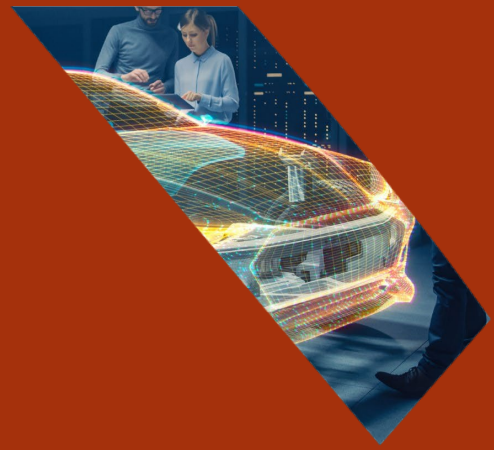
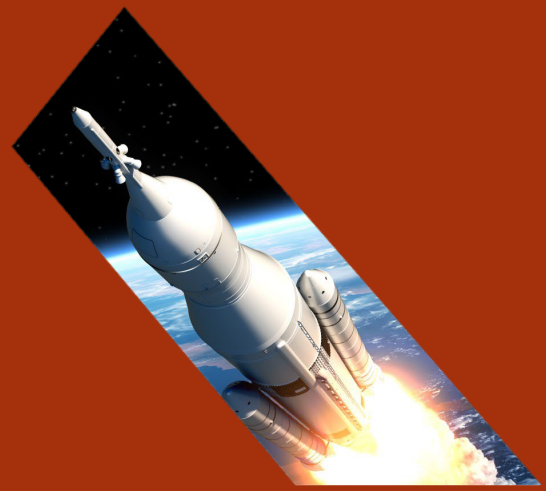
Characterizing AM parts for residual stresses and microstructures



Villigen, 20.06.2024

Cynthia Chang

anaxam

analytics for advanced manufacturing

Agenda

- Motivation
- Principle of Residual Stress Analysis by Neutron Diffraction
- Case Studies
  - Steel Wall
    - Effect of printing strategies
    - Effect of energy density
  - IN738LC
    - Near surface residual stress
    - Effect of heat treatment
    - Extra → High resolution strain mapping by Bragg Edge Imaging

Motivation – Cracking of AM materials

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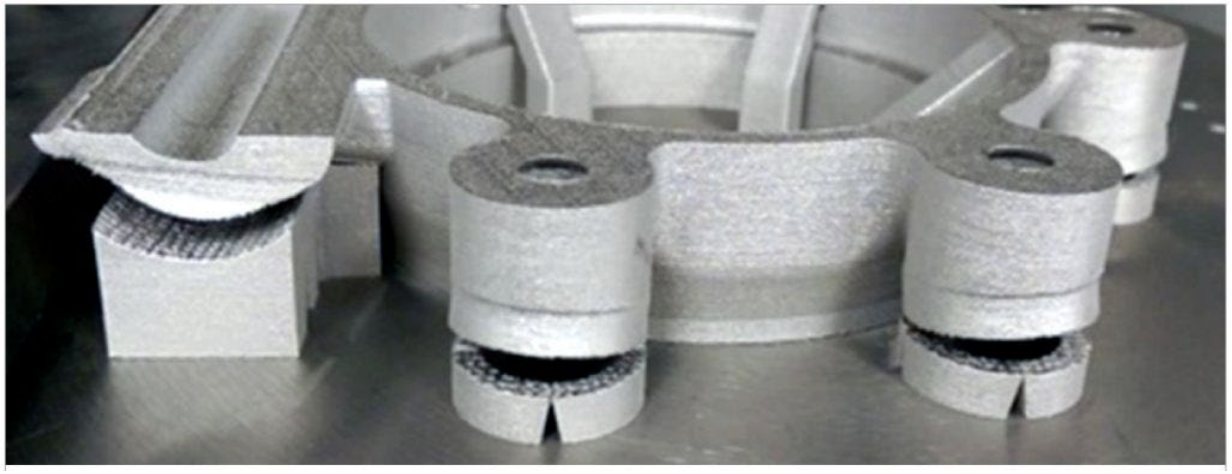
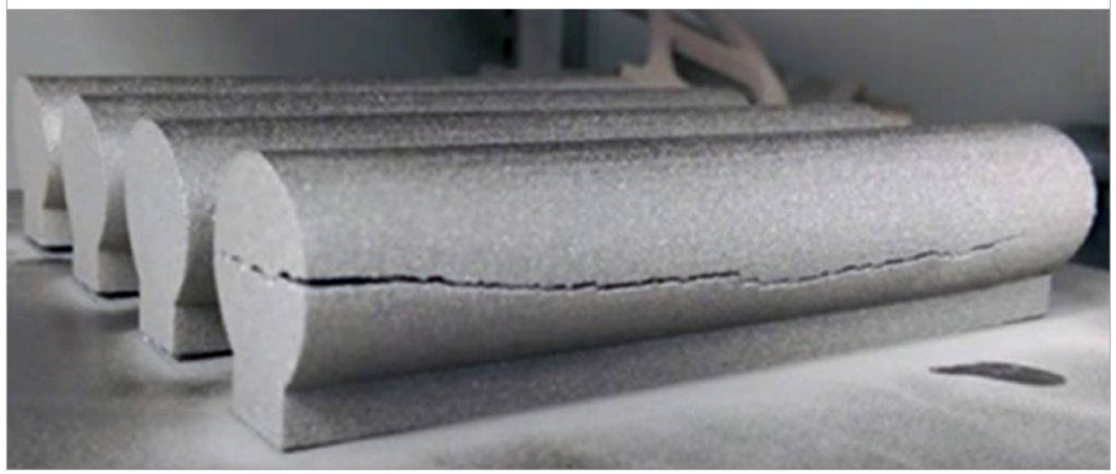


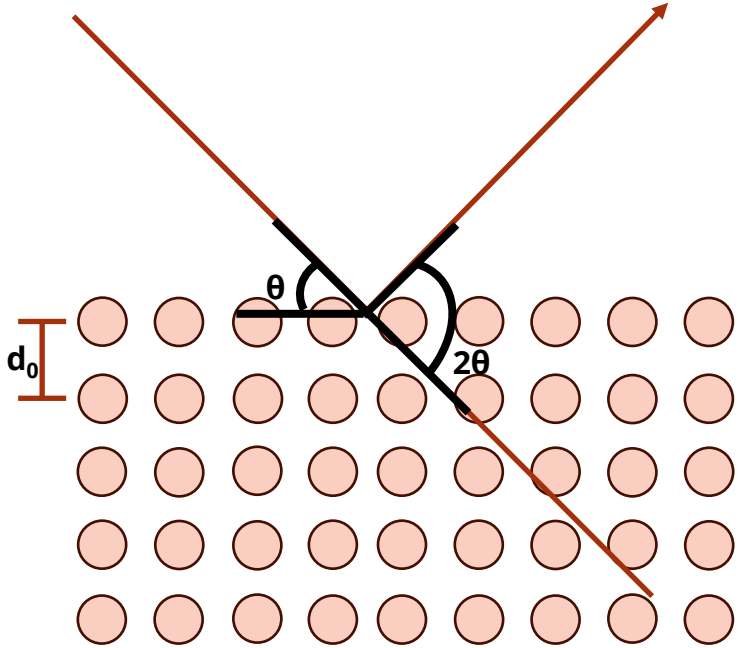


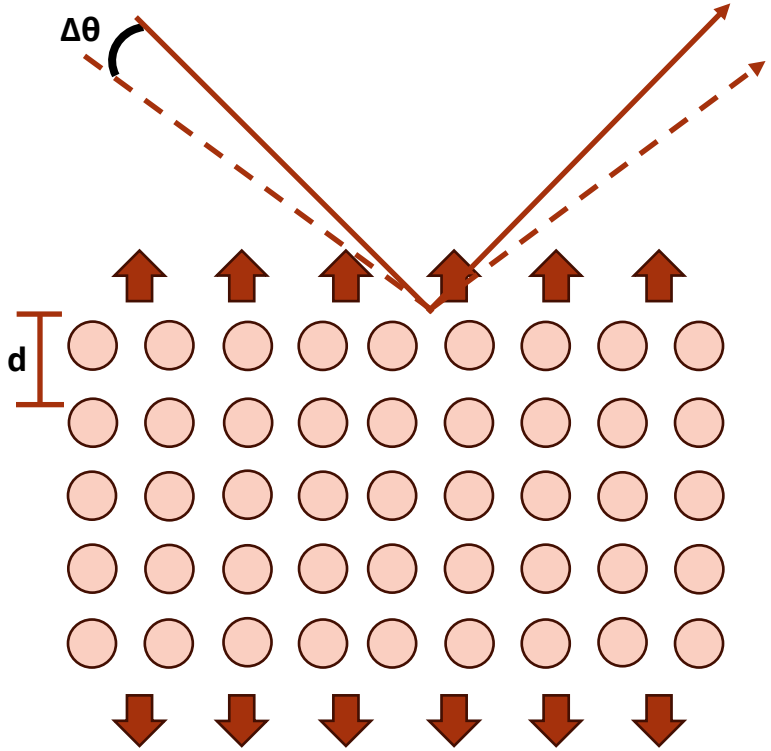
Cracking of 3-D printed materials because of residual stress

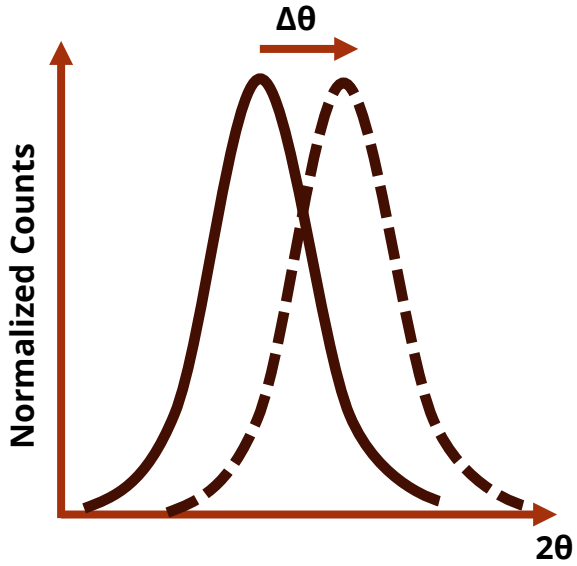
- Quality control requires controlling residual stress after AM process
- Can we measure residual stress non-destructively?

https://www.metal-am.com/articles/how-residual-stress-can-cause-major-build-failures-in-3d-printing/?utm_source=copy&utm_medium=website&utm_campaign=SocialSnap

Principle of residual stress analysis

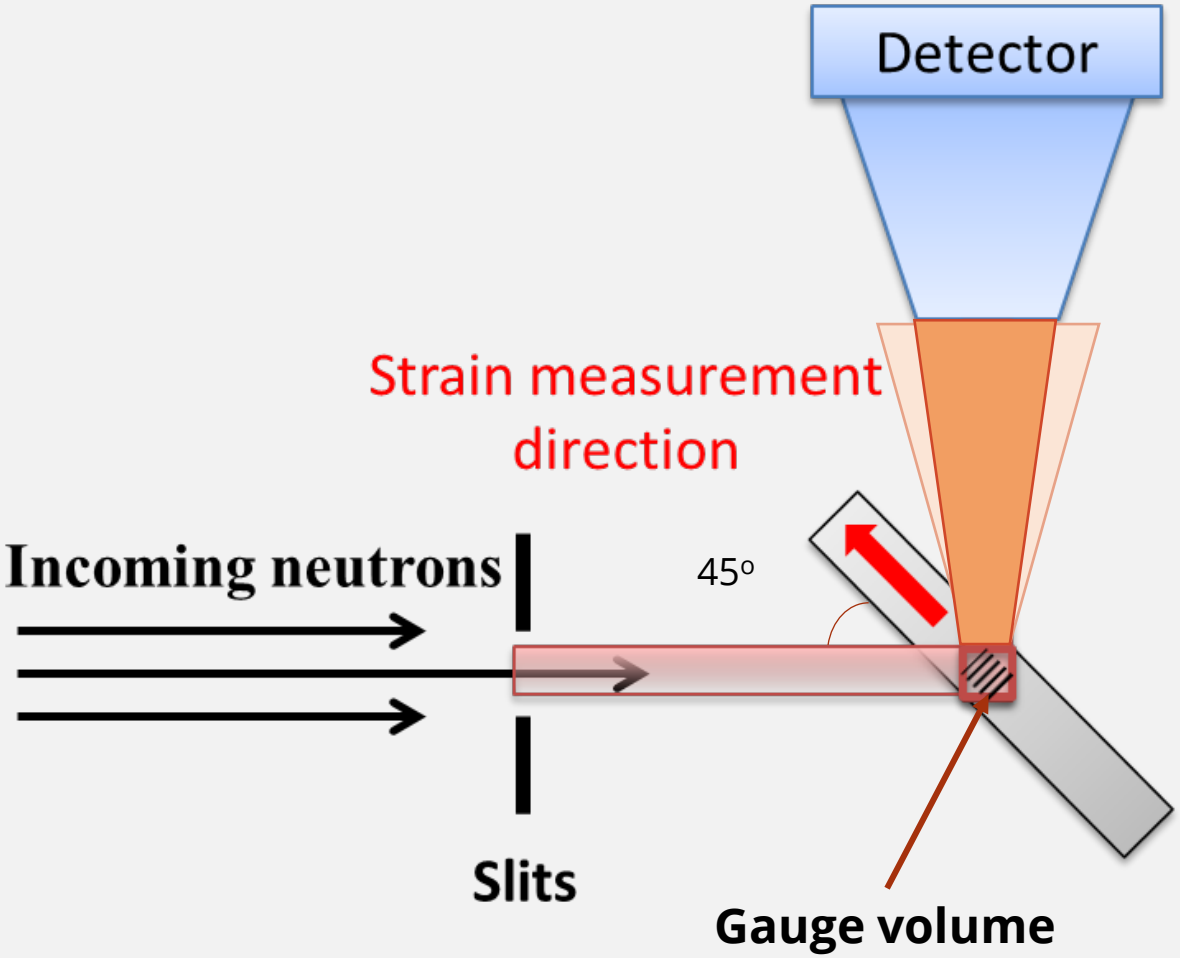






Strain in *hkl* set of planes $\varepsilon_{hkl} = \frac{d_{hkl} - d_{0,hkl}}{d_{0,hkl}}$

d- *hkl* plane spacing
d_0 – *d* of stress-free sample



POLDI – Residual stress analysis setup using time of flight machine

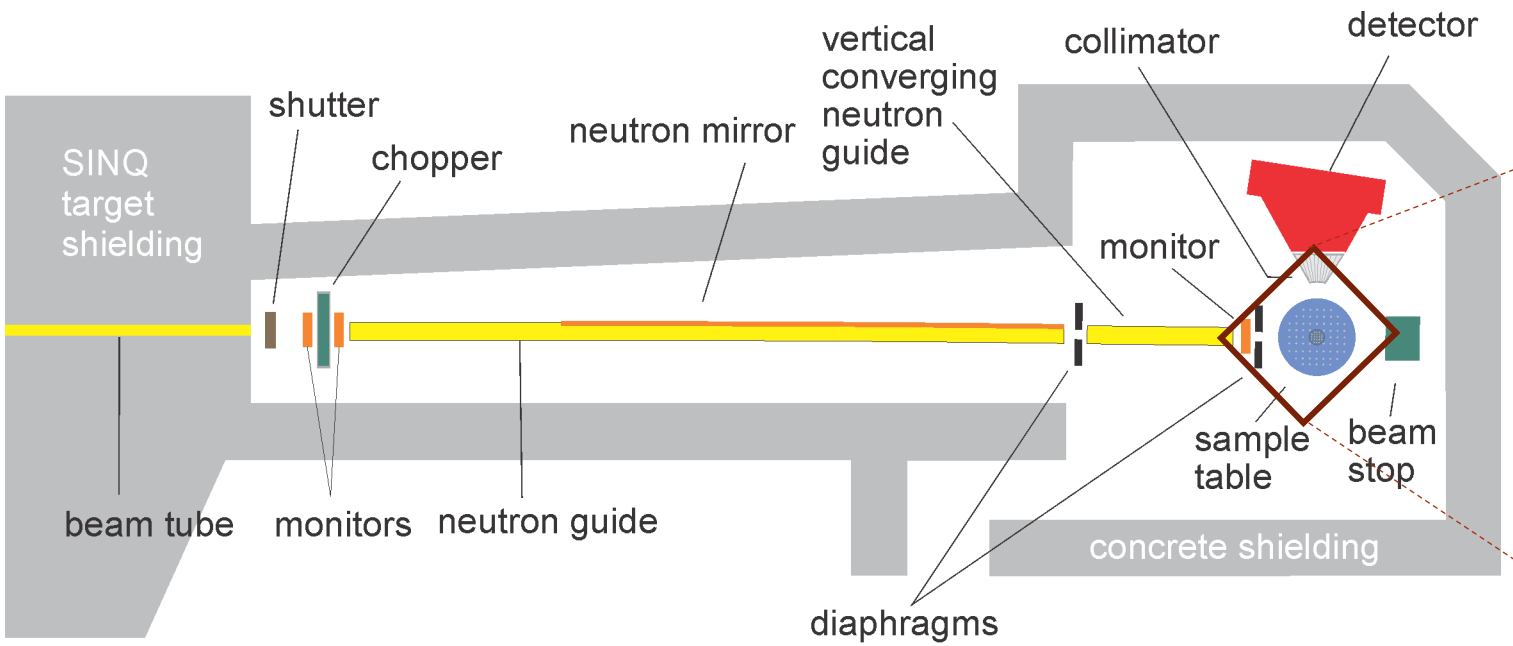
- Incoming neutrons with different wavelength
- Measure at 90° → Ensure cuboidal gauge volume
- Generalized Hooke's Law

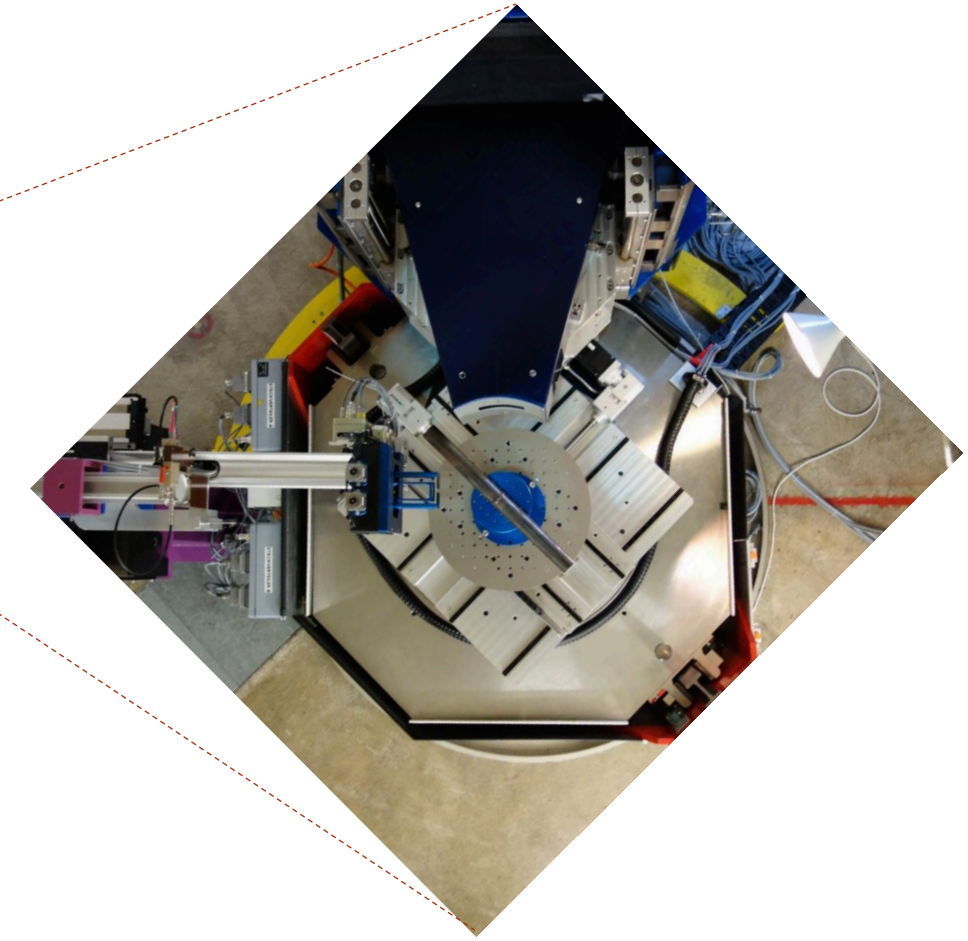
$$\begin{pmatrix}\sigma_{11}\\ \sigma_{22}\\ \sigma_{33}\end{pmatrix} = \frac{E}{(1+\nu)(1-2\nu)}\begin{pmatrix}1-\nu & \nu & \nu\\ \nu & 1-\nu & \nu\\ \nu & \nu & 1-\nu\end{pmatrix}\begin{pmatrix}\varepsilon_{11}\\ \varepsilon_{22}\\ \varepsilon_{33}\end{pmatrix}$$

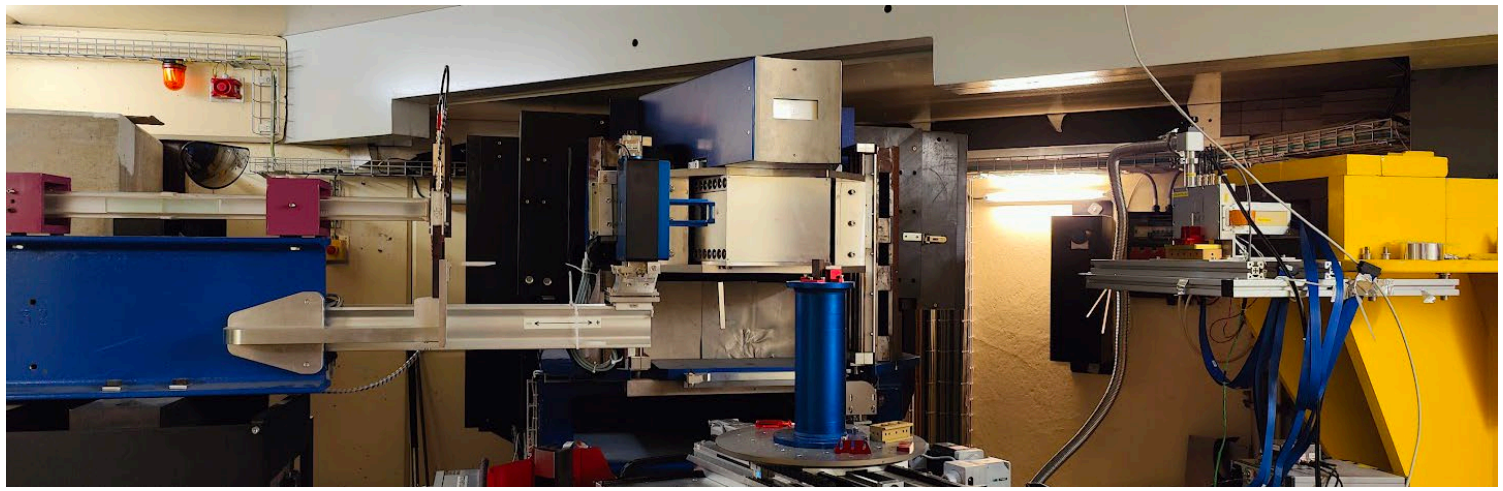
σ – stress components
E – Young's modulus
ν – poison's ratio


POLDI

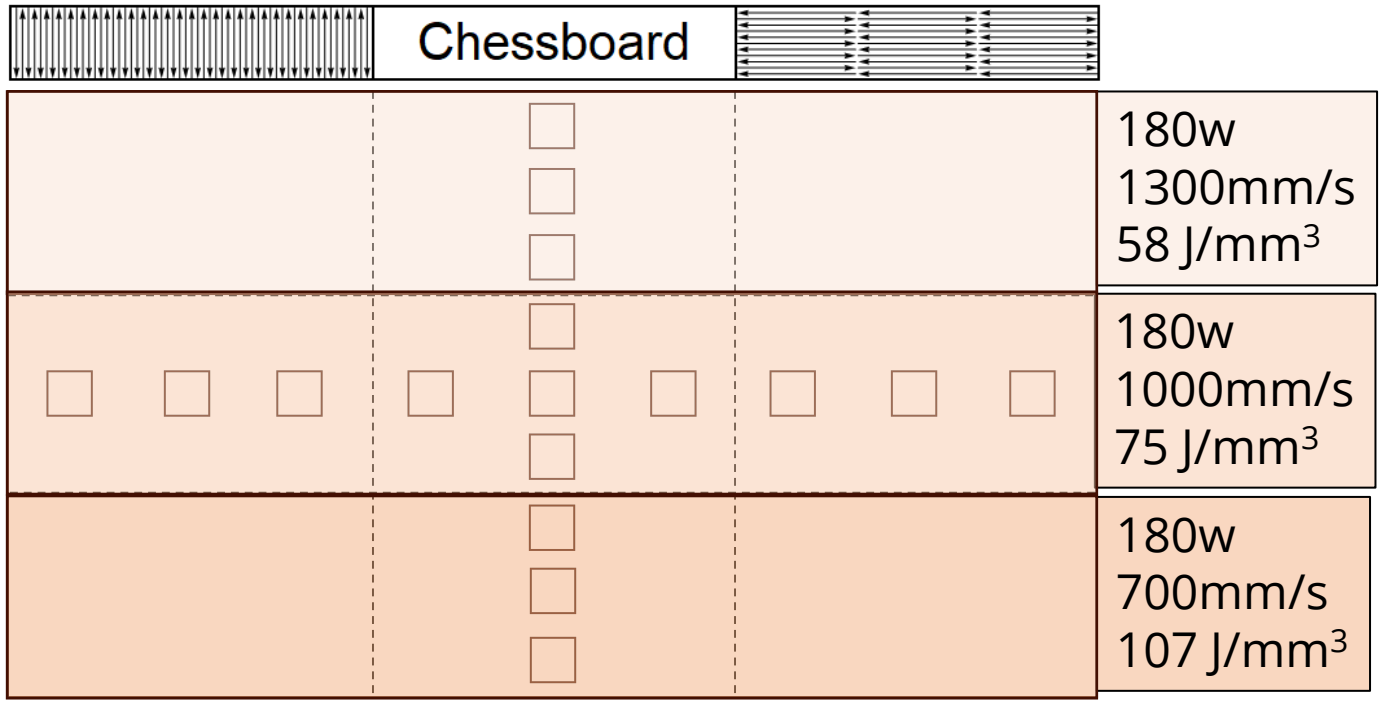
Principle of residual stress analysis – Setup at POLDI

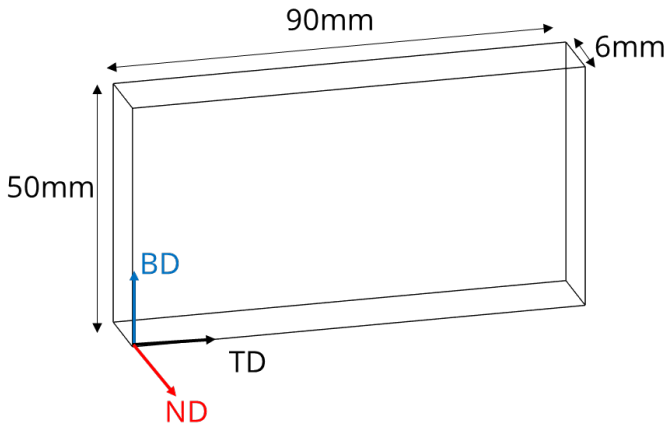






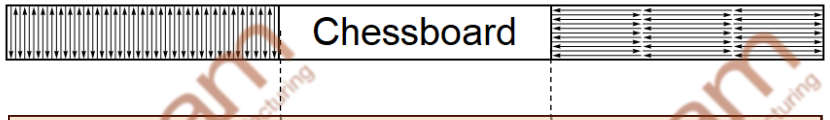
Steel Wall – printing parameters



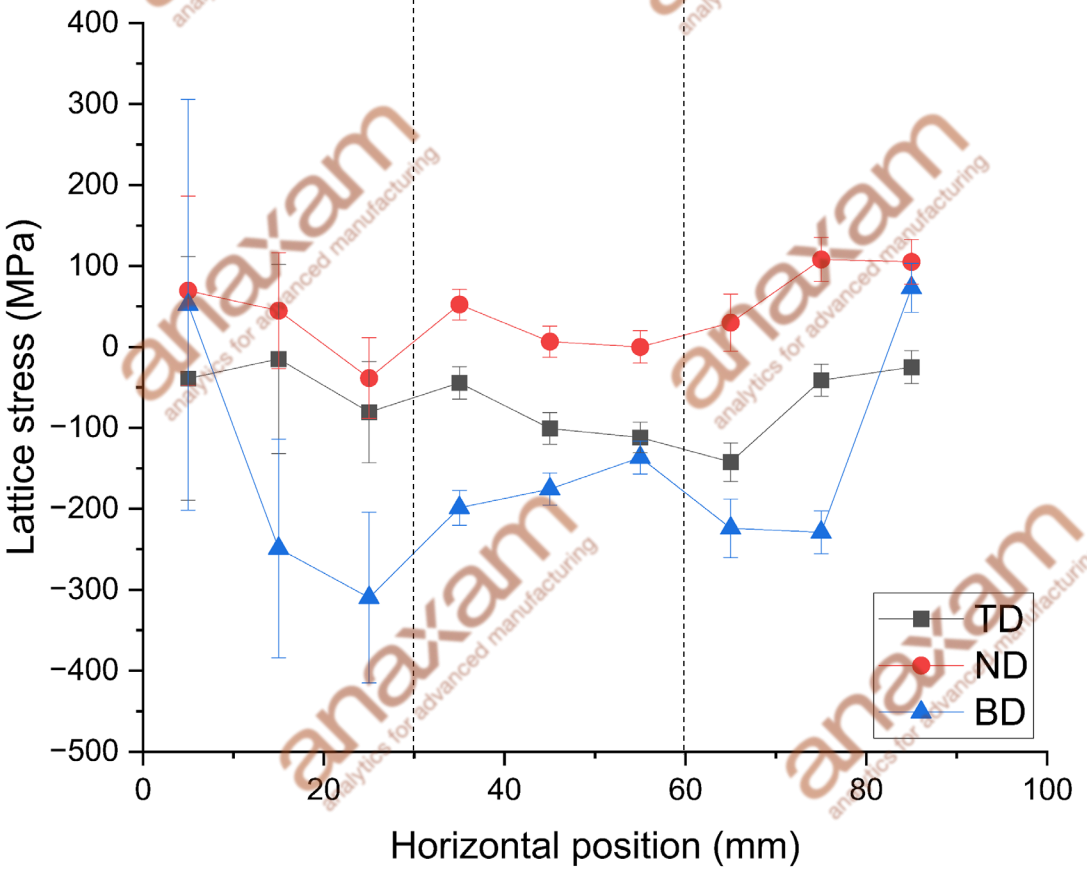


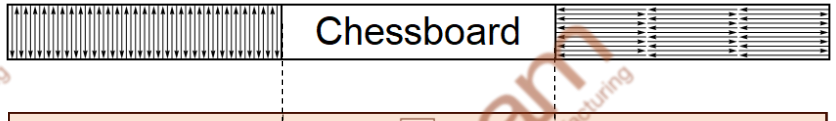
PBF-LB System	Aconity Midi+
Alloy	1.4404/316L
Laser power	180W
Layer thickness	30µm
Hatch distance	80µm
Spot size	80µm
Gauge Volume	**3.8x3.8x3.8mm³**

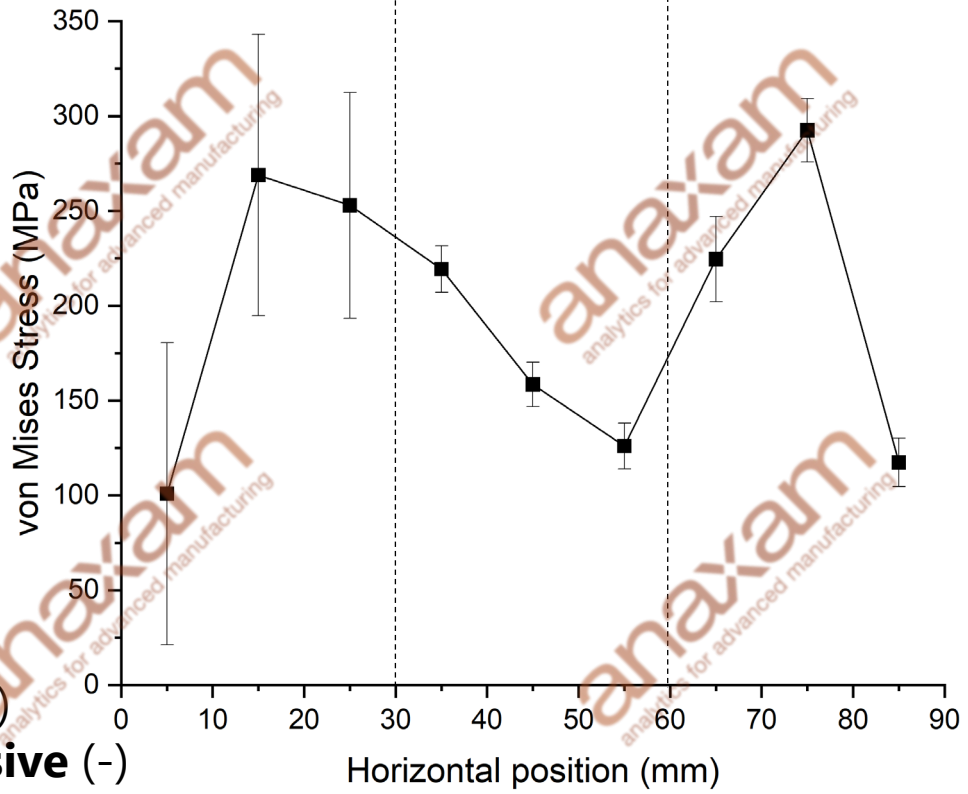
A- Inspire SS316L – Effect by the printing strategy



180 W
1000 mm/s
75 J/mm^3

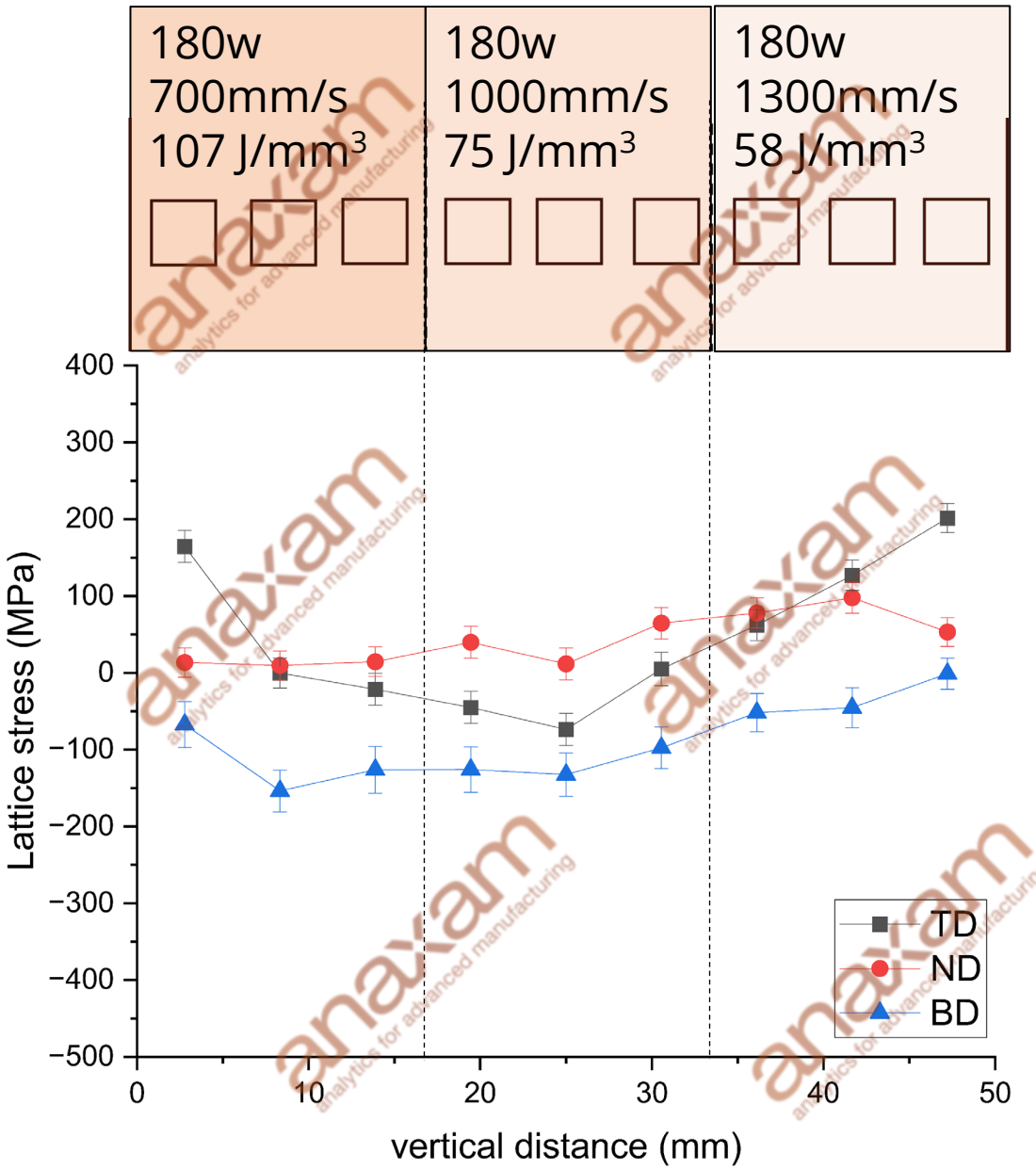


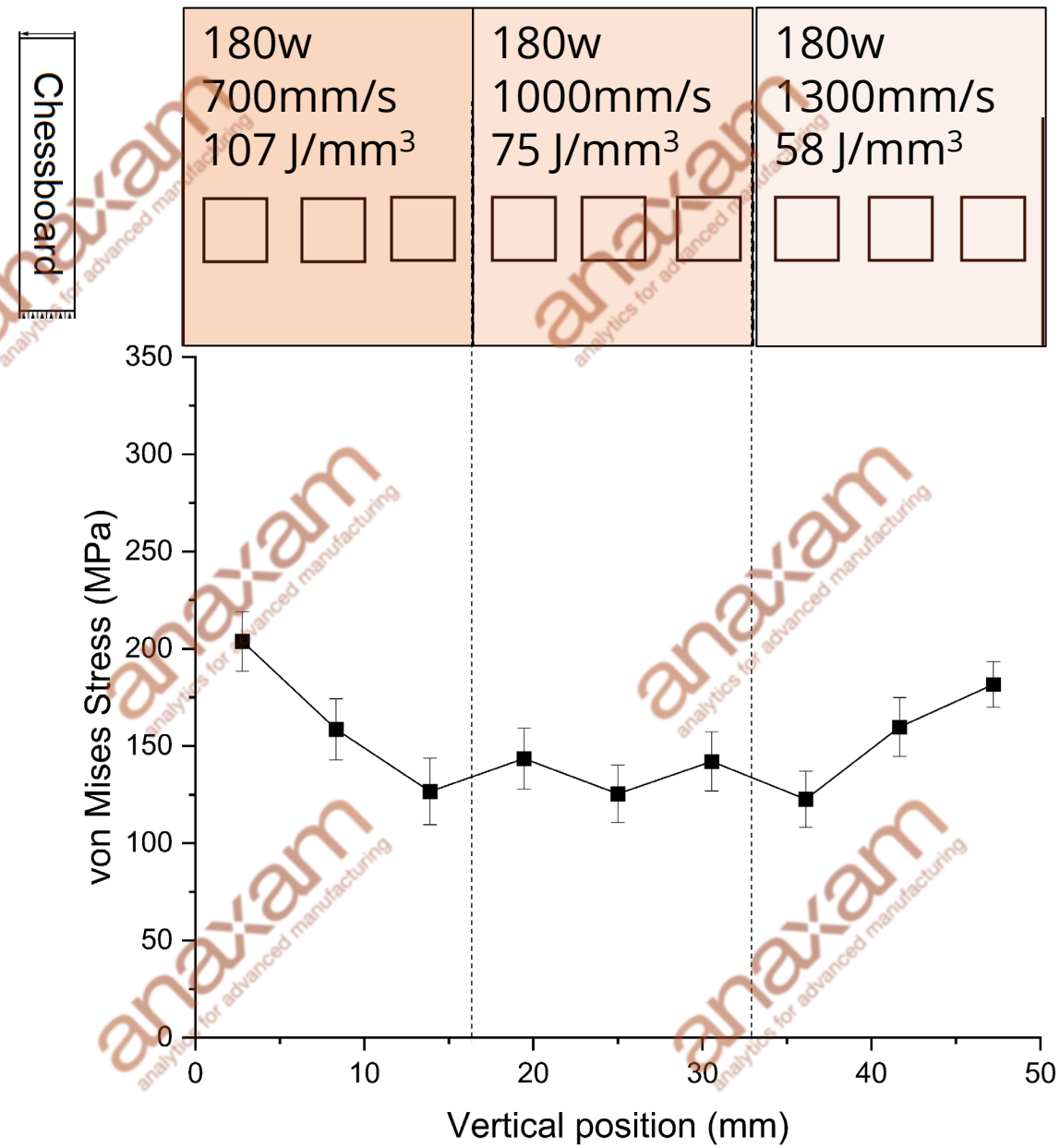




- **Tensile** (+)
- **Compressive** (-)

A- Inspire SS316L – Effect by the energy density



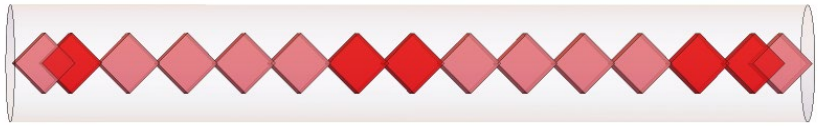


IN738LC – Stress profile and the effect of heat treatment

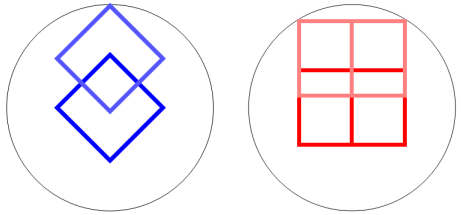
- Samples → IN738LC
  - As printed
  - Heat treated
- Gauge volume
  - 3.8x3.8x3.8mm^3

- Precipitation after heat treatment
  - Induce strain age cracking

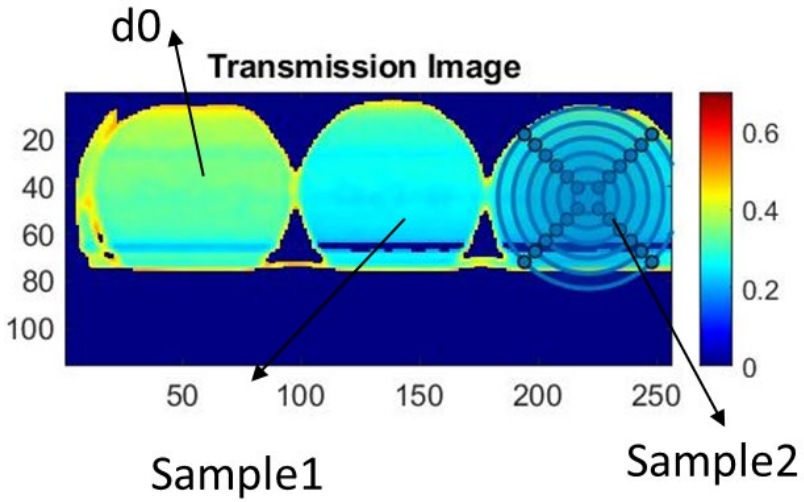
Center measurements

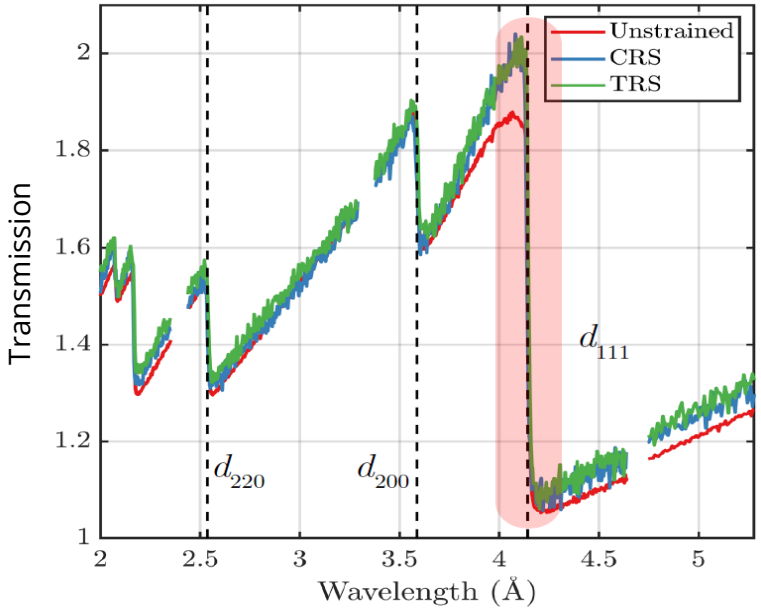


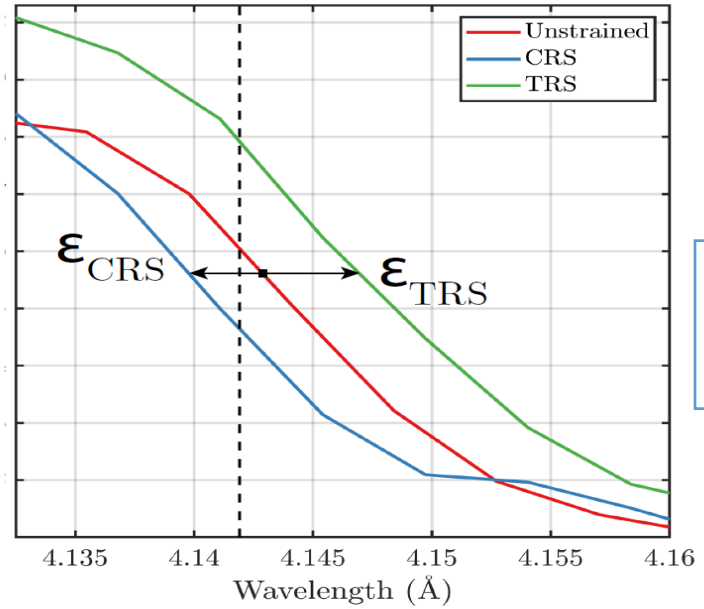
Off center measurements



Bragg Edge Imaging – High resolution strain measurements

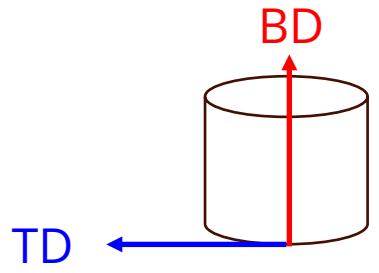






$$\epsilon_{hkl} = \frac{d_{hkl} - d^0_{hkl}}{d^0_{hkl}}$$

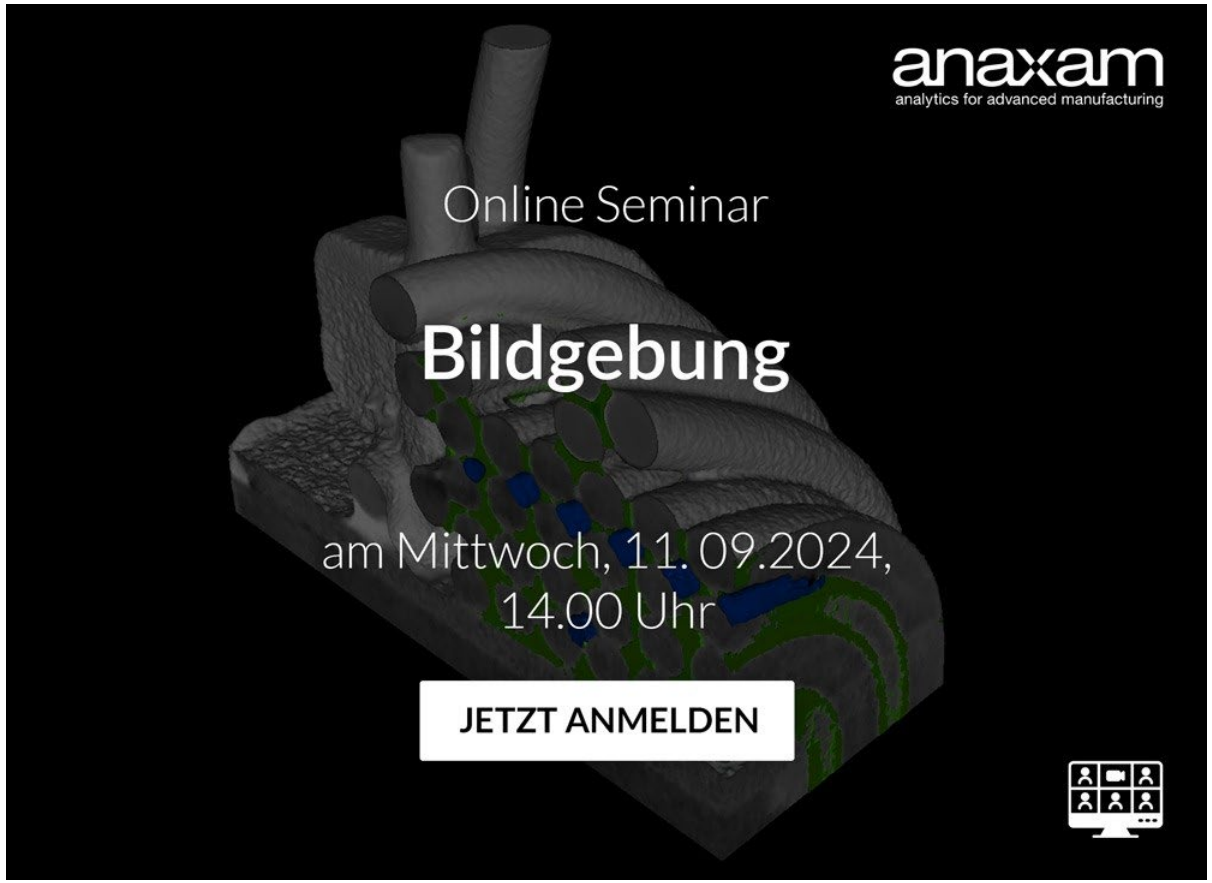
- **Tensile** (+)
- **Compressive** (-)



Busi, M., et al. *Scientific Reports* (2021)

Summary

- Neutron Diffraction → Non-destructive residual stress analysis
  - Effect of energy density
  - Effect of printing strategy
  - Effect of heat treatment
- Bragg edge imaging → High resolution strain analysis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Online Seminar
Bildgebung
am Mittwoch, 11. 09.2024,
14.00 Uhr
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Online Seminar
Diffraktion
am Mittwoch, 18. 09.2024,
14.00 Uhr
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