Thermographie-Forum 2021
Eugendorf, A

Frühzeitige Erkennung von Materialschädigungen aufgrund mechanischer Belastung mittels Thermographie

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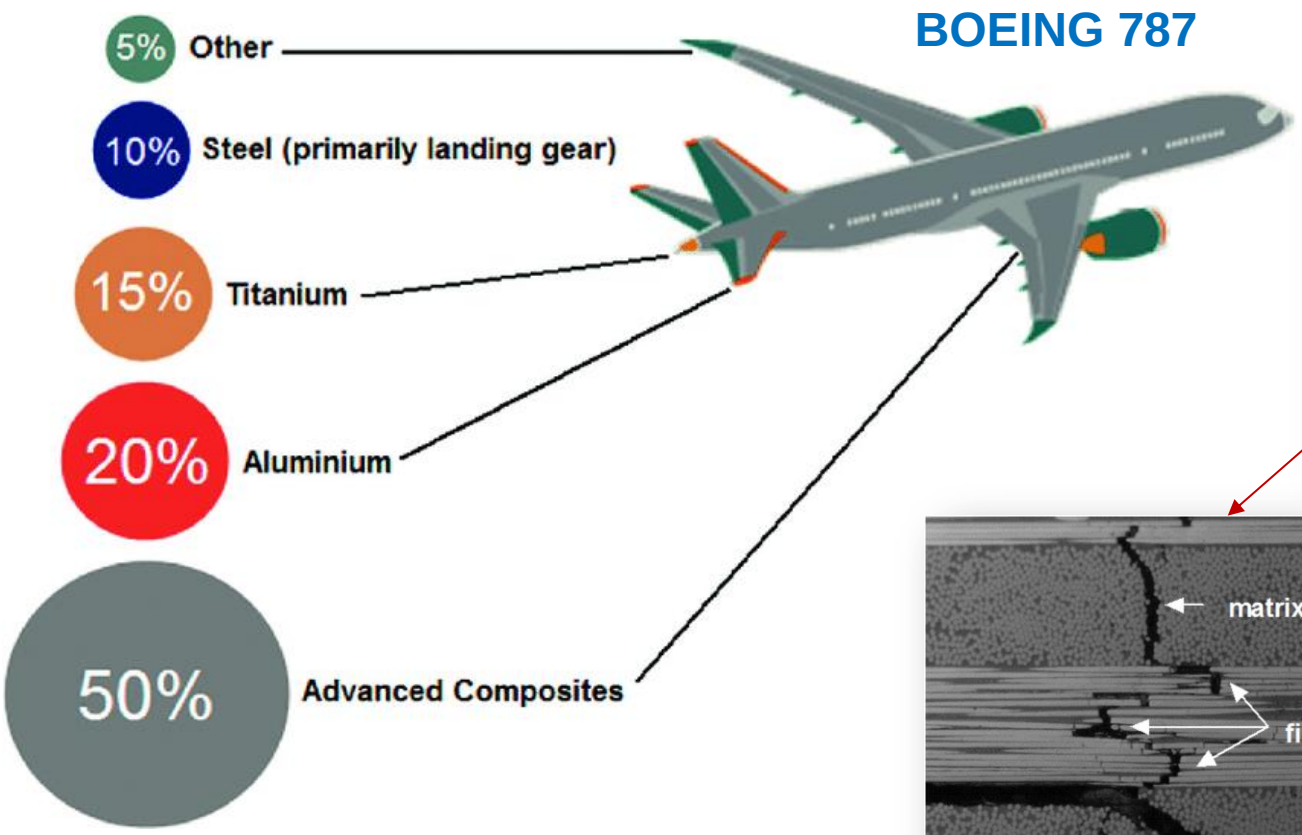
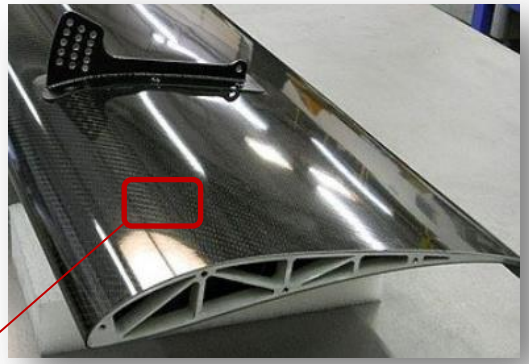
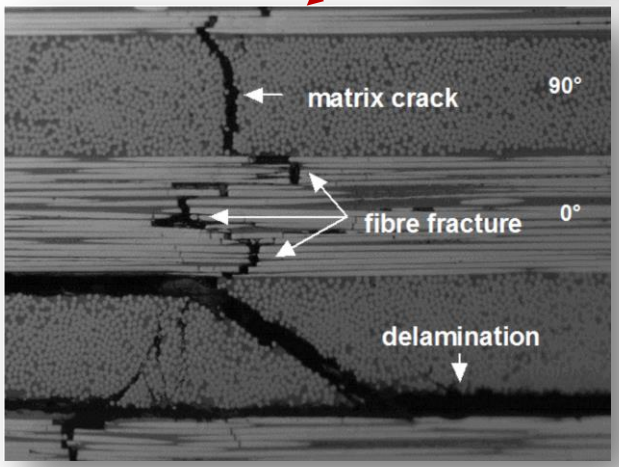
Motivation

Advanced composites in the aircraft industry



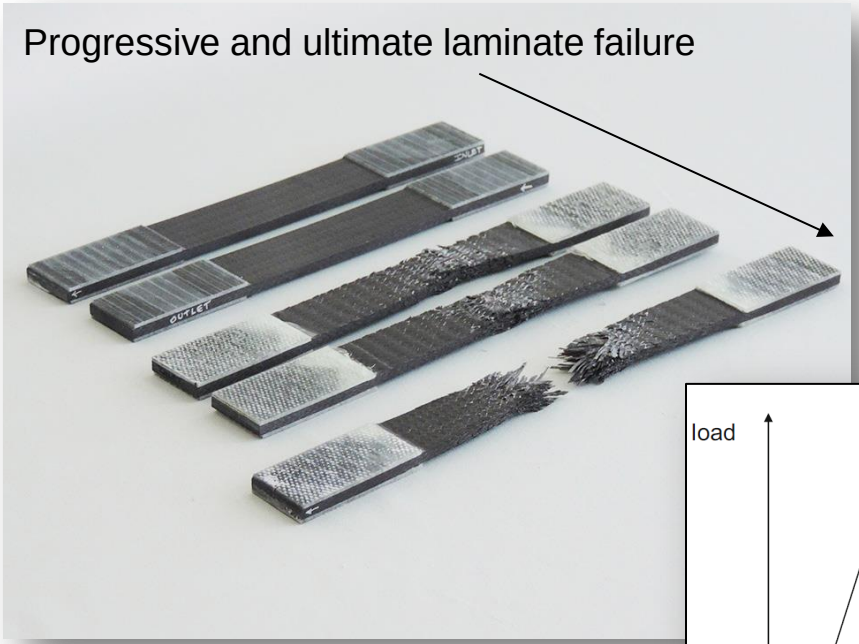
BOEING 787





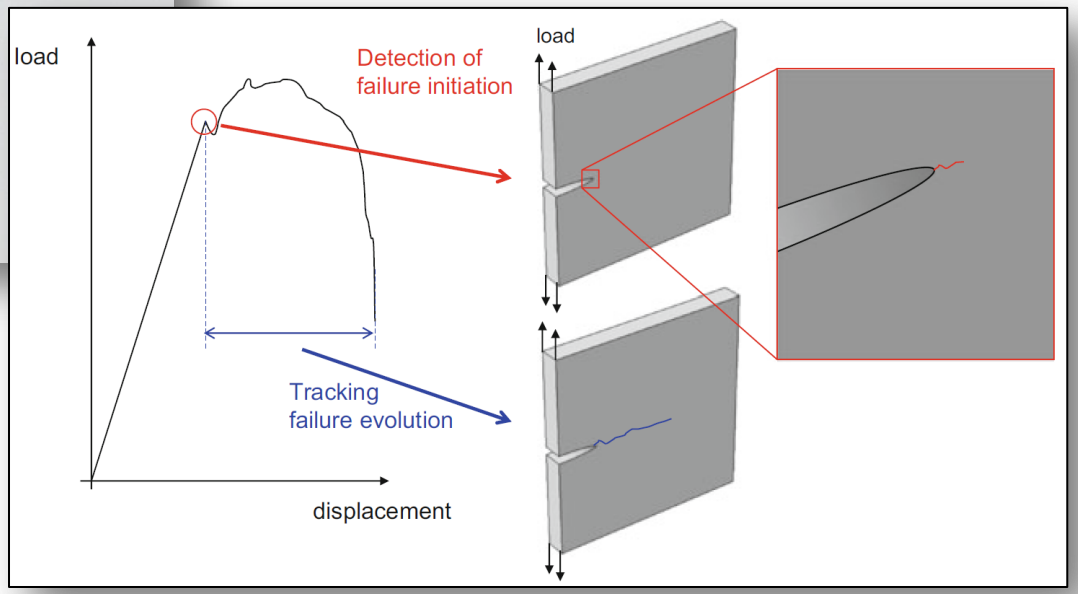
Motivation

In-situ failure analysis of multidirectional composites



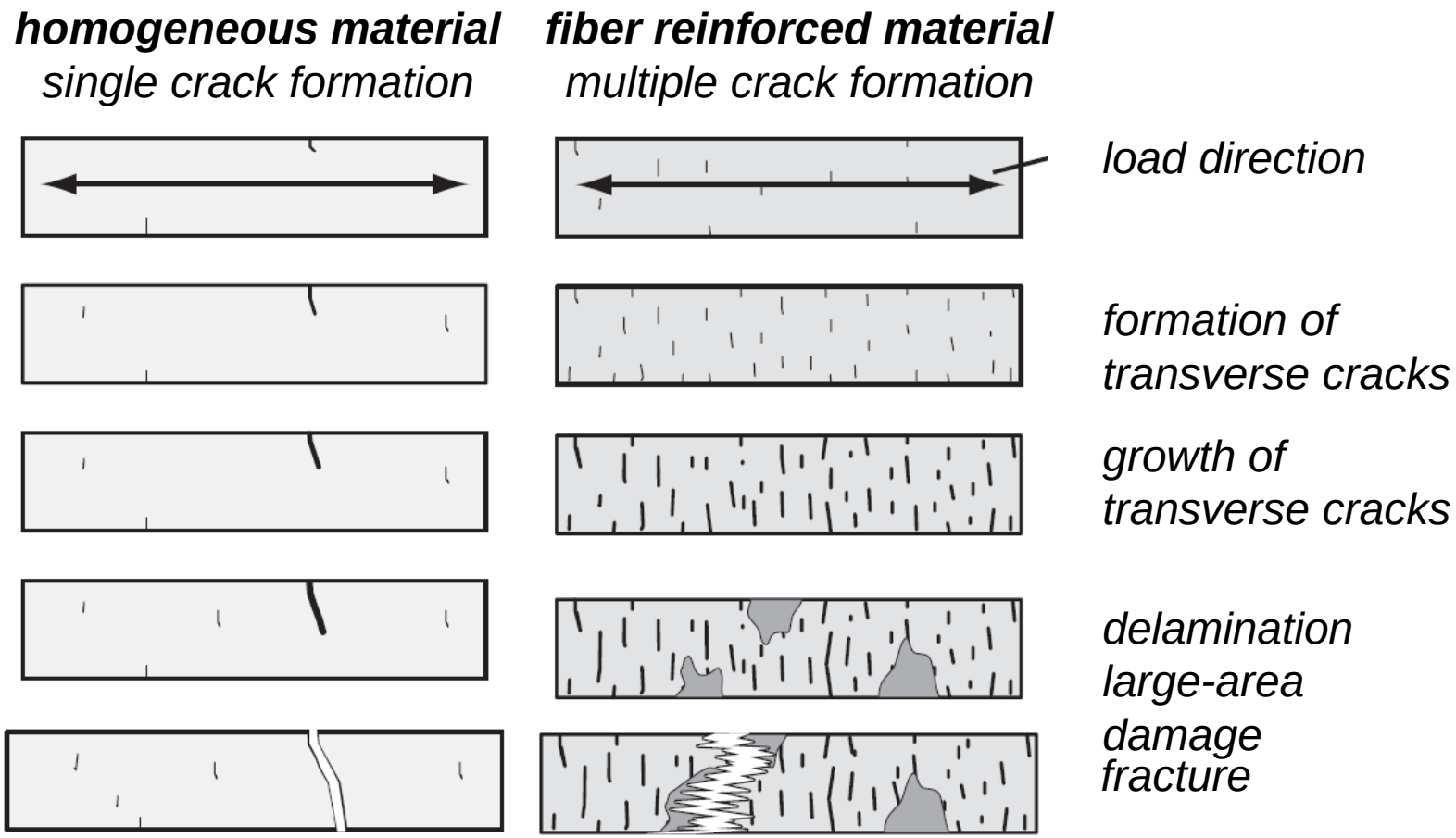
Objectives:

- Detection of failure initiation
- Tracking failure evolution
- Quasi-static and fatigue load



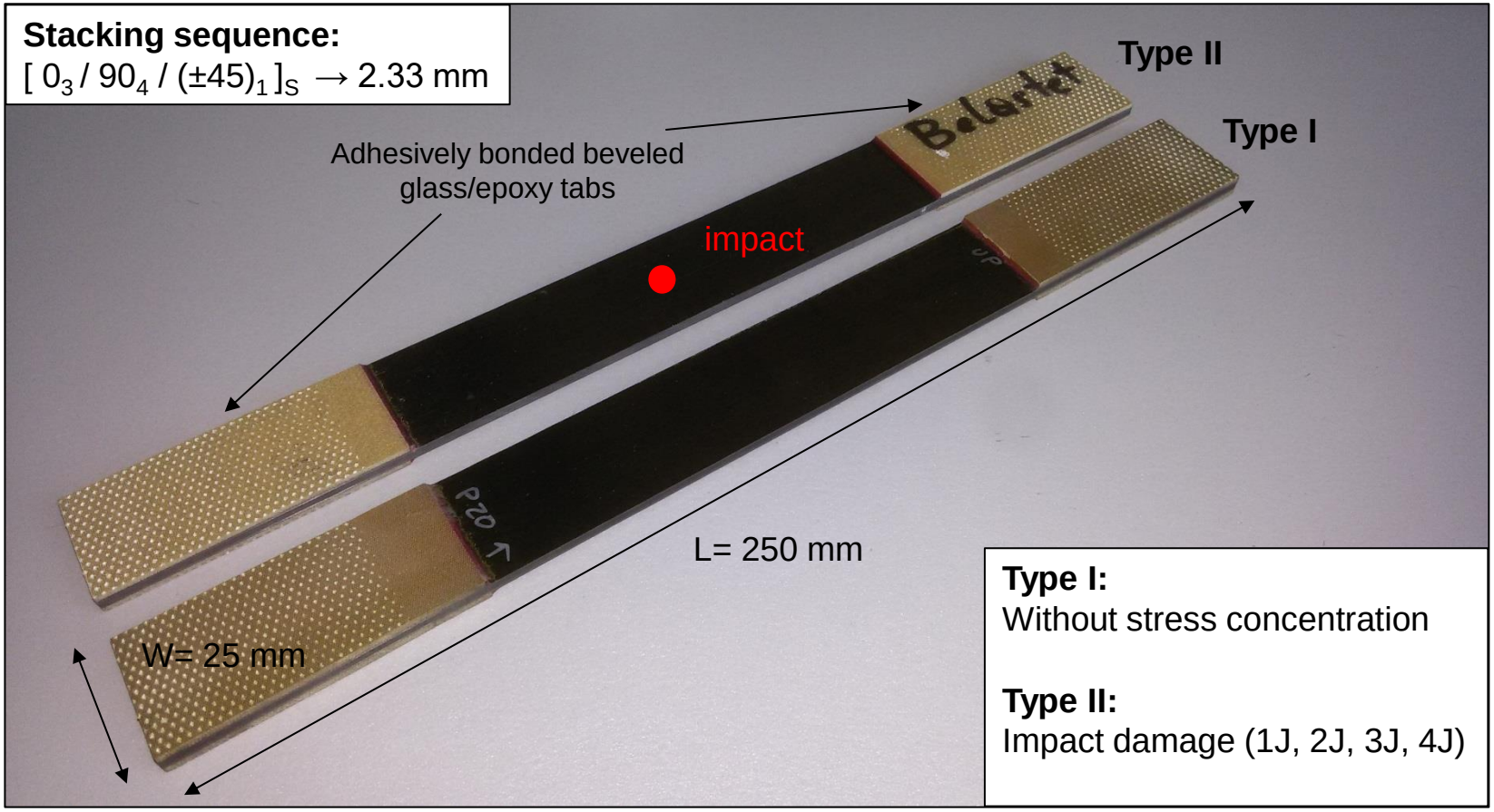
Motivation

Fatigue-behavior of composite materials



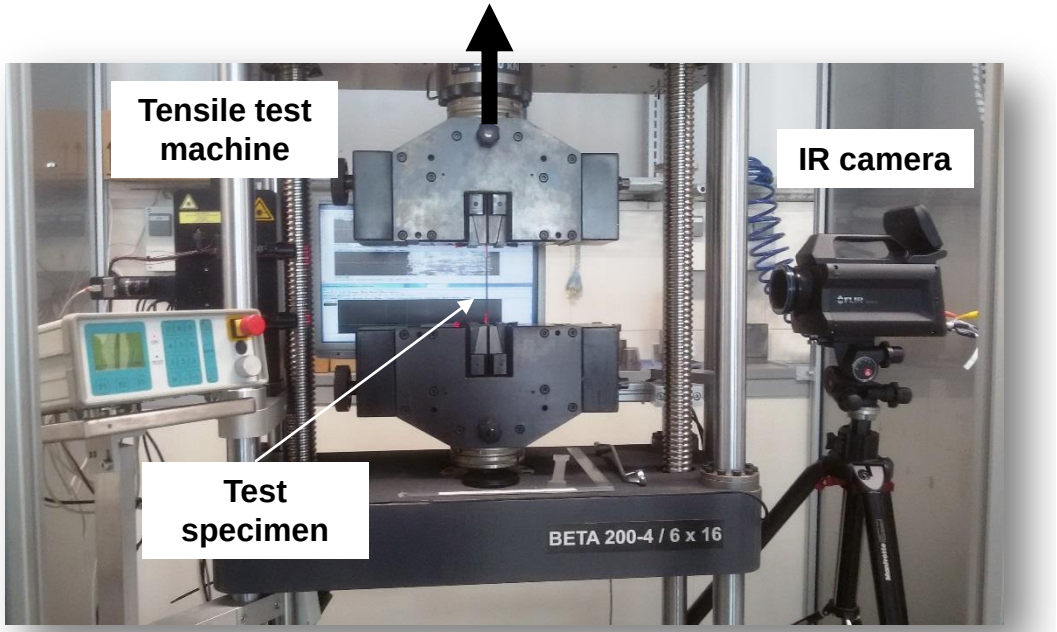
Test specimens

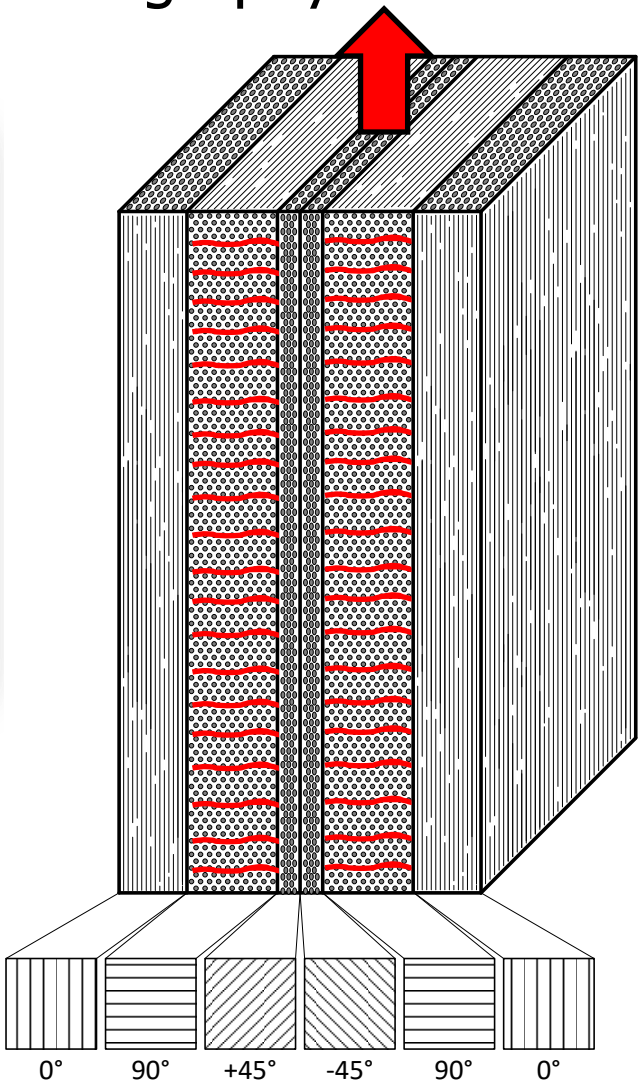
Multidirectional laminate of CFRP



Quasi-static uniaxial tensile tests

Experimental setup – In-situ passive thermography





IR camera

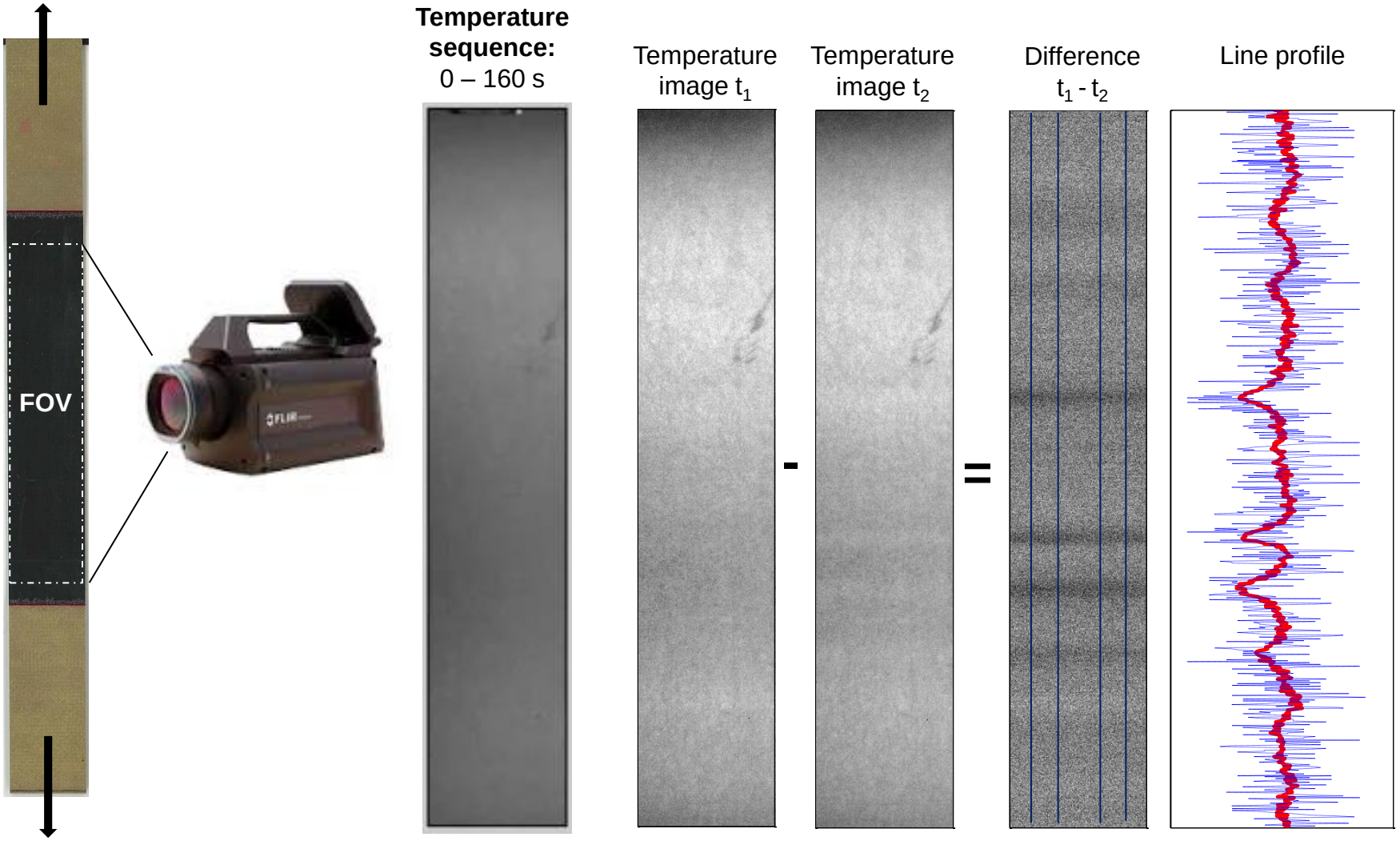
- FLIR X8400sc
- 1024 x 256 pixel (920)
- 50 FPS

Tensile test machine

- Messphysik BETA 200-4/6X16
- Test speed: 2 mm / min
- Maximum stress: σ_{max} = 550 MPa

Quasi-static uniaxial tensile tests

Type I – Transverse matrix cracking



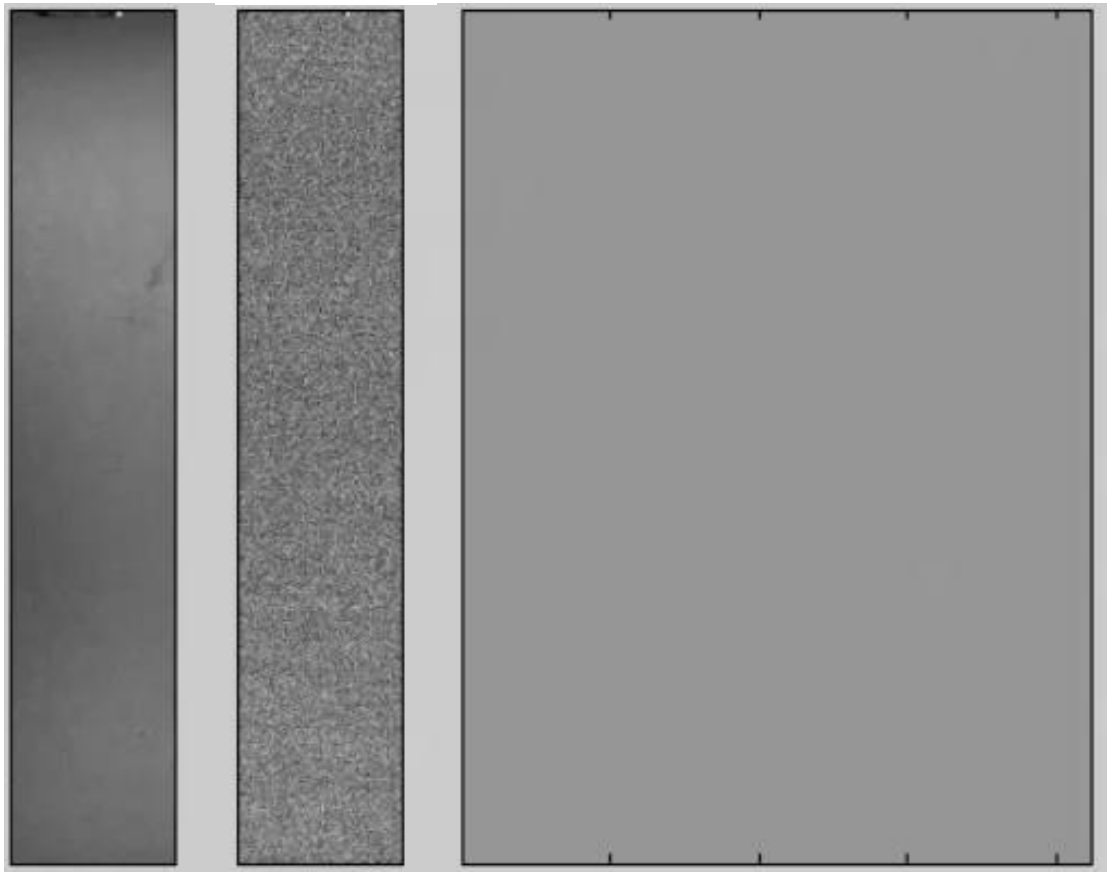
Quasi-static uniaxial tensile tests

Type I – Transverse matrix cracking

Temperature sequence:
0 – 160 s

Difference image:
$t_1 - t_2$

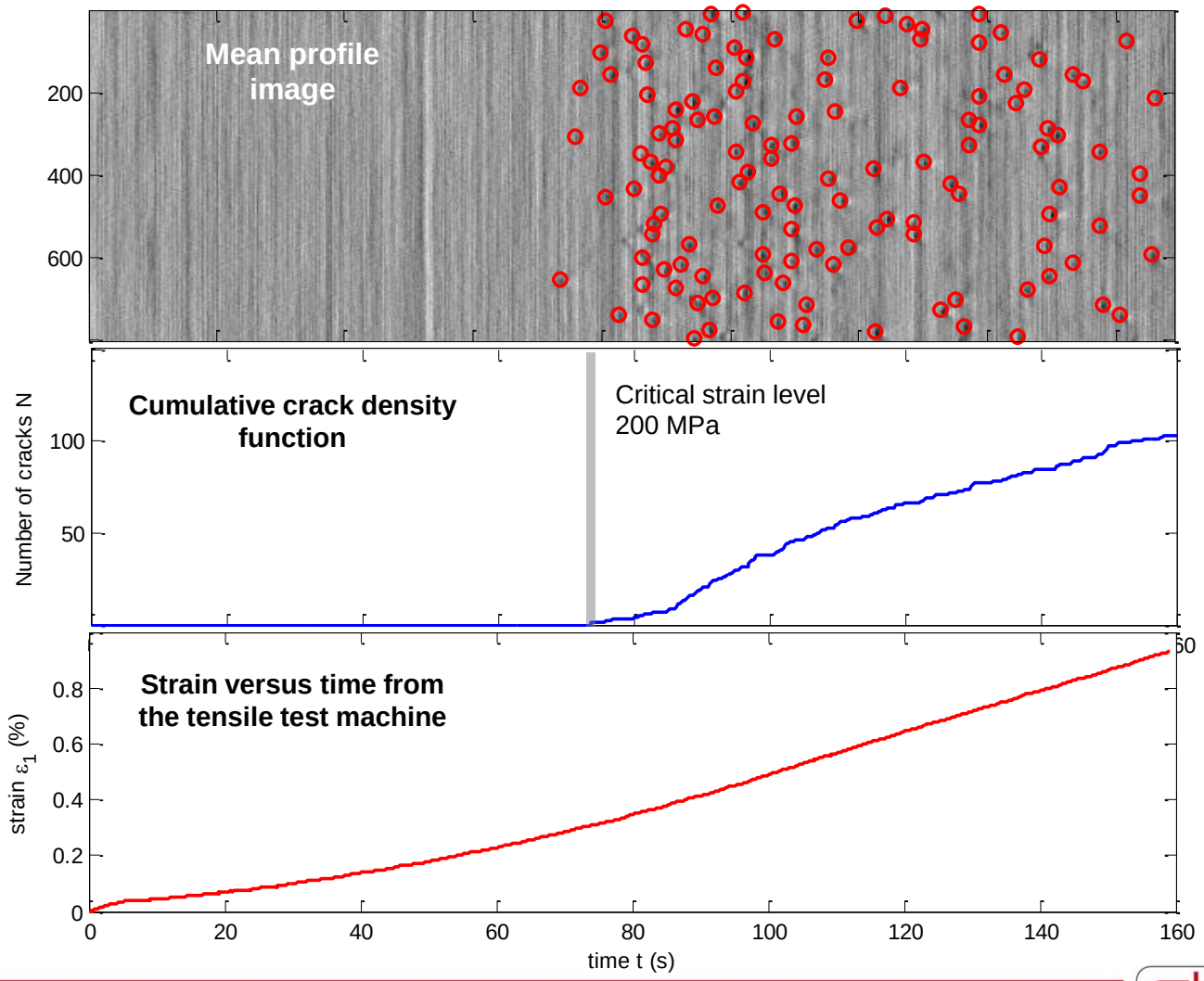
Mean profile image
for
matrix cracks tracking



Measurement time (strain)

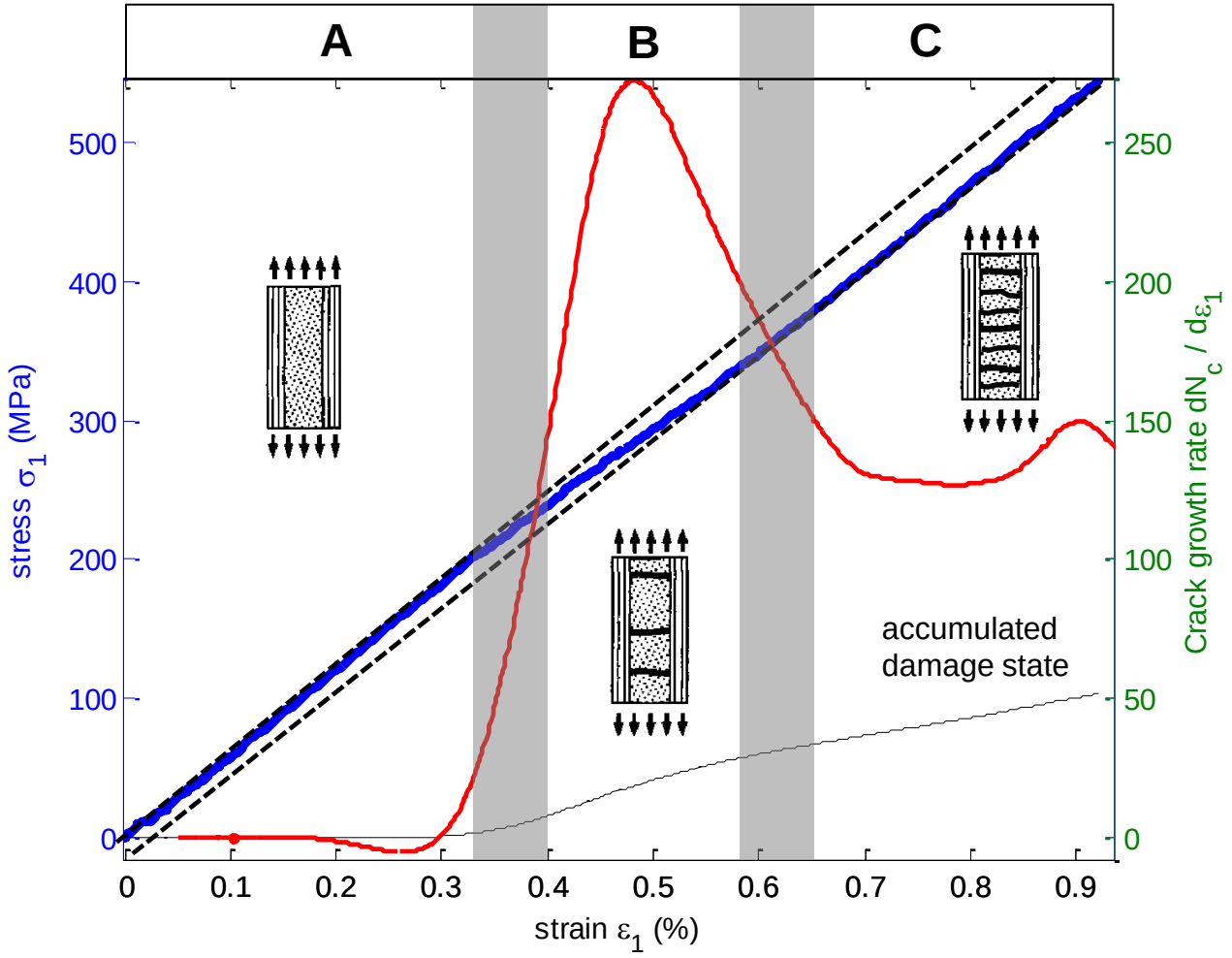
Quasi-static uniaxial tensile tests

Type I – Transverse matrix cracking



Quasi-static uniaxial tensile tests

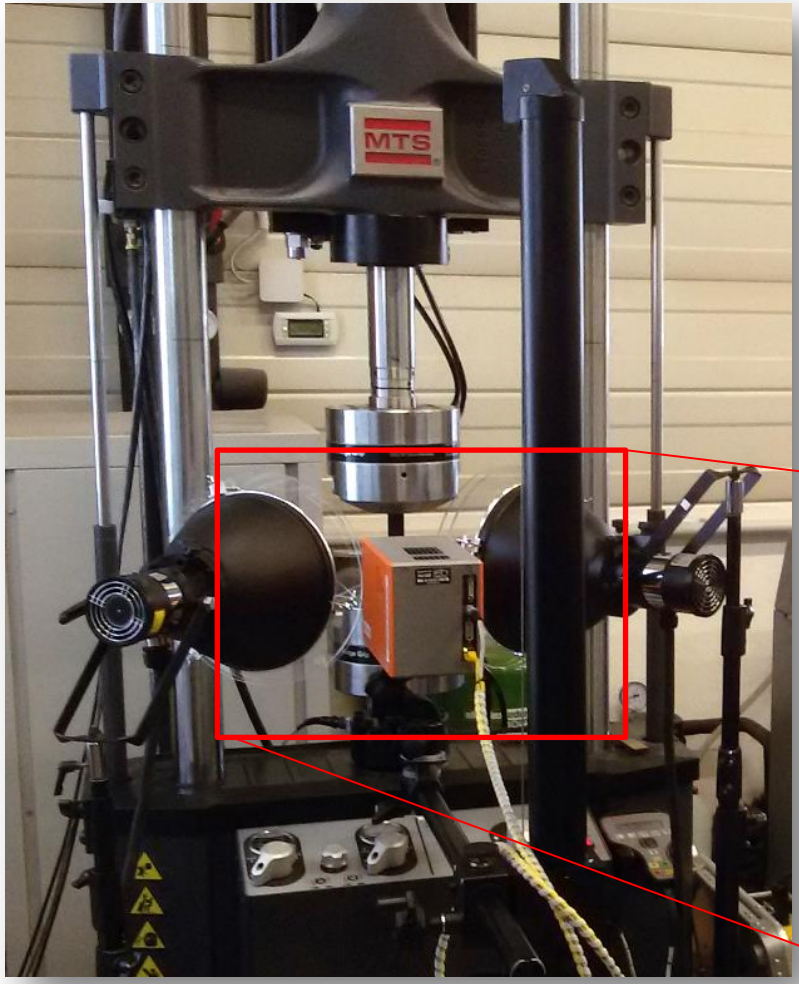
Type I – Transverse matrix cracking



- **Region A:**
  no cracks
- **Region B:**
  transverse matrix cracking and stiffness reduction
- **Region C:**
  minimum crack spacing → characteristic damage state

Fatigue uniaxial tensile tests

Experimental setup – Pulsed thermography



Servo-hydraulic tensile test machine

MTS 370.10 Landmark ±100 kN

Frequency = 10 Hz

Maximum stress: σ_{max} = 500 MPa

Minimum stress: σ_{min} = 50 MPa

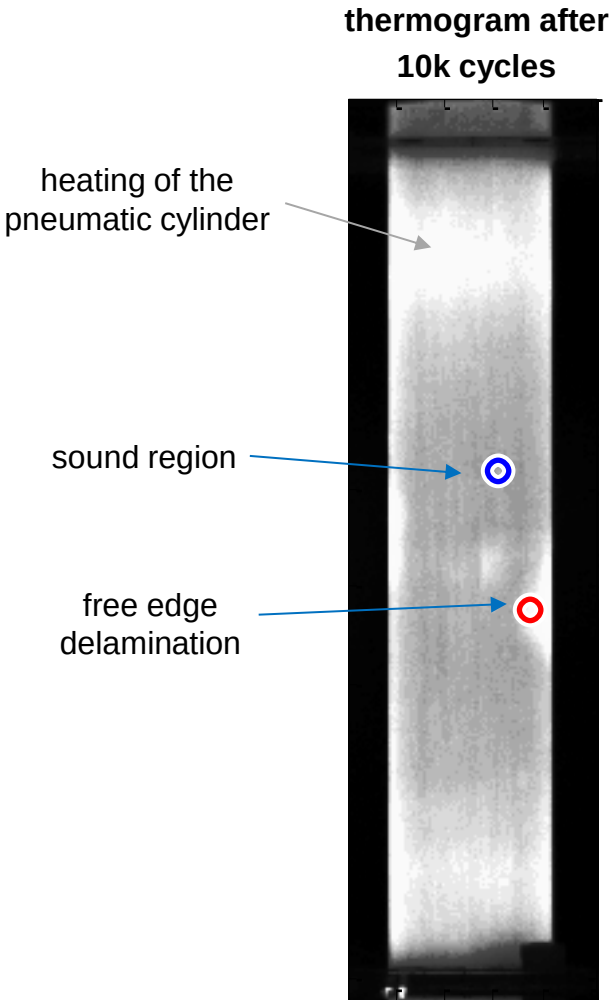
Pulsed thermography setup

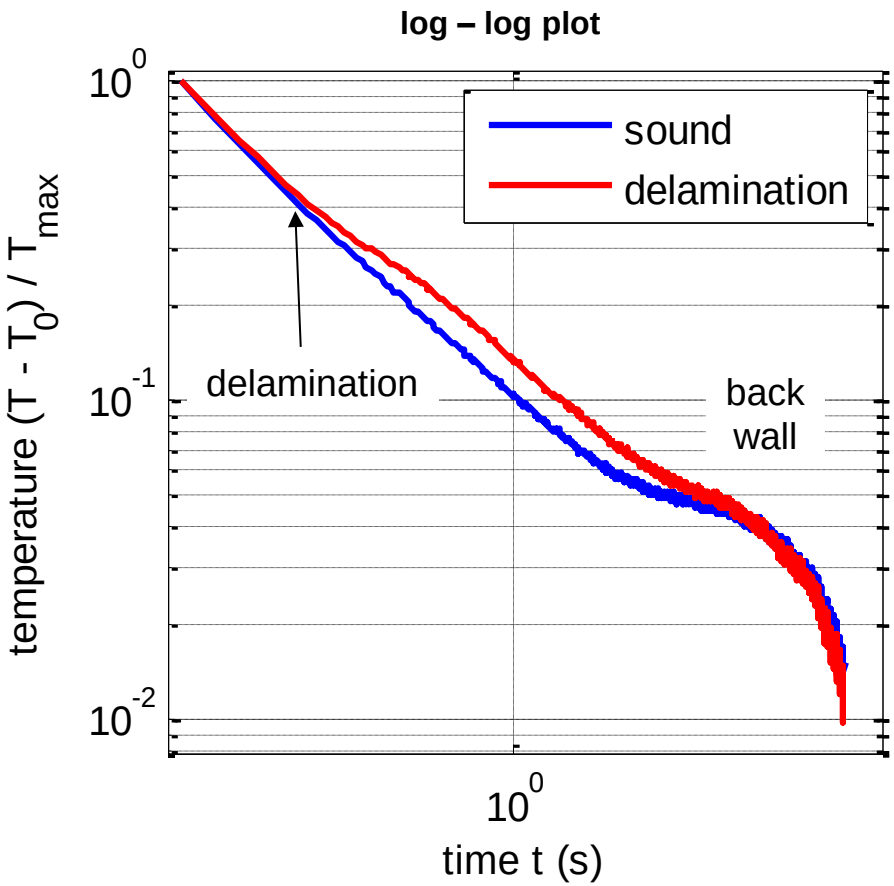
IRCAM Equus 81k M Pro

Flash light: Bläsing G6000z

Fatigue uniaxial tensile tests

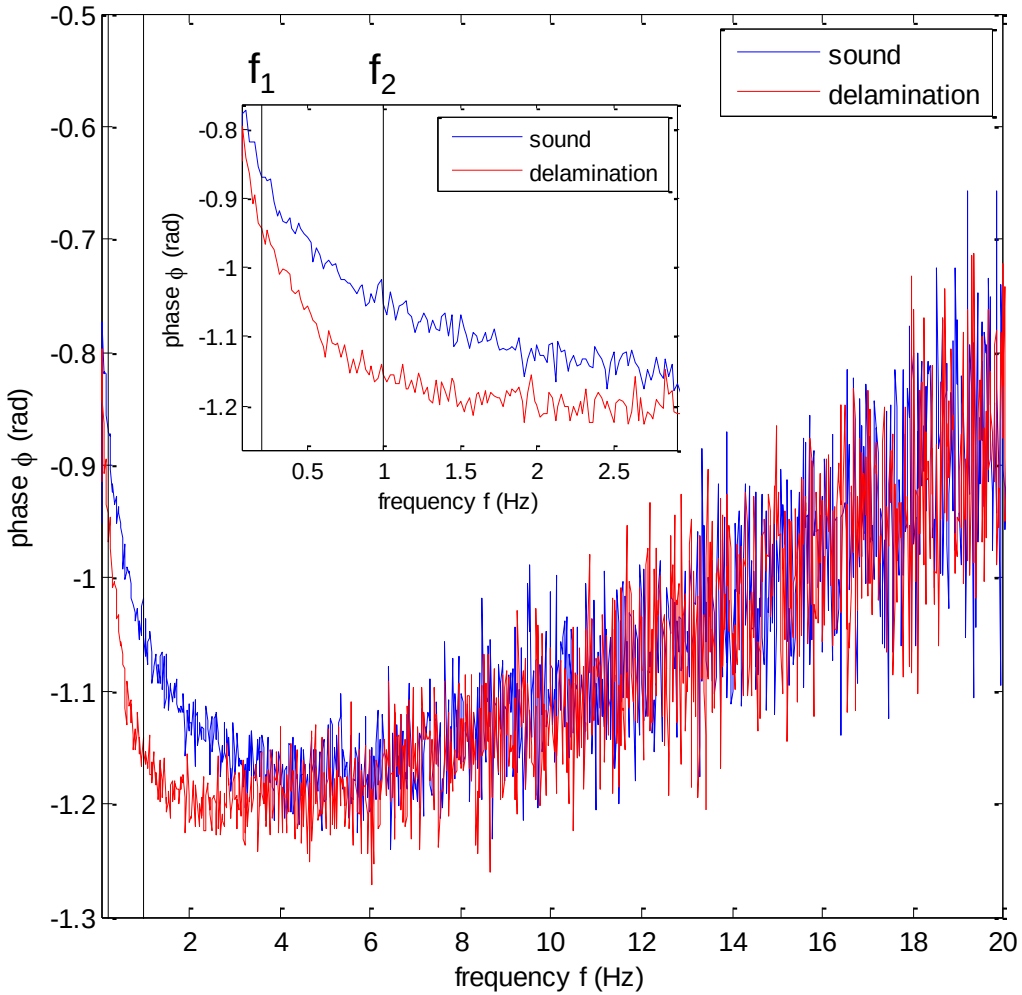
Pulsed thermography – temperature evolution

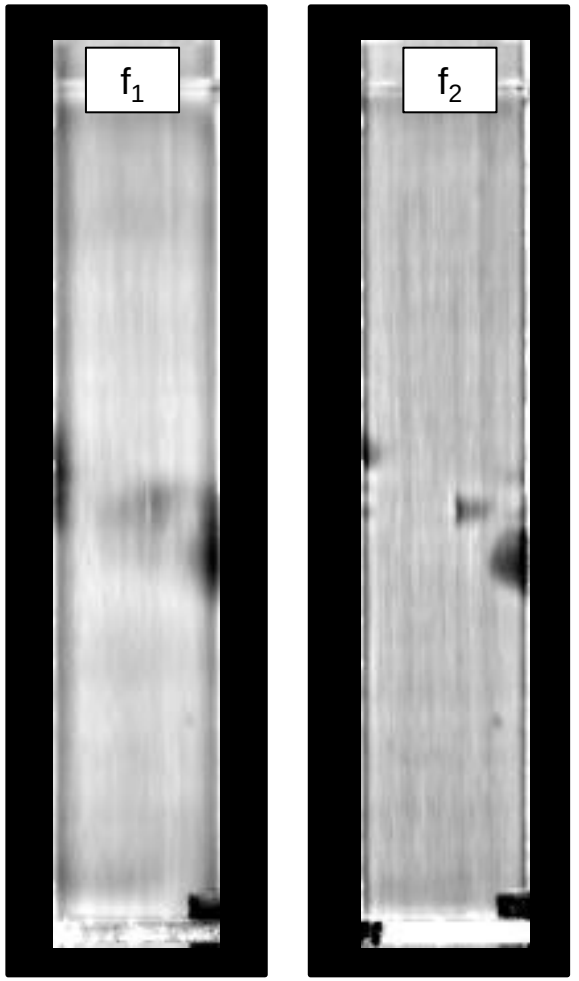




Fatigue uniaxial tensile tests

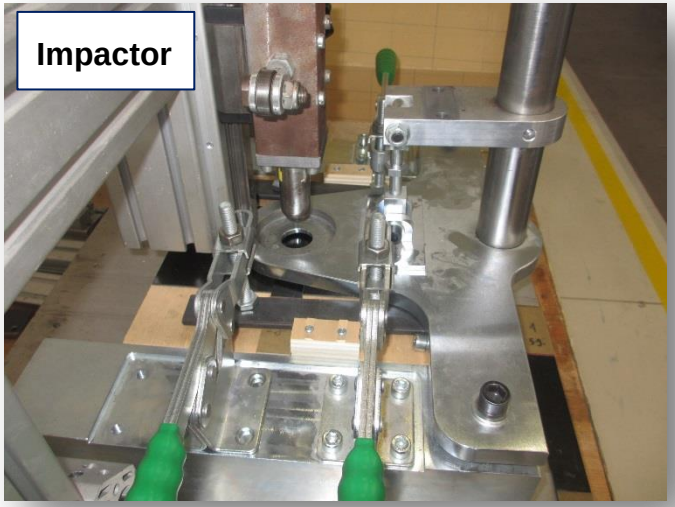
Principle of Pulse Phase Thermography (PPT)

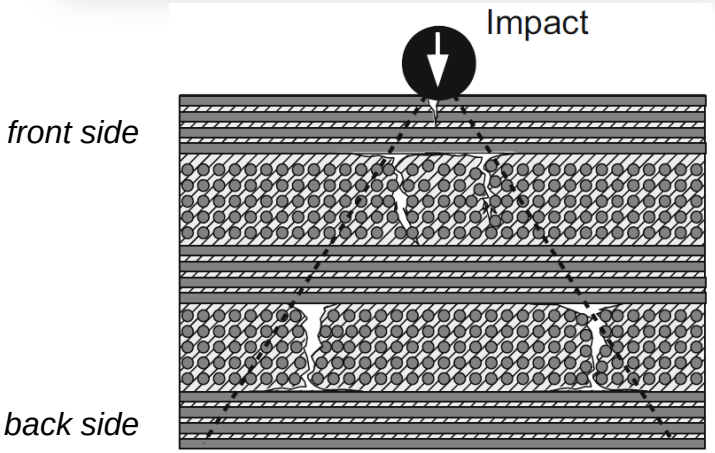


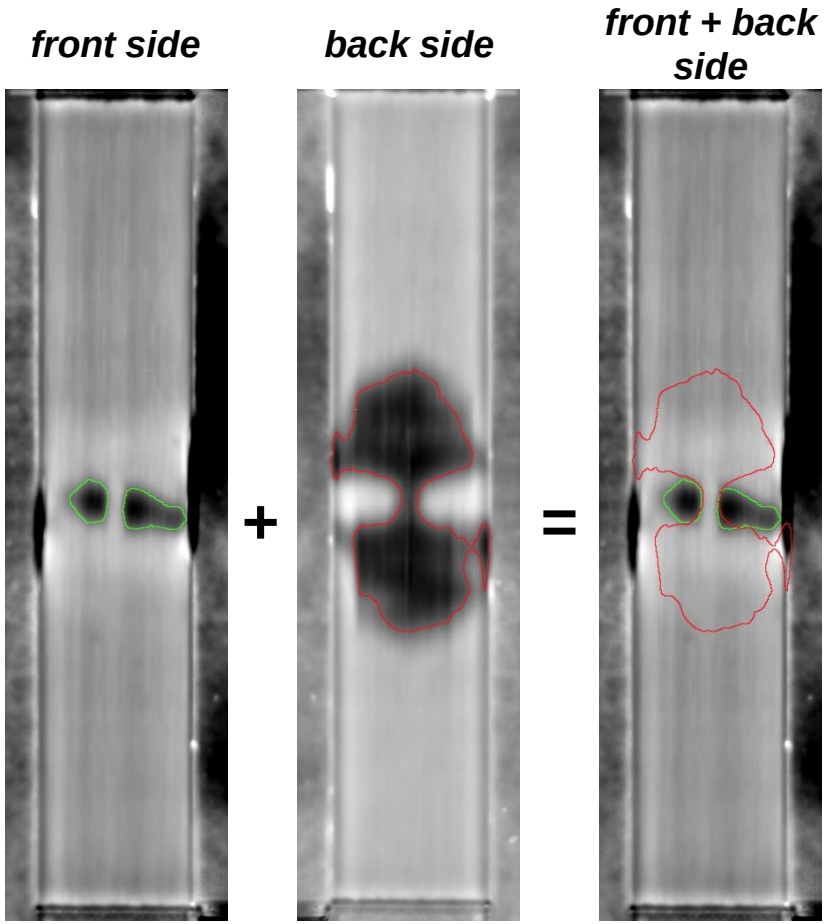


Fatigue uniaxial tensile tests

Type II: Impact damage without tensile loading

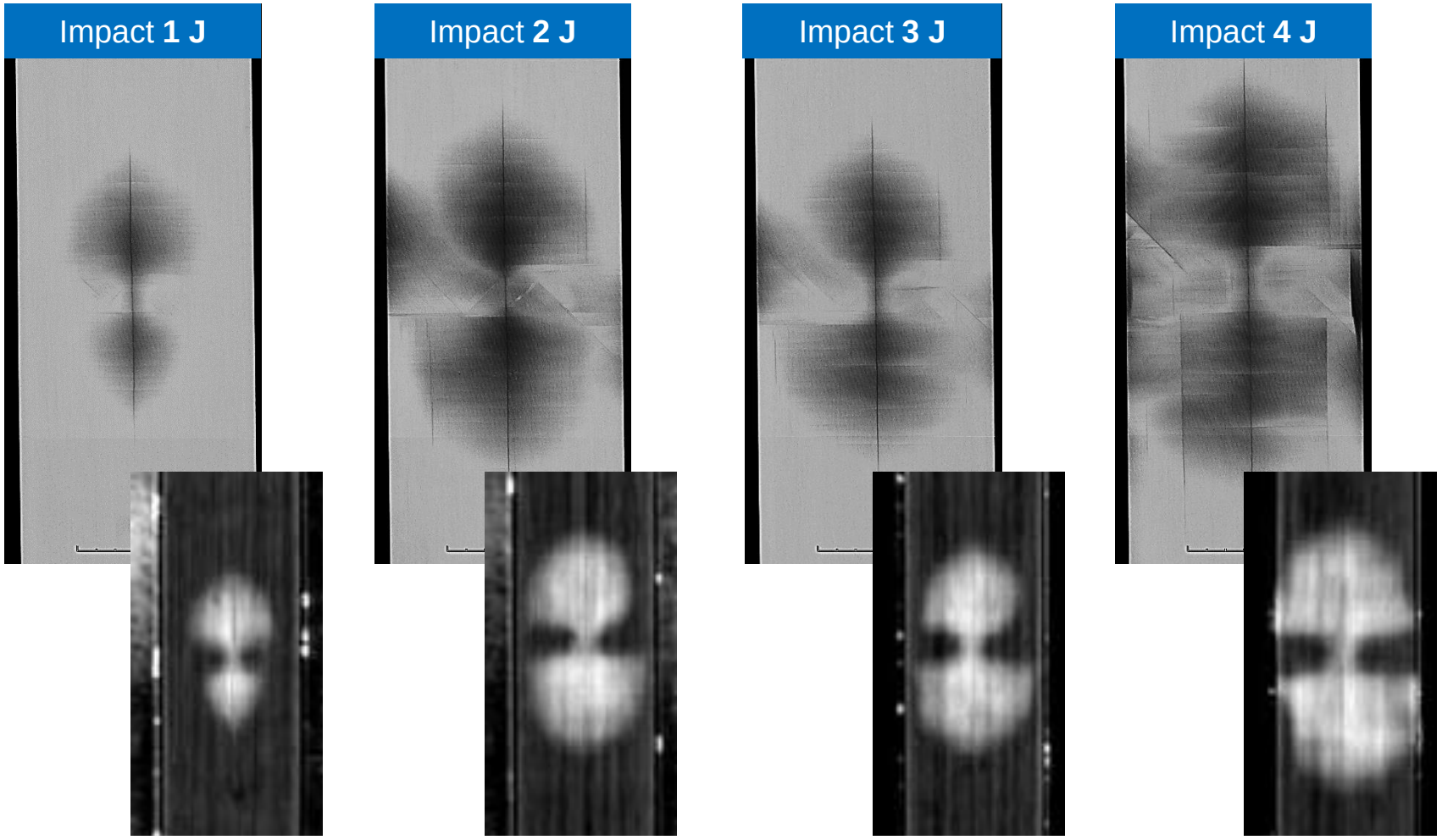






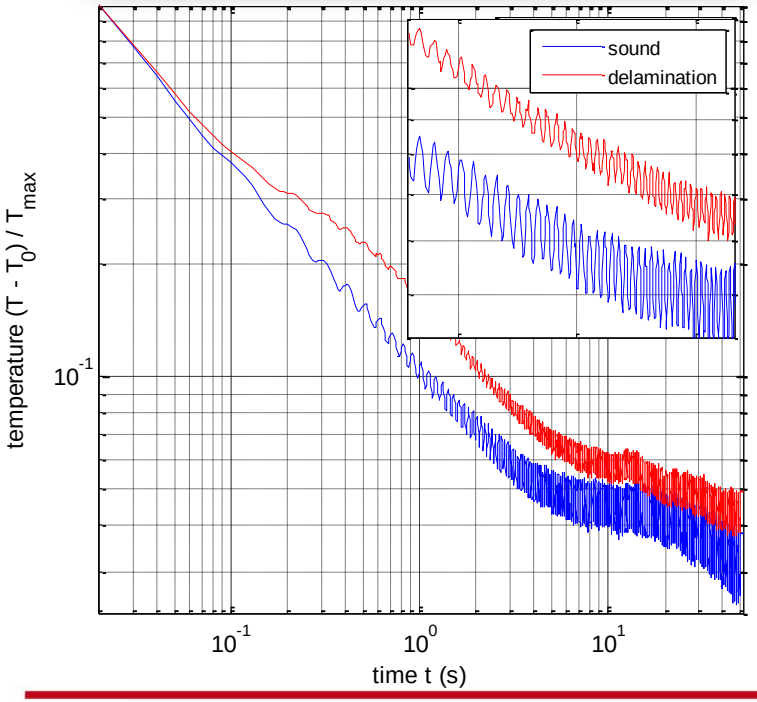
Fatigue uniaxial tensile tests

Type II: Comparison with 3D-Xray Computed Tomography (XCT)

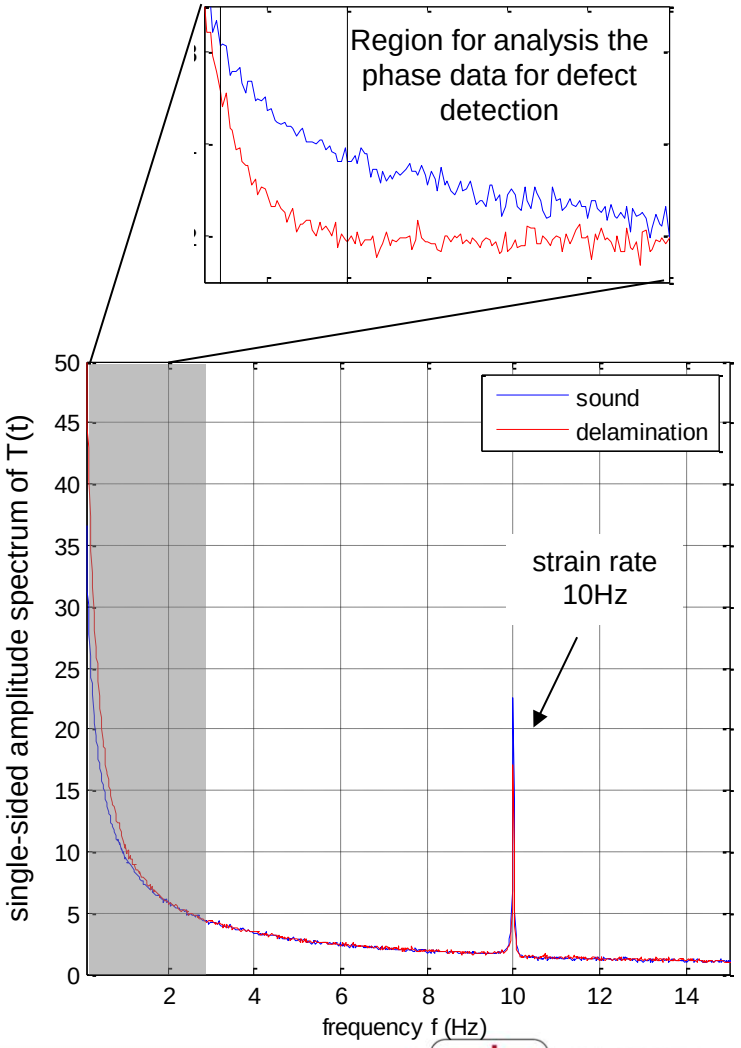


Fatigue uniaxial tensile tests

In-situ PPT with separation of the strain rate



FFT



Fatigue uniaxial tensile tests

Damage progression under increasing number of cycles

Increasing number of cycles up to 250 k

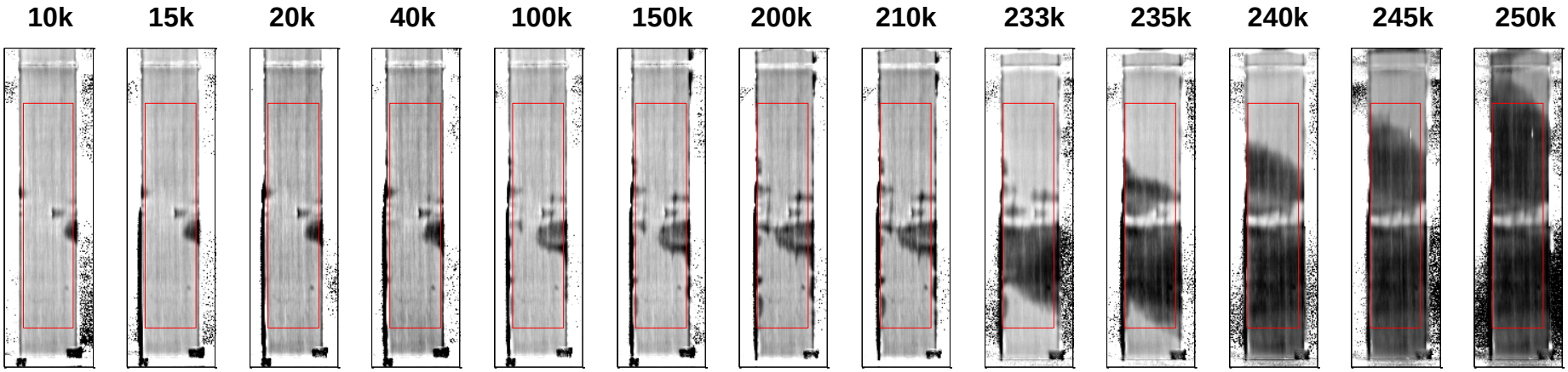
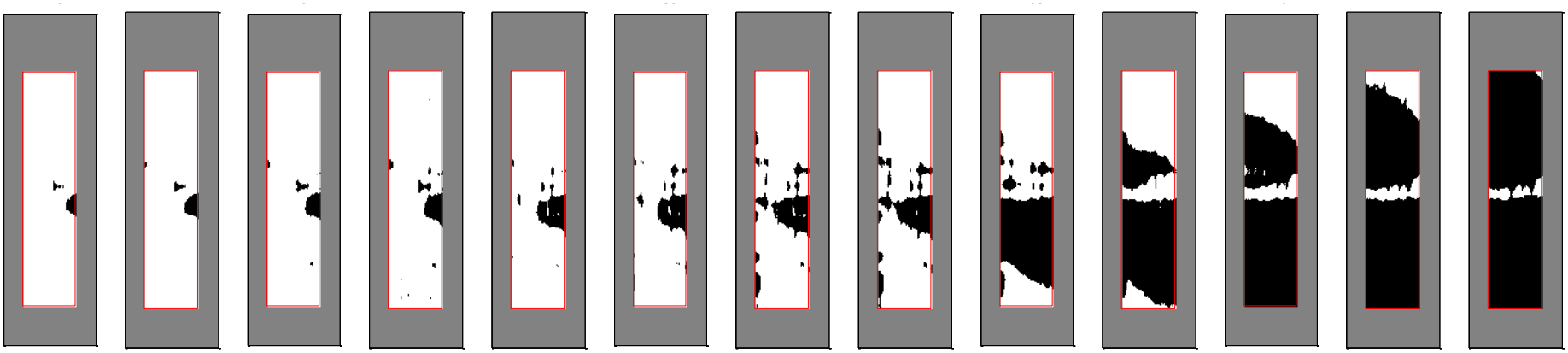
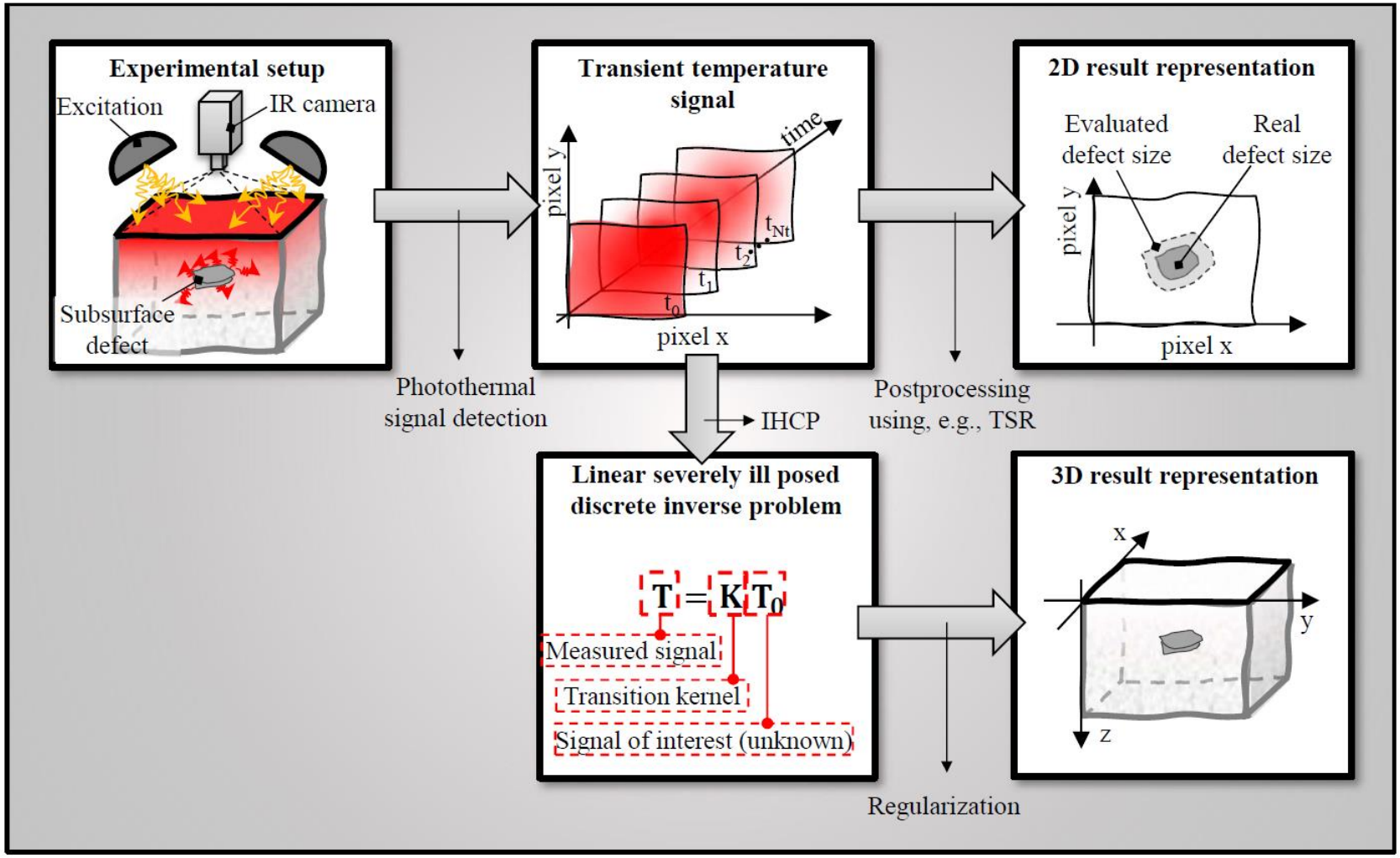


image segmentation for the determination of the delamination size



3D Thermo-Tomography

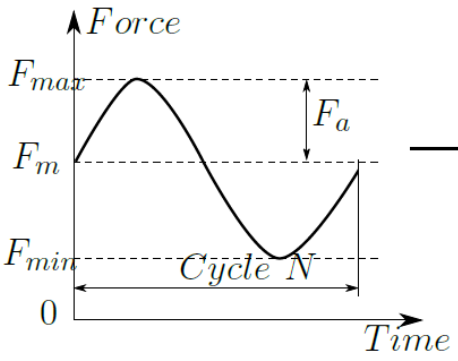
Virtual Wave Concept for Image Reconstruction



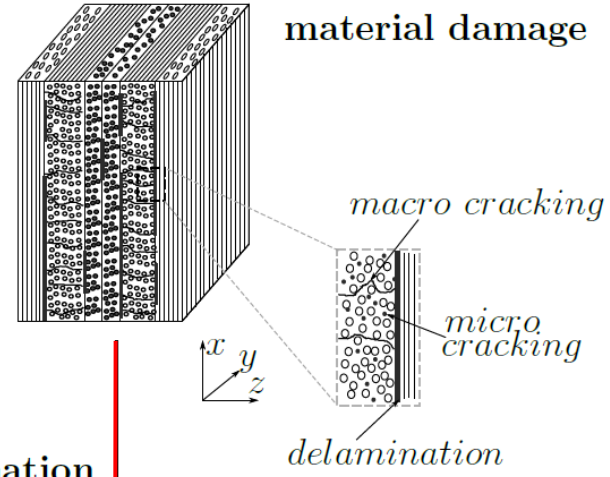
3D Thermo-Tomography

Damage Imaging

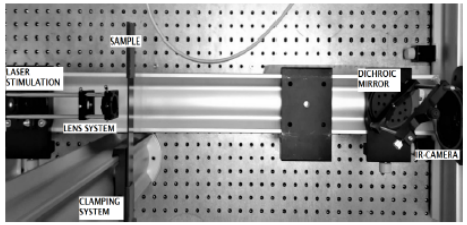
defined loading



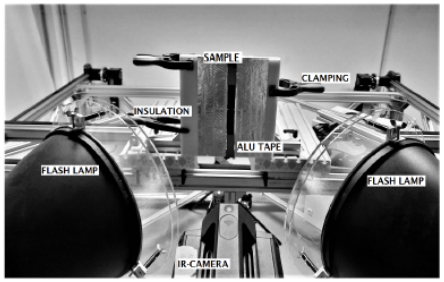
material damage



material parameter estimation

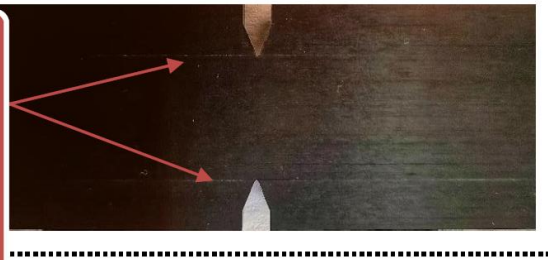


active IRT measurement

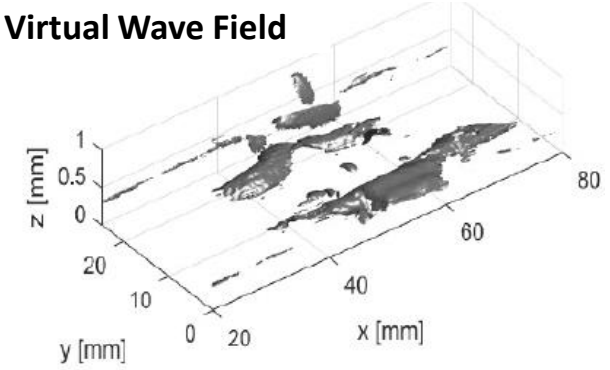


3D reconstruction of internal defects

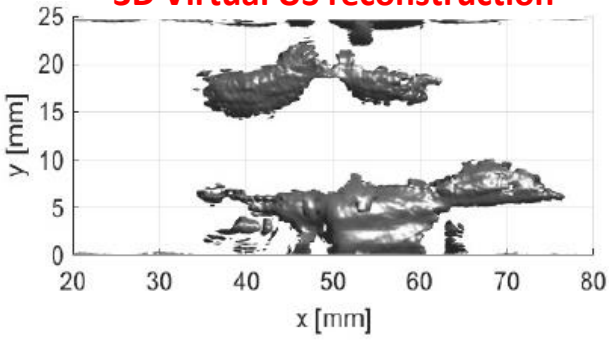
visible surface defect lines



Virtual Wave Field

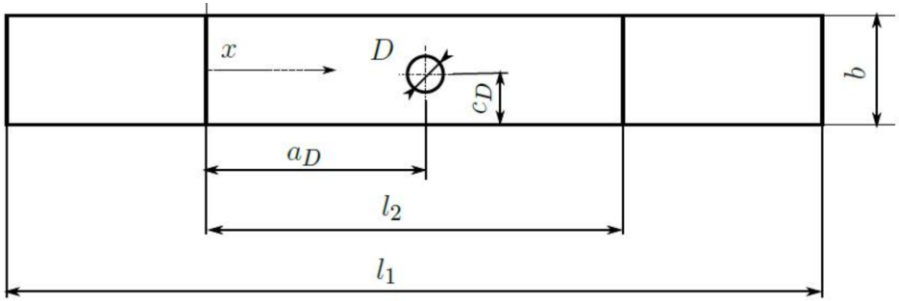


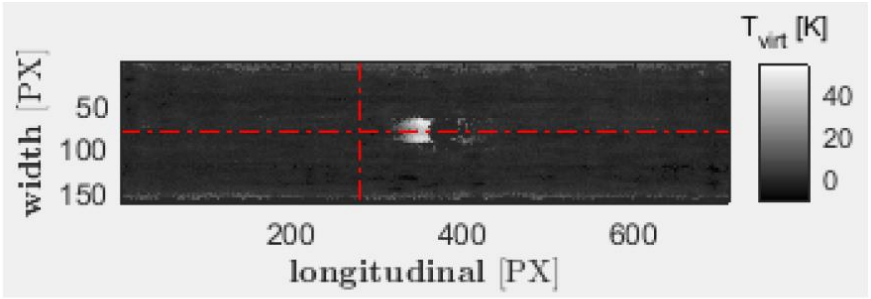
3D Virtual US reconstruction

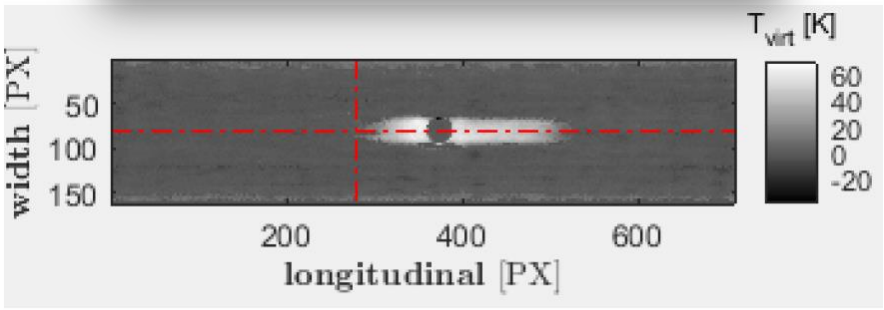


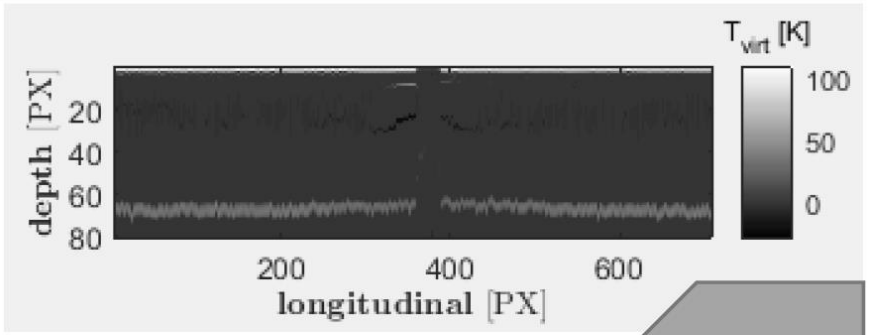
3D Thermo-Tomography

Virtual Wave Concept for Image Reconstruction

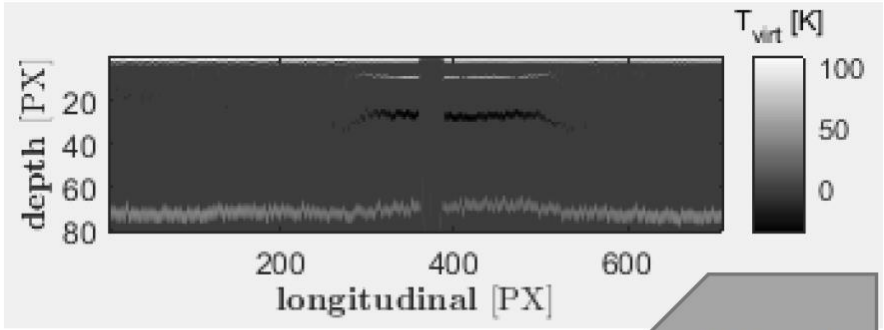








@12k cycles



@32k cycles

Conclusion

- The **initiation** and **progression** of **matrix cracking** in a carbon/epoxy laminate can be detected **in-situ** with **passive thermography**
- The detected **matrix crack density** function explain the measured **stiffness reduction** due to tensile loading
- The **frequency separation** in PPT allows the **in-situ** identification of the **delamination size** without any disturbance of the mechanical loading and deformation
- The **Virtual Wave Concept** enables a **3D imaging** of the defect with increasing fatigue

Outlook

Application on components under fatigue loading

Source: Colt

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