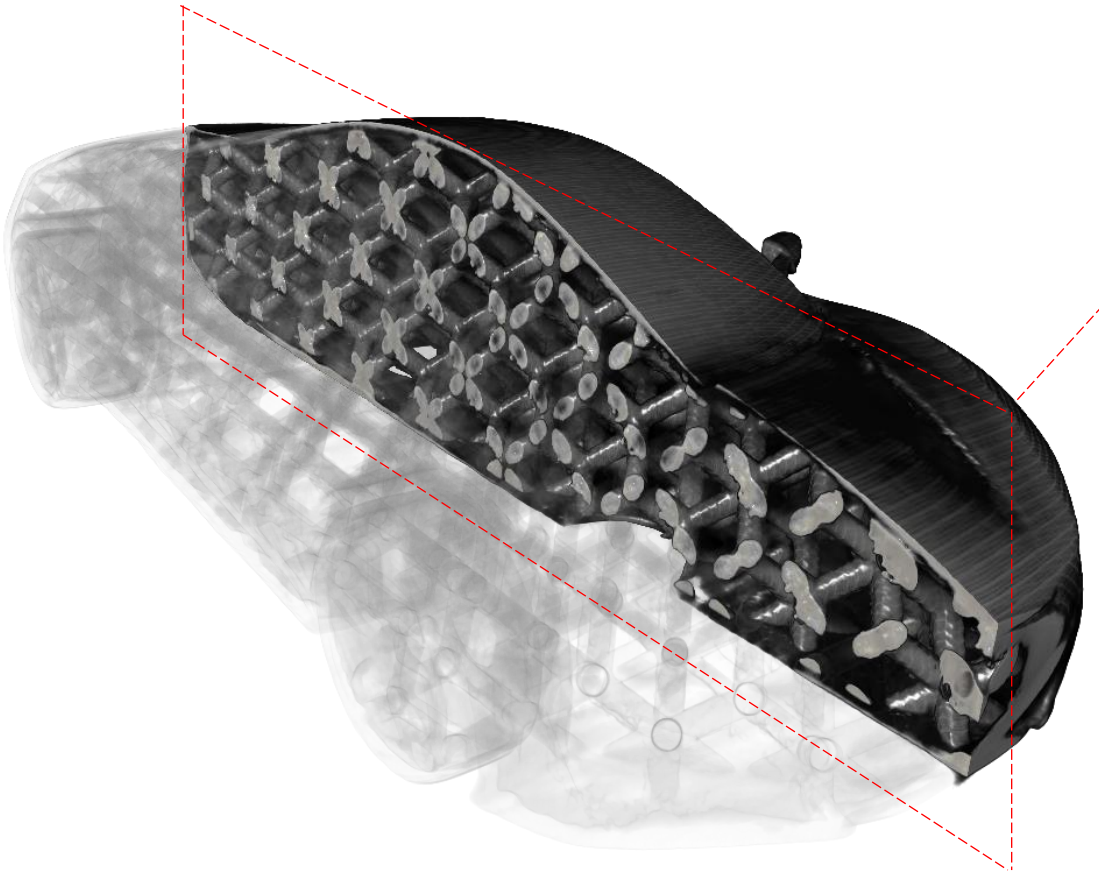
Superalloy (Inconel®)

(PBF)

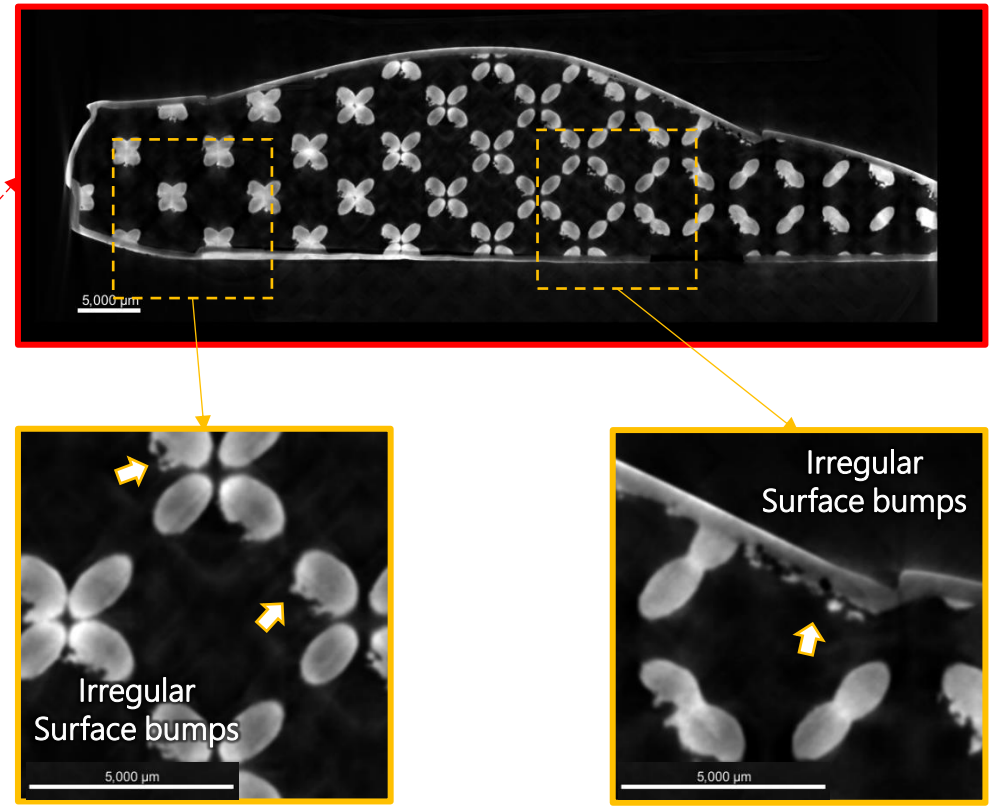
Superalloy (Inconel®)- CT scan process

Finest voxel resolution 1.5 µm

Superalloy (Inconel®)- 3D visualization



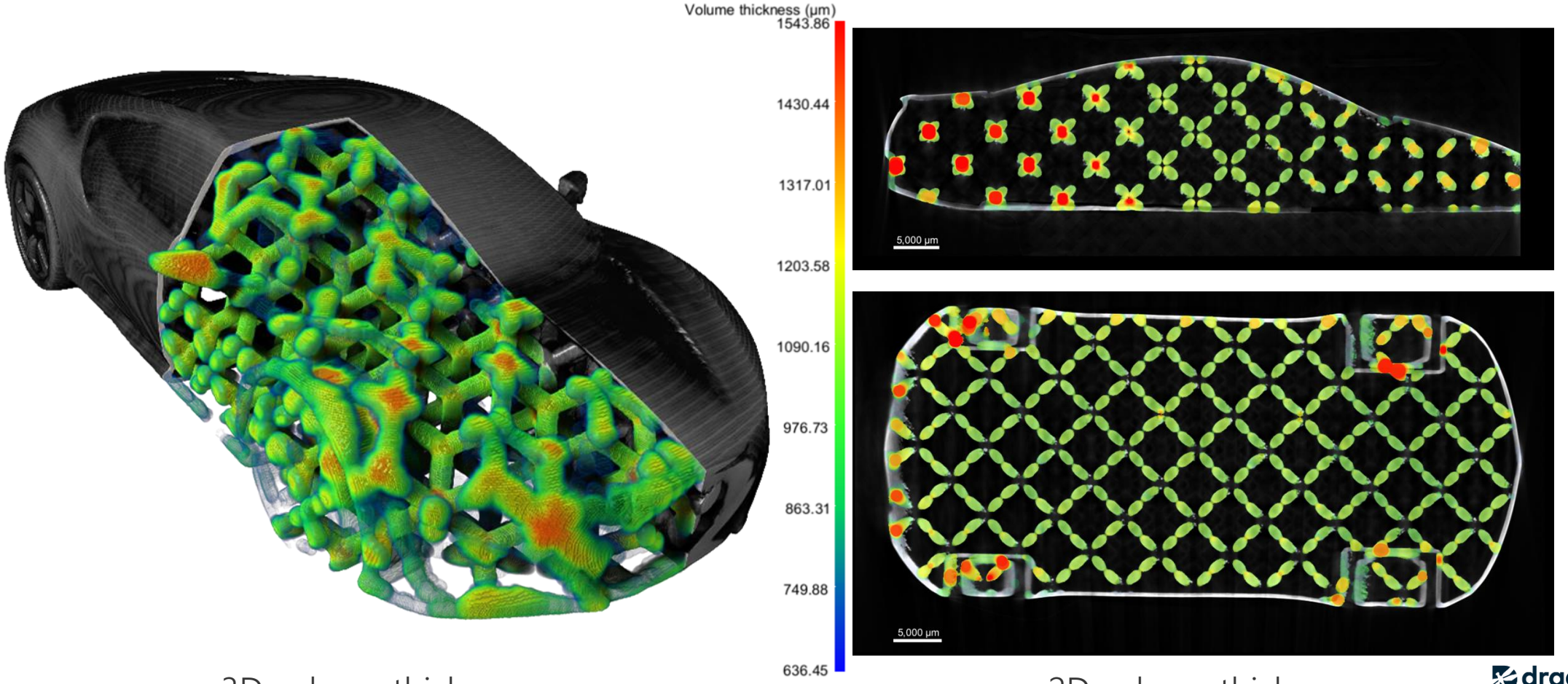
3D render



2D views

dragonfly 3D World

Superalloy (Inconel®)- 3D visualization



3D volume thickness

2D volume thickness

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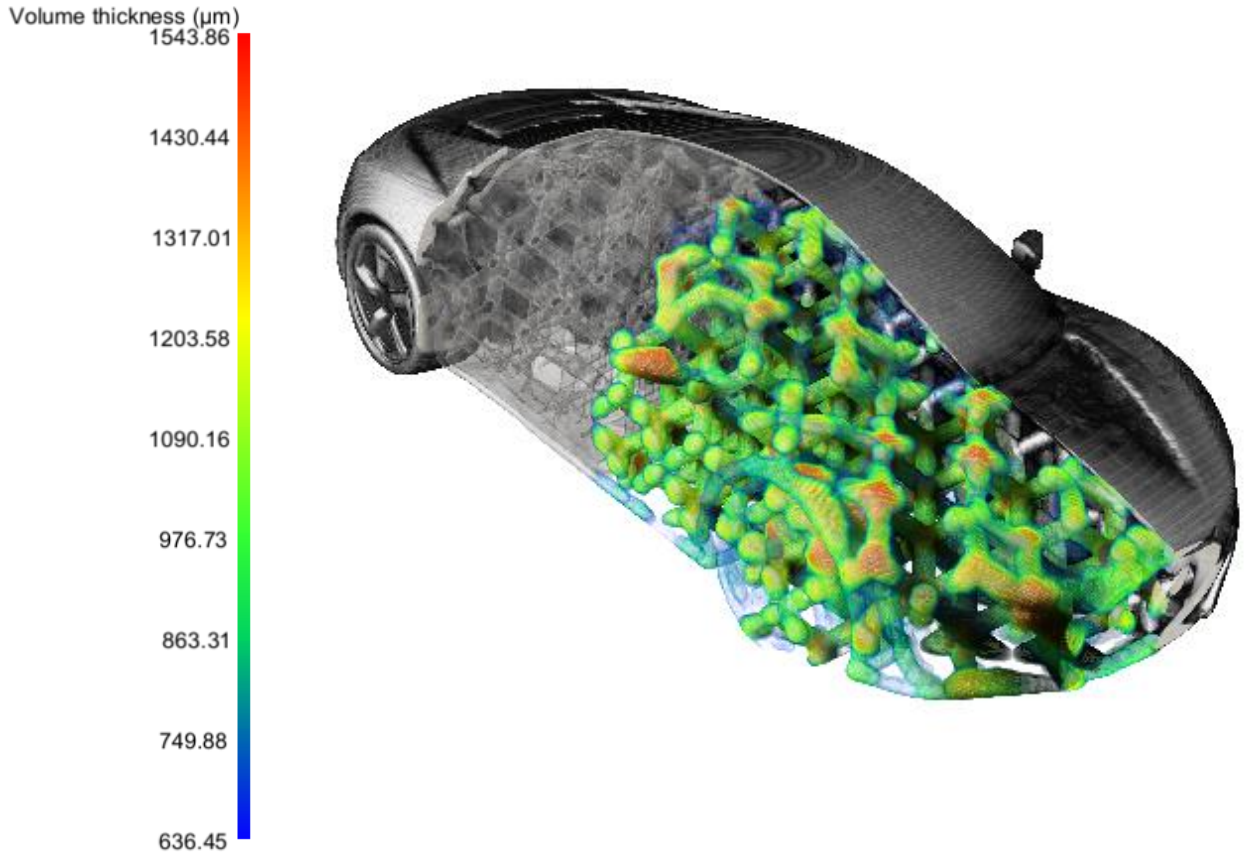
Superalloy (Inconel®)- 3D visualization



- Simulation
- Load distribution

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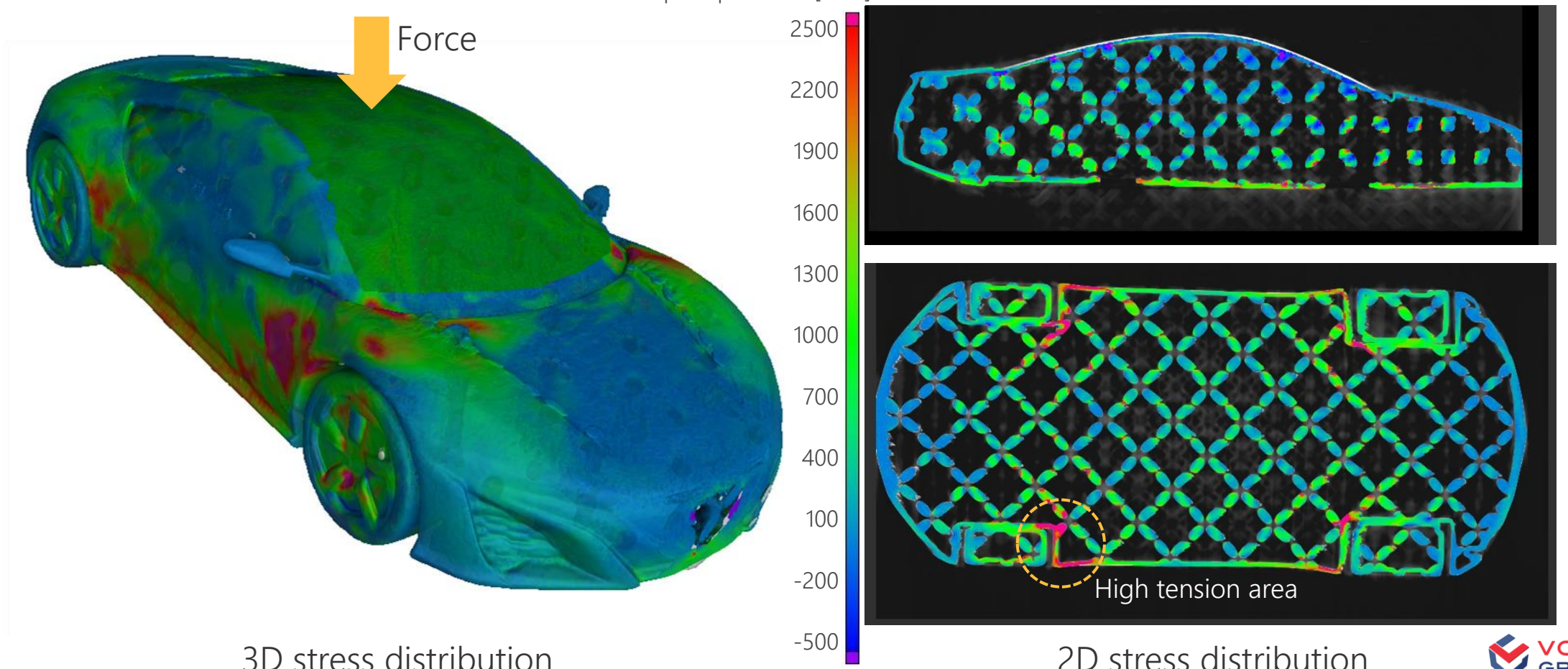
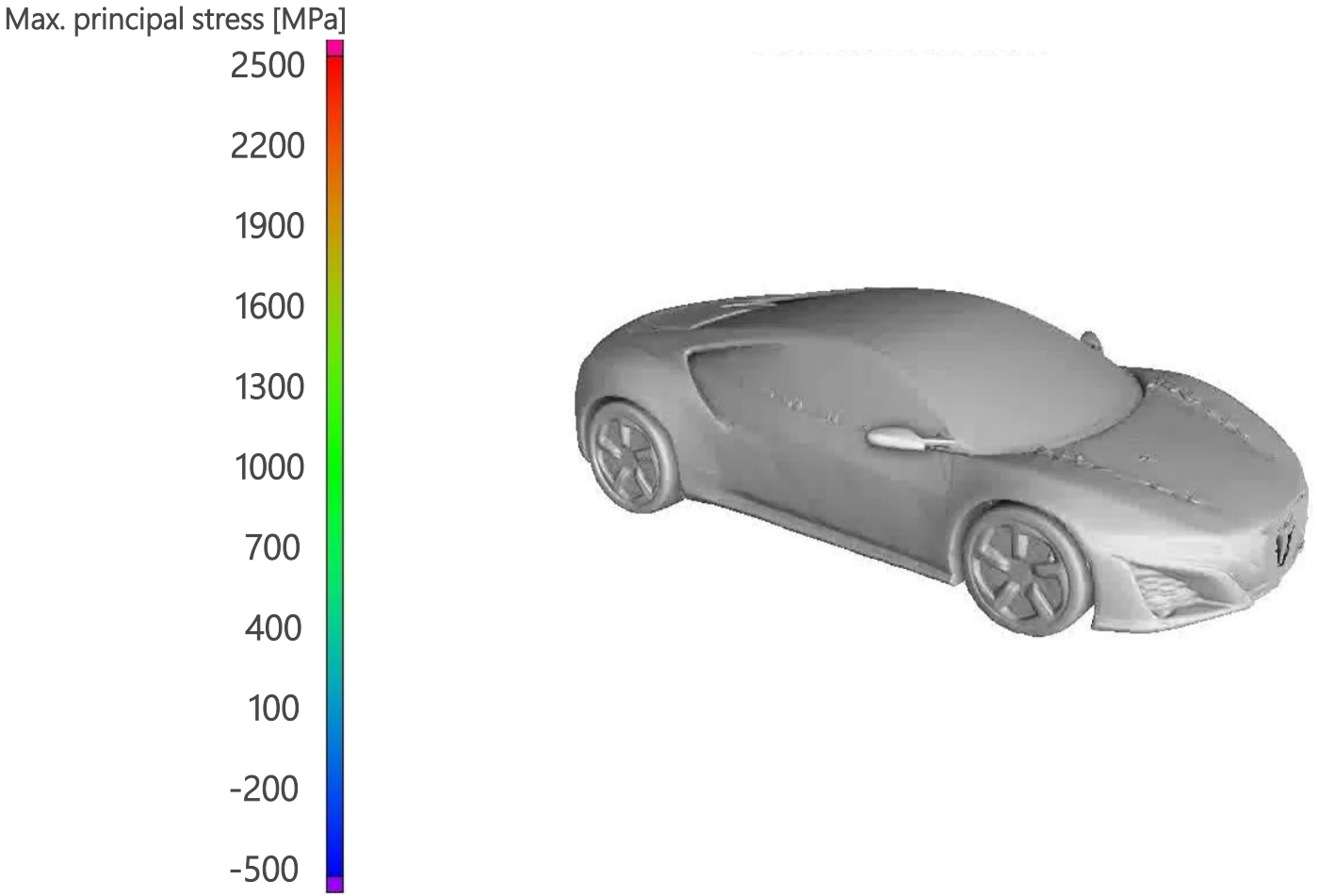
Superalloy (Inconel®)- Load simulation



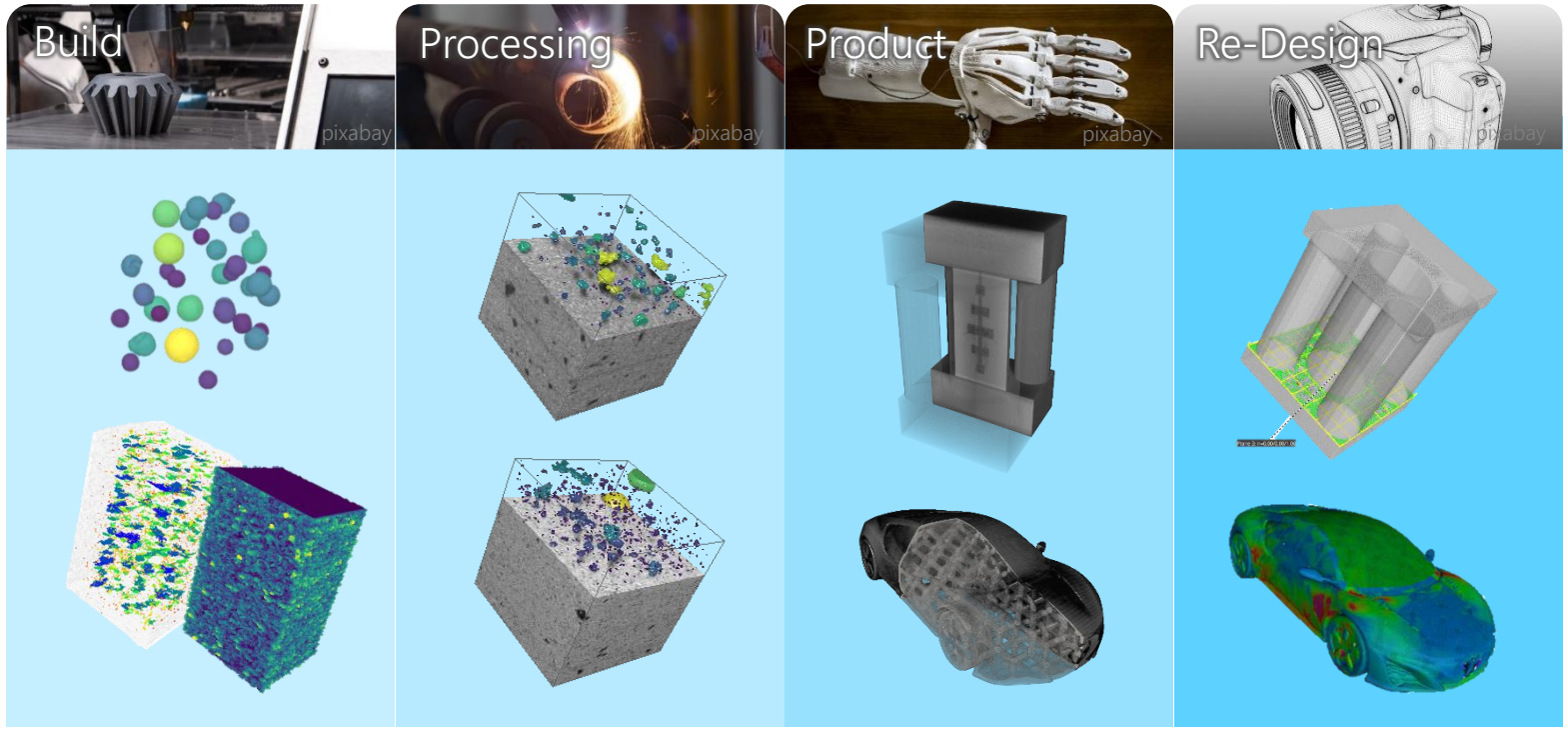
3D stress distribution

2D stress distribution

Superalloy (Inconel®)- Load simulation



Examples summary



You have learned

- What is additive manufacturing (AM)
- Why structure analysis is vital to AM
- What is x-ray CT
- How x-ray CT helps you throughout AM

Q & A Session

Year End Survey

Link to survey