# In-situ Damage Characterisation of Natural Fibre Composites

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*Publication date:*
2011



*Citation (APA):*
Rask, M., Madsen, B., Sørensen, B. F., & Lauridsen, E. M. (2011). In-situ Damage Characterisation of Natural Fibre Composites [Sound/Visual production (digital)]. Comptest 2011, Lausanne (CH), 14-16 Feb, 01/01/2011

Technical University of Denmark

Animation have been replaced by still pictures in this web edition

# *In situ* Damage Characterisation of Natural Fibre Composites

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Presentation at CompTest 2011, Lausanne, EPFL

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National Laboratory for Sustainable Energy

# Motivation

- Can the plants we grow in fields be used for structural components?
- Can plant fibers be optimized to perform similar to fossil based fibers?
- A part of this optimization  is to understand the damage mechanics

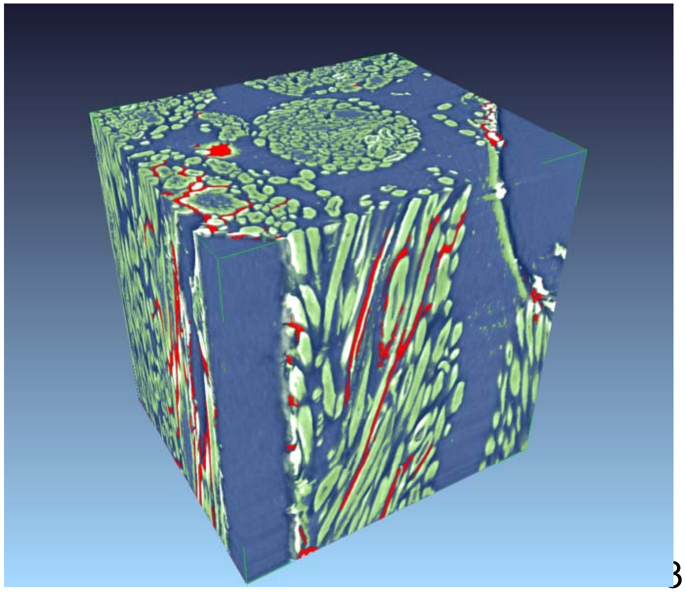

*tinyurl.com/lp34pc*

*tinyurl.com/ox42gc*


*tinyurl.com/lukvqq*

# Outline

- Natural Fibre Composites
- X-ray tomography
- Results
- Conclusion



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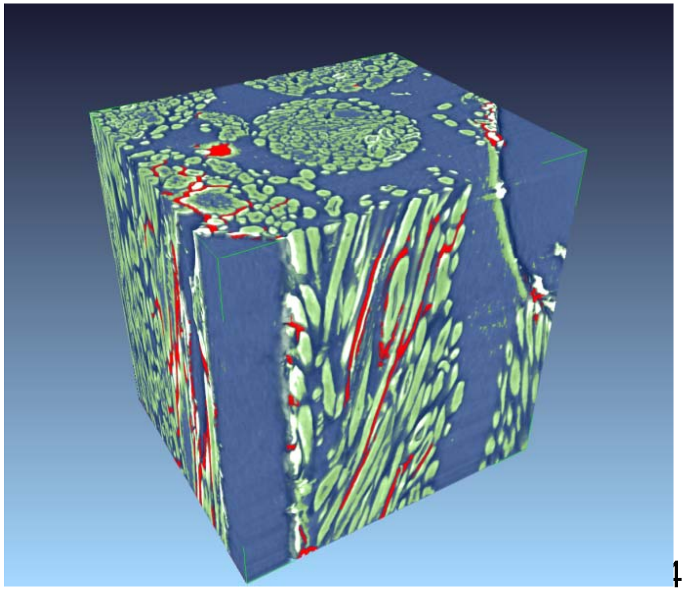
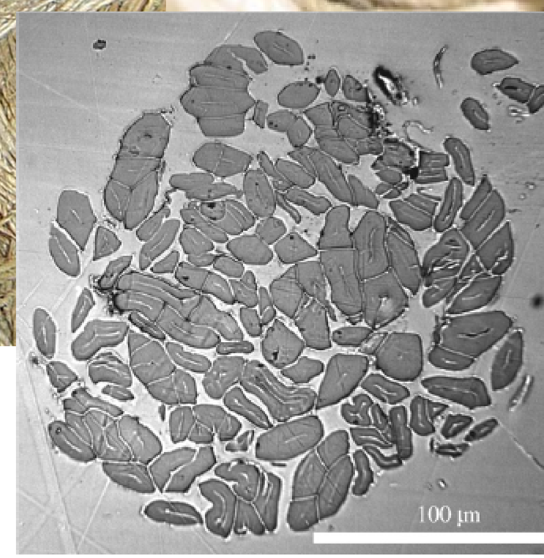


# A piece of hemp yarn

- Yarn is spun from a large number of fibres
- Lenght of fibres
  - 50mm
- Diameter of yarn
  - 200-500μm
- Diameter of fiber
  - 5-15μm

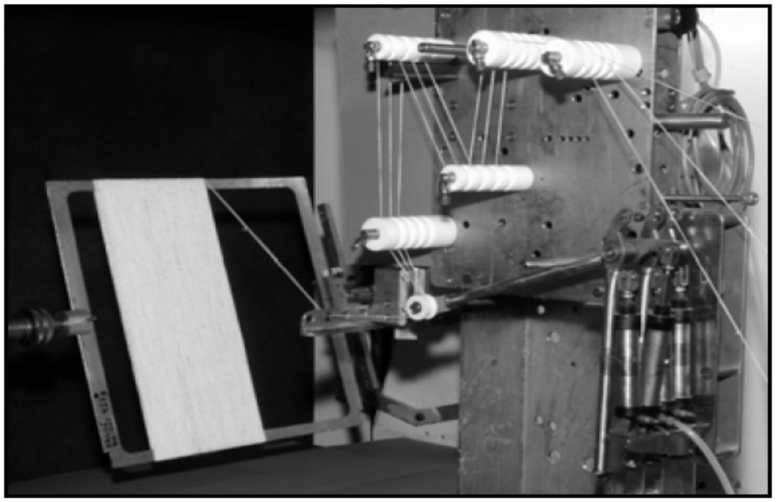
Short fibres → twisting
Fibres can form bundles

*tinyurl.com/n675jn*




*B Madsen et. al. Comp Part A. 2007.*

# Composite fabrication



*Picture courtesy of Bo Madsen*

*tinyurl.com/n4yxka*

## Commingled filament winding

- Hemp/flax fibers and polymermatrix systems
- Unidirectional laminates
- Uniform distribution of fibres and matrix
- Well-controlled fiber volume fraction

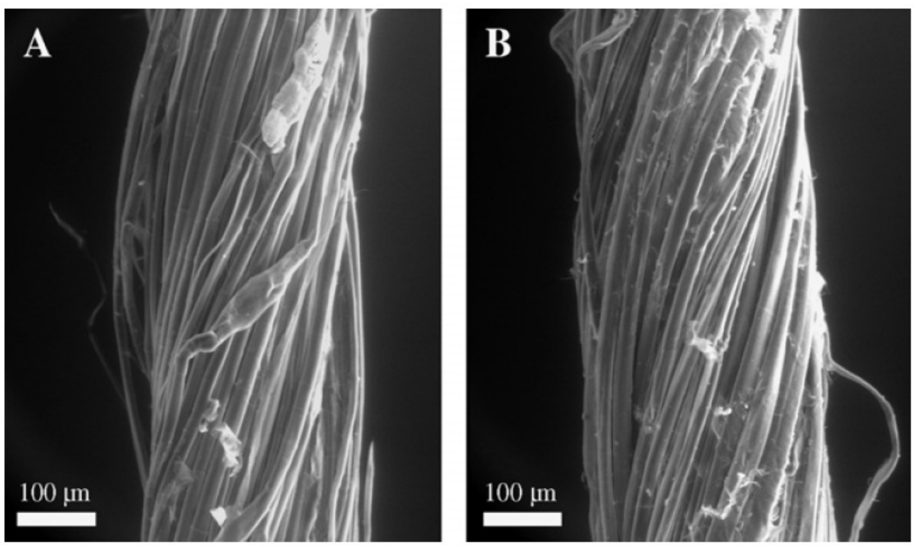
## Press consolidation

- Small amount of porosities
- Short consolidation time

# Porosities in natural fibre composites

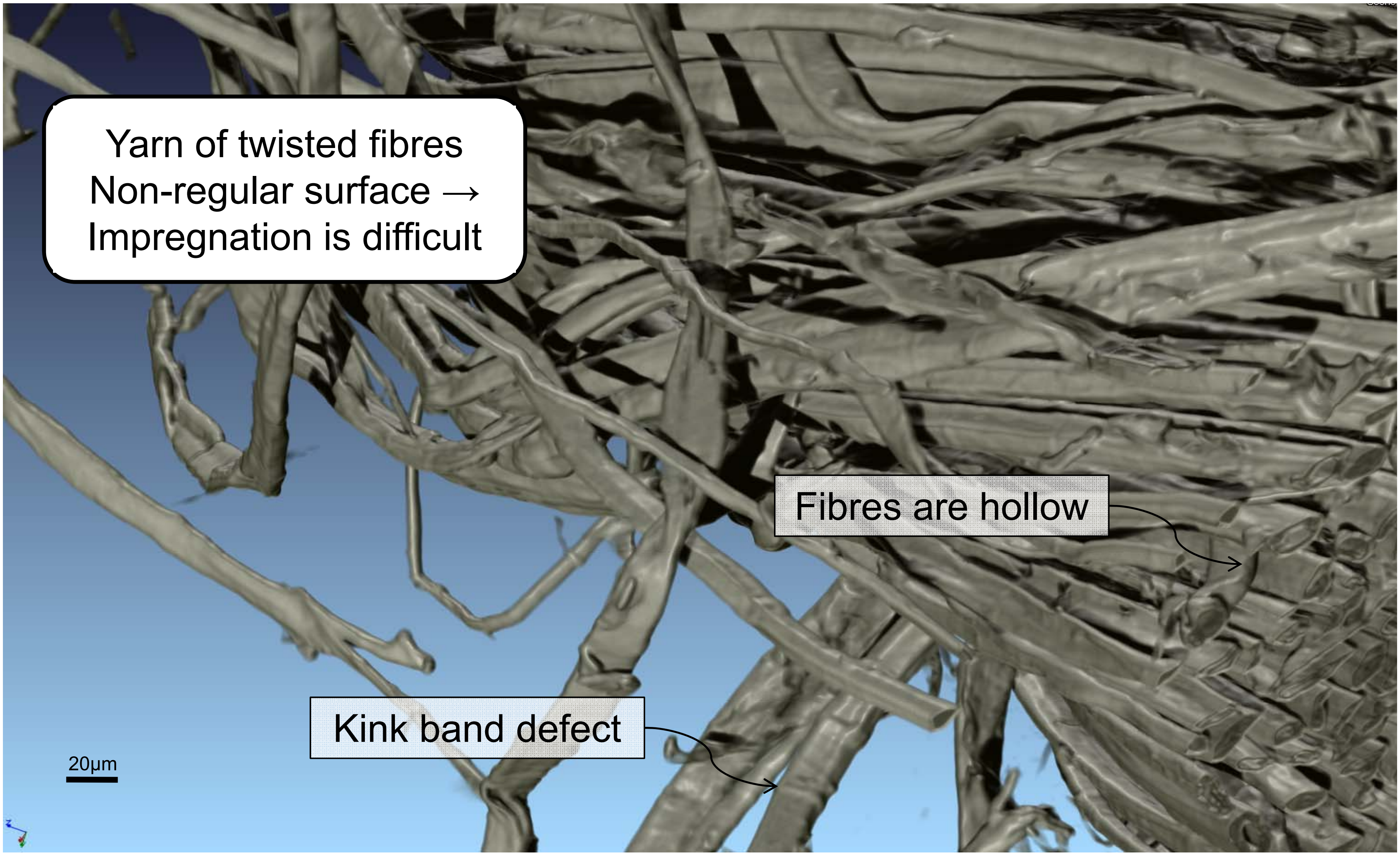
- Complicated surface chemistry
- Irregular form  and dimension along fibres
- Fibres are closely packed by twisting

Porosities is of special concern for natural fibre composites

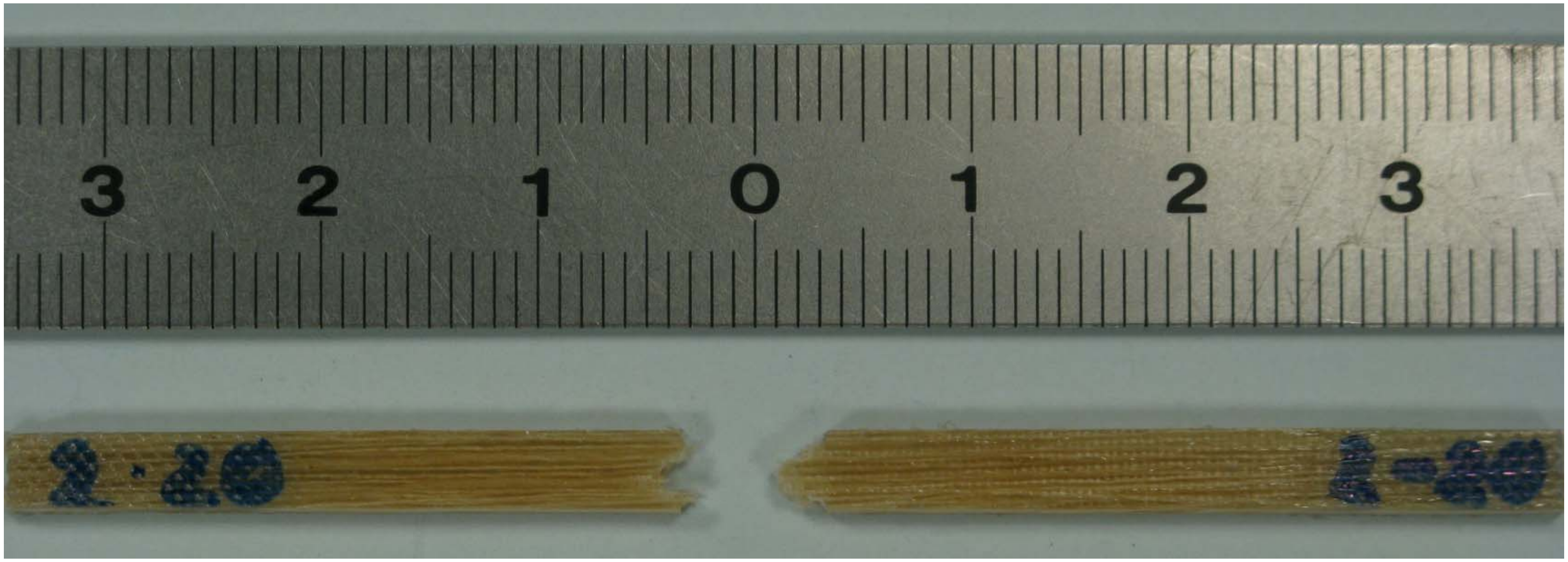



*B Madsen et. al. Comp Part A. 2007.*

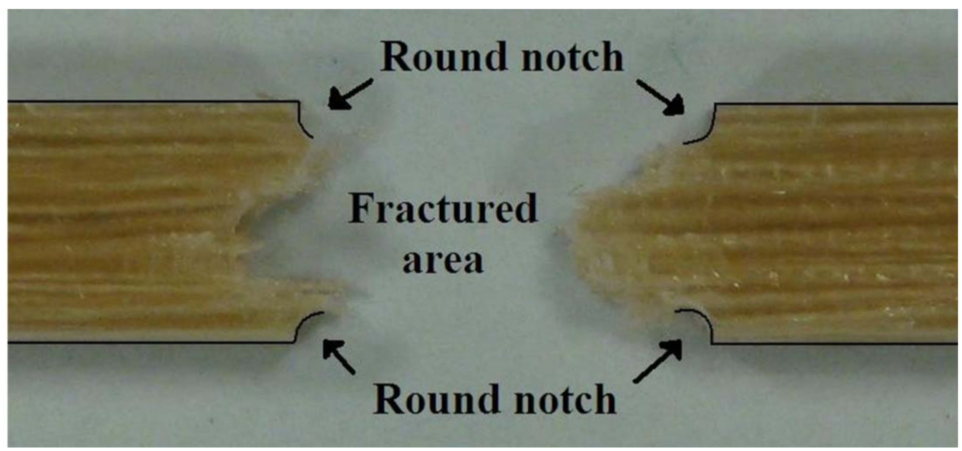
# 3D volume of yarn – close up



# Do porosities influence damage?




- Unidirectional composites can display splitting along fibres.
- How can this be energetically favourable?
  - Weak planes caused by porosities?



# Damage characterisation

Traditional Methods:

I. Microscopy post-failure inspection
II. Acoustic emission
III. Ultrasound scanning
IV. Serial sectioning

Limitations:

I. Limited to surface, destructive
II. No information on type of damage
III. Limited resolution, crack direction sensitive
IV. Polishing artifacts, destructive

With these methods it is not possible to characterise damage completely
→ Tomography

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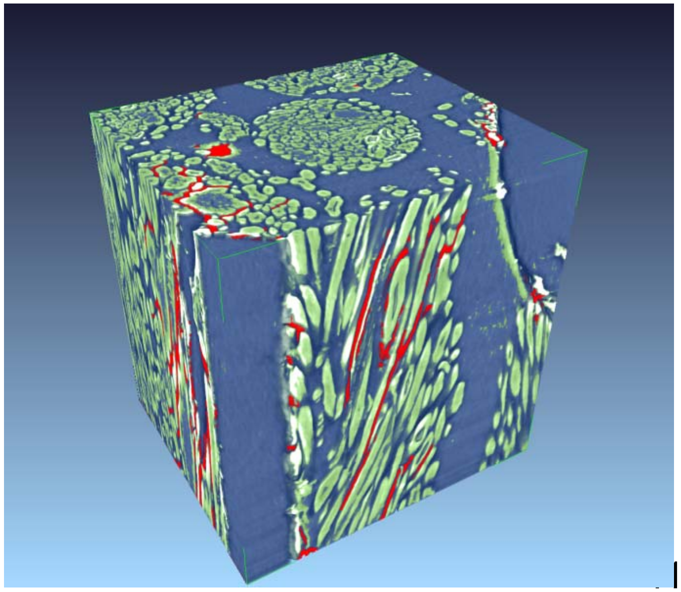
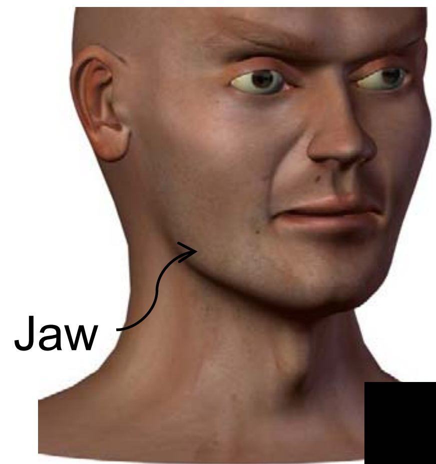
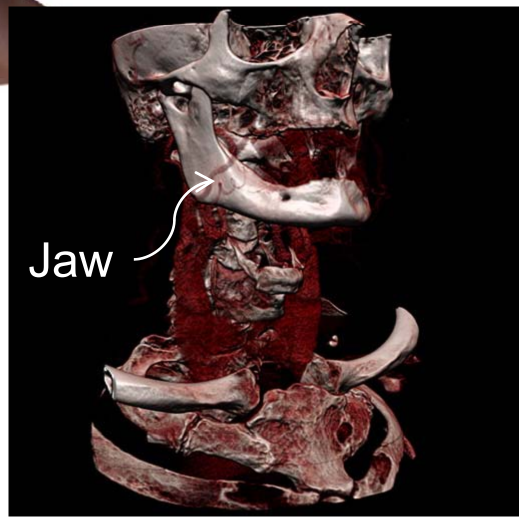


# X-ray Tomography

- A synchrotron X-ray beam is used to scan the material of choice.
- A computer algorithm converts the large number of 2D projections to 2D slices.
- From these slices, the 3D structure can be reconstructed.
- Advantages:
  - 3D imaging
  - High resolution (~ 1$\mu$m)
  - Non-destructive

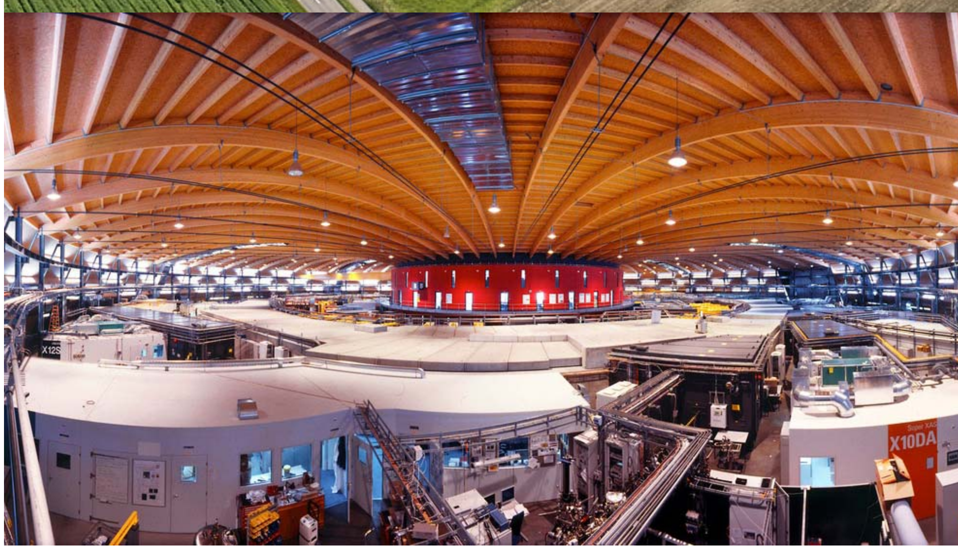
Example: CT-scanning

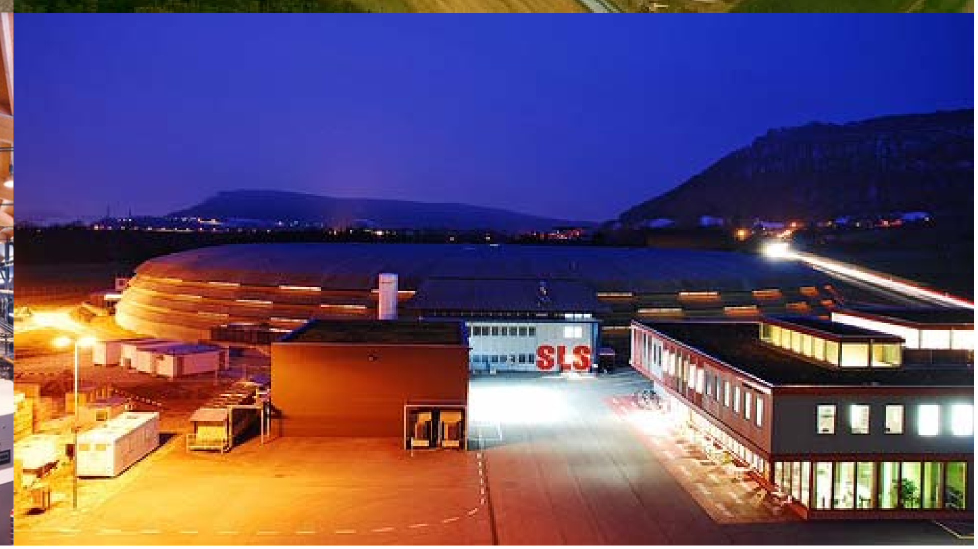



*tinyurl.com/lekvys*

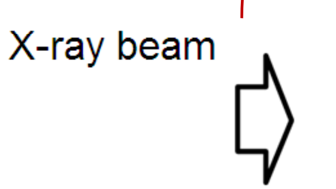
# SLS - Swiss Light Source

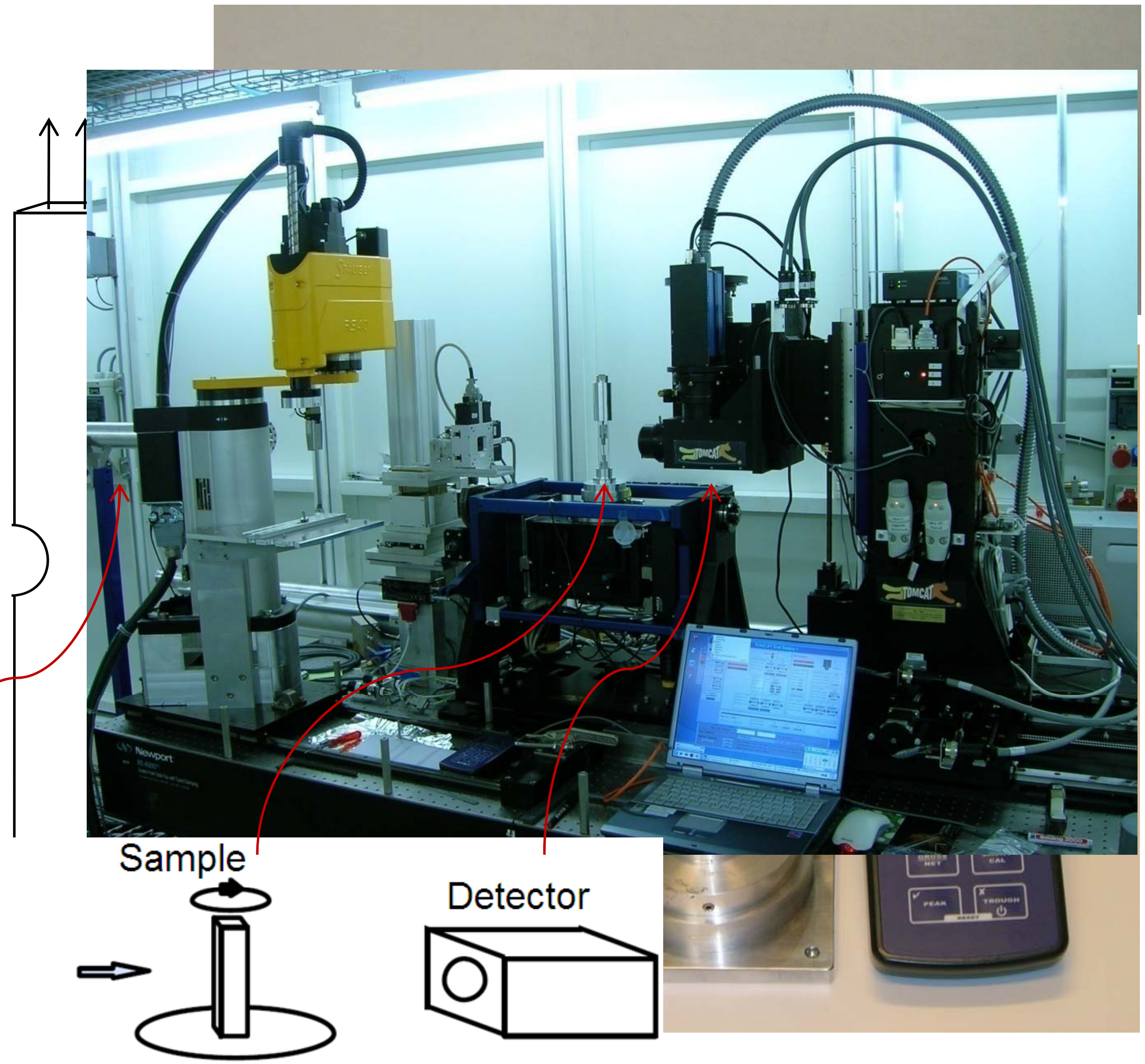


# Test specimens and fixture

- Small notched composite specimens were scanned
- Different yarn samples were scanned
- Scanning was done at different load levels in special loading fixture



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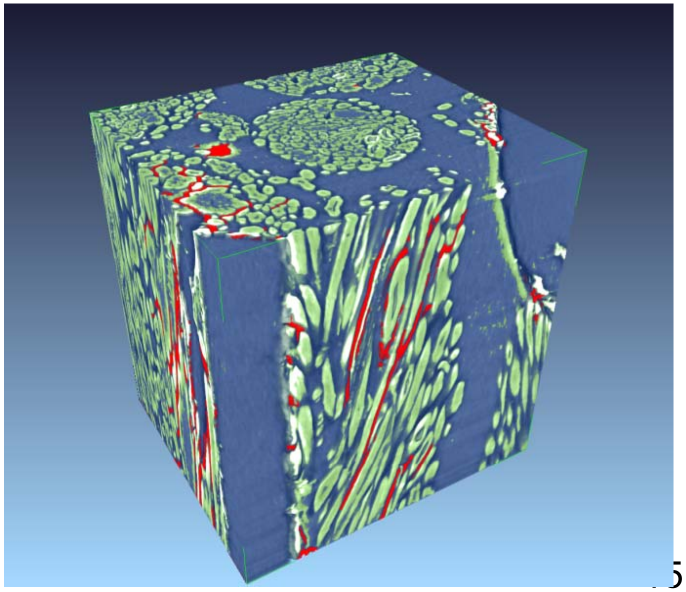
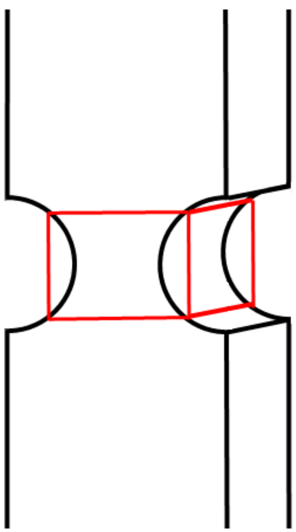
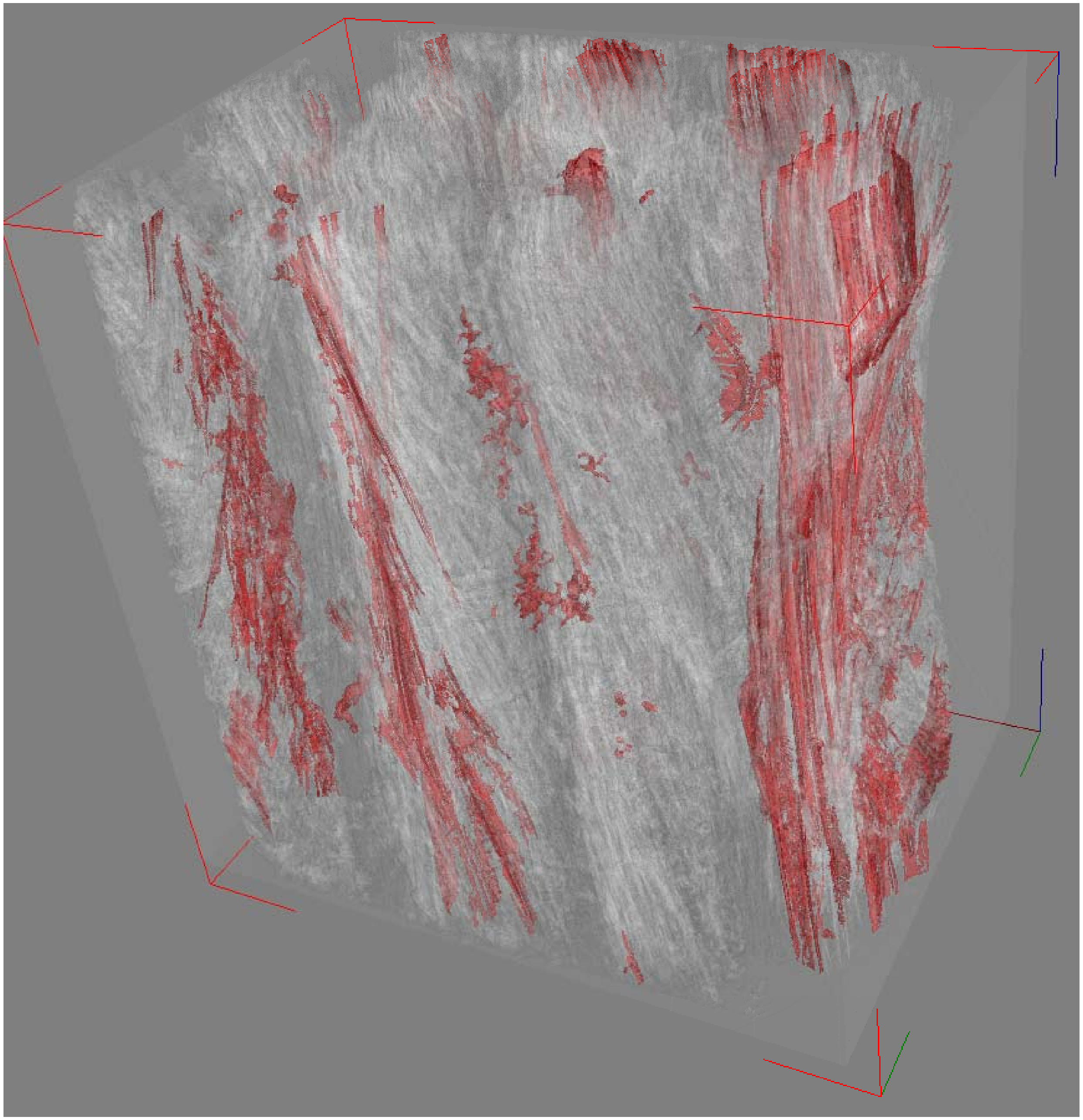


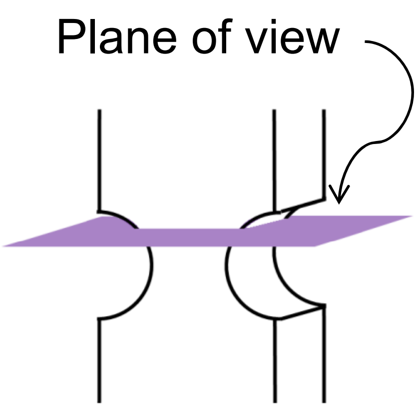
# 3D animation

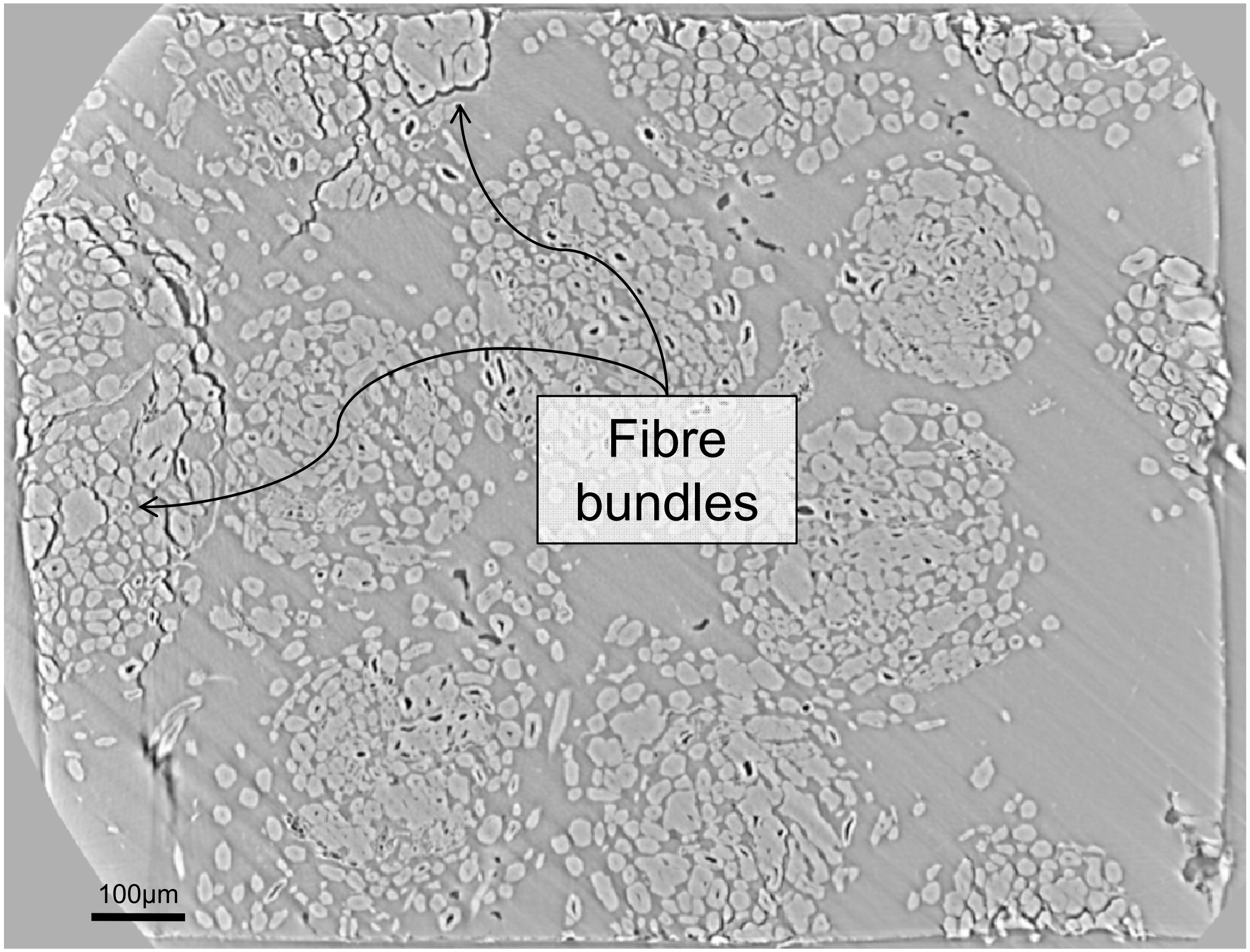
- Fibres are light grey
- Matrix is transparent
- Cracks are red
- Animation shows red box below
- Dimensions of box is 1.4 x 1.4 x 1.4 $mm^3$



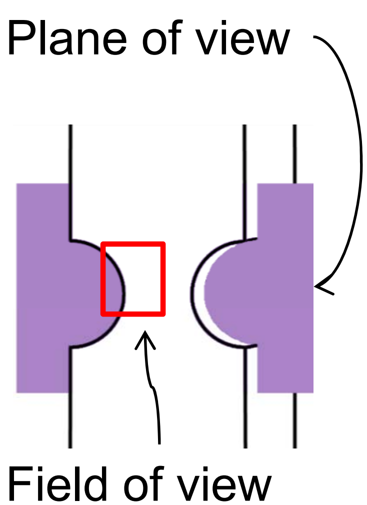


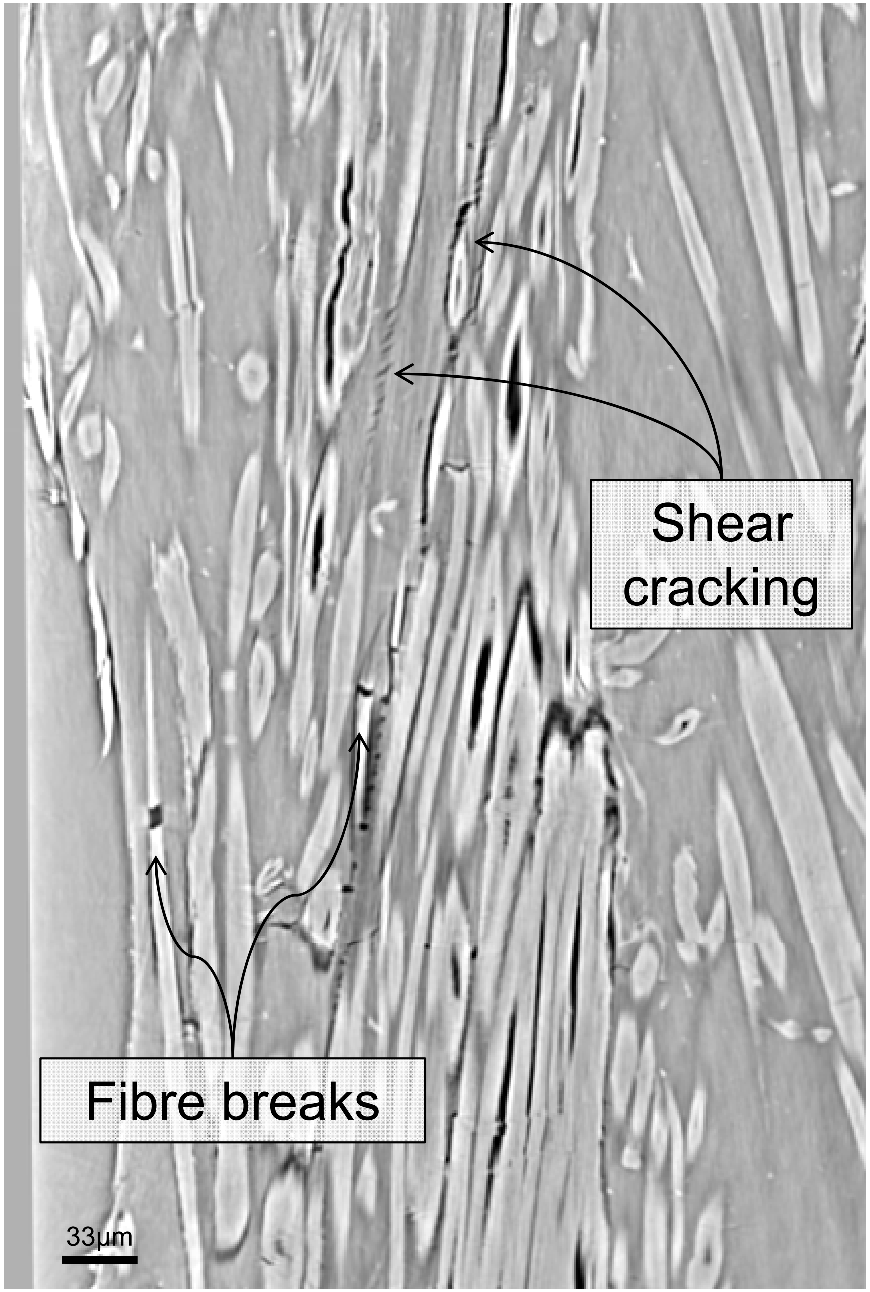
- Evolution of interface cracks
- Cracks are often seen at fibre bundles



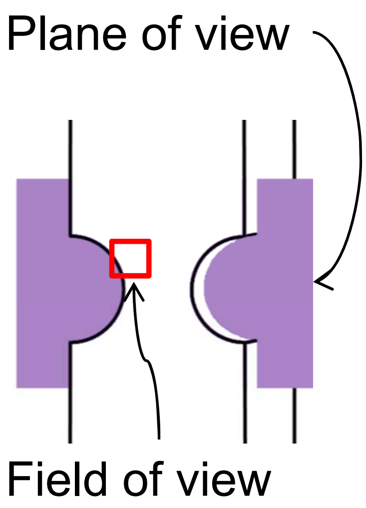



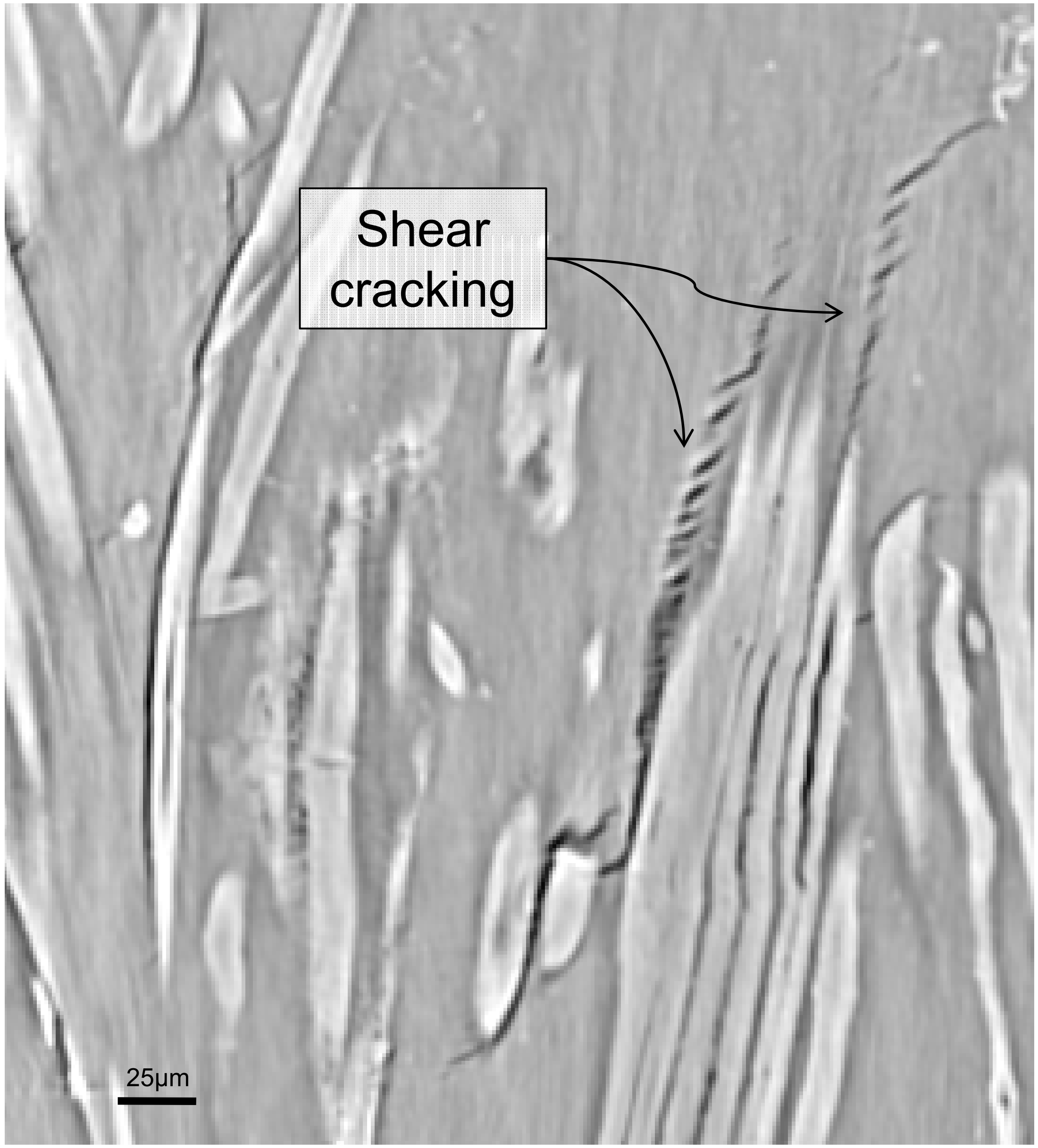
- Two fibre breaks
- Shear cracks
- Cracks follow fibre/matrix interfaces



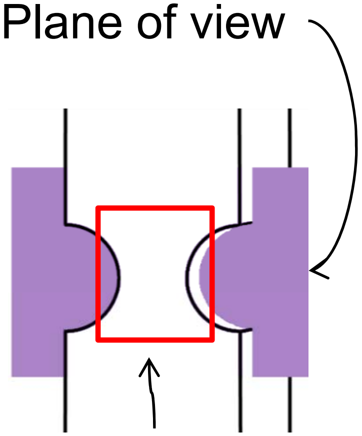
- Evolution of shear cracks



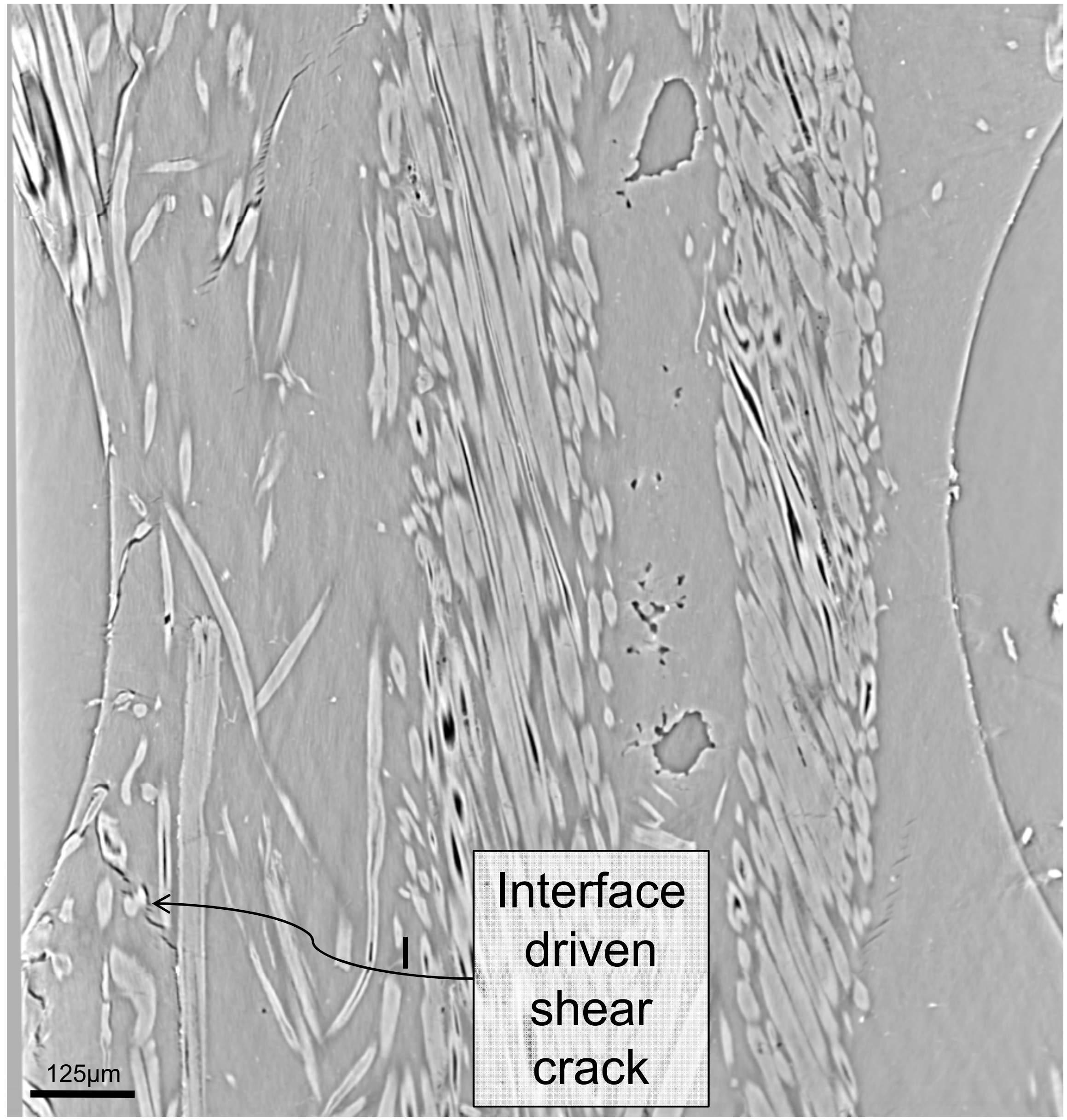



- Shear cracks
- Path is dictated by fibre/matrix interfaces

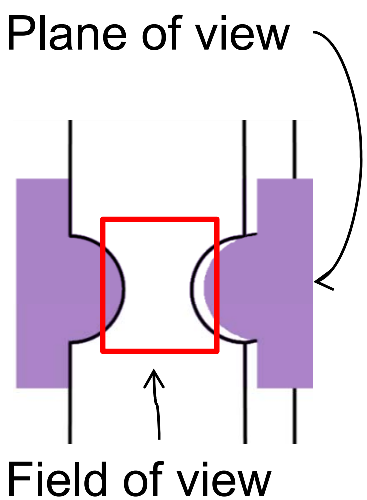
Plane of view

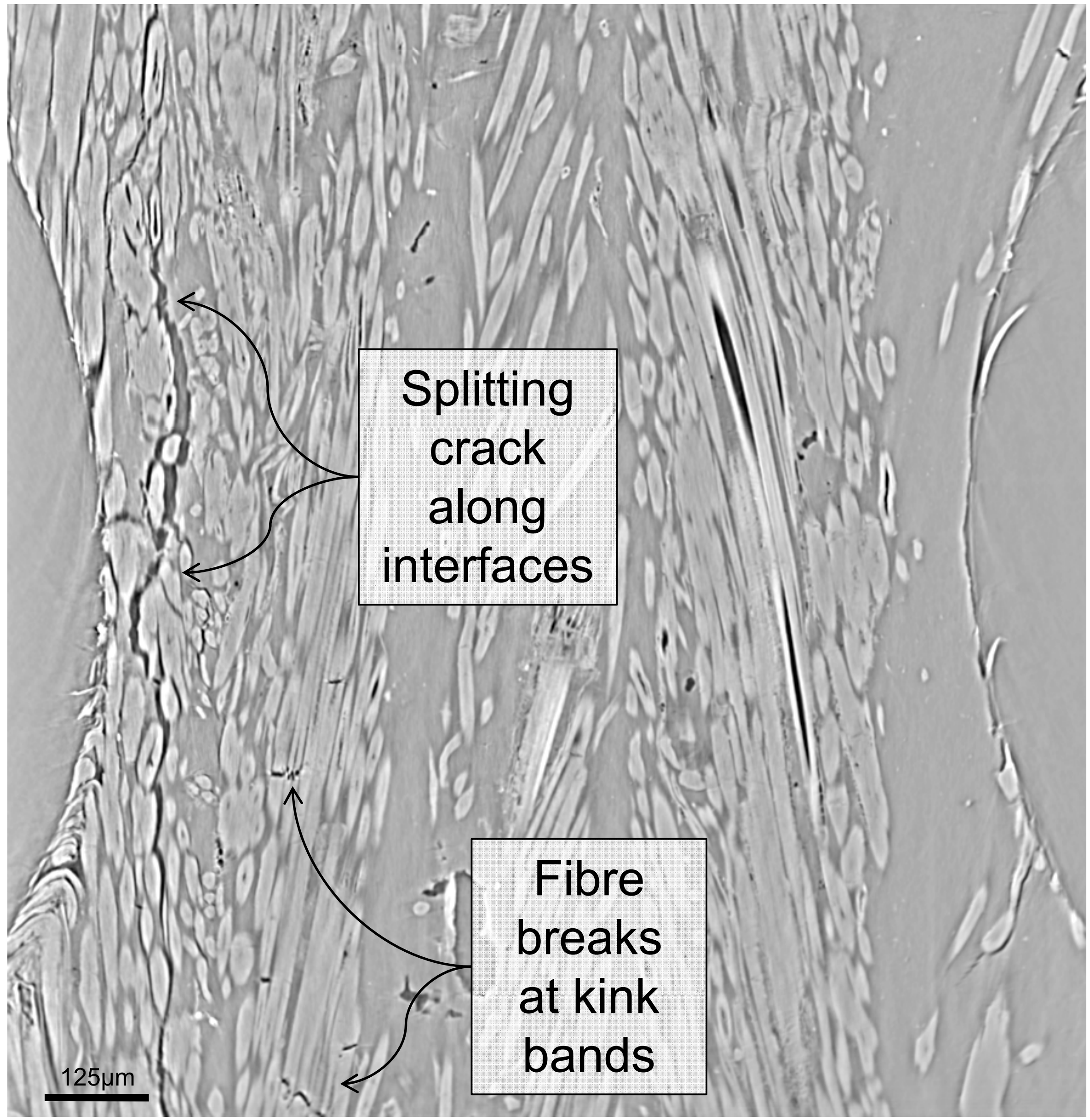


Field of view

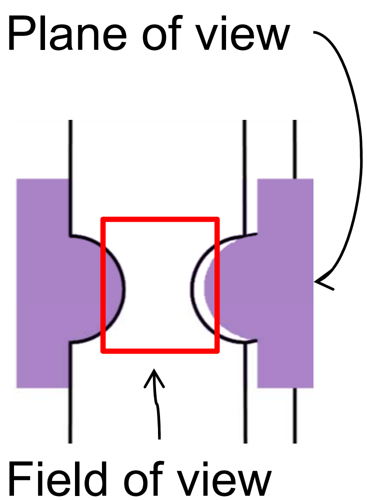


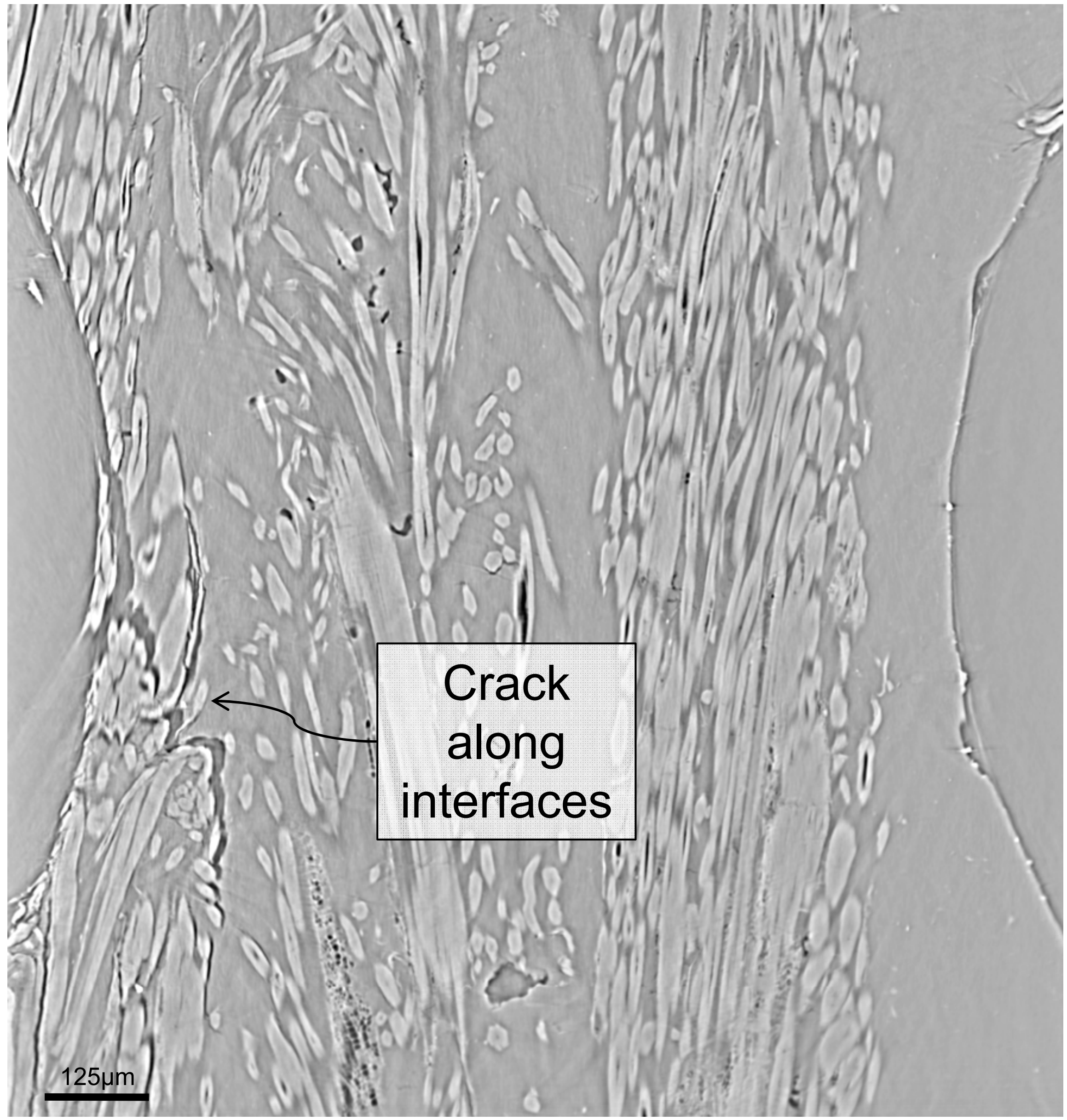
- Long splitting crack emanating from notch stress concentration
- Path follows fibre/matrix interfaces
- Eight fibre breaks are visible, some weak bands are seen.



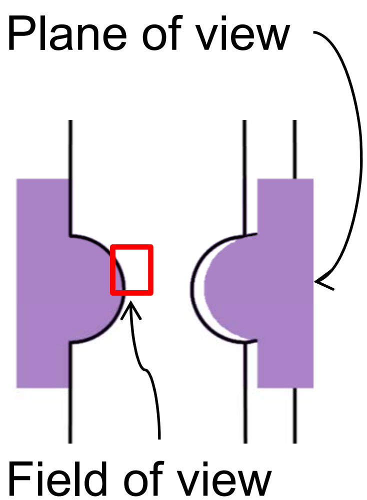



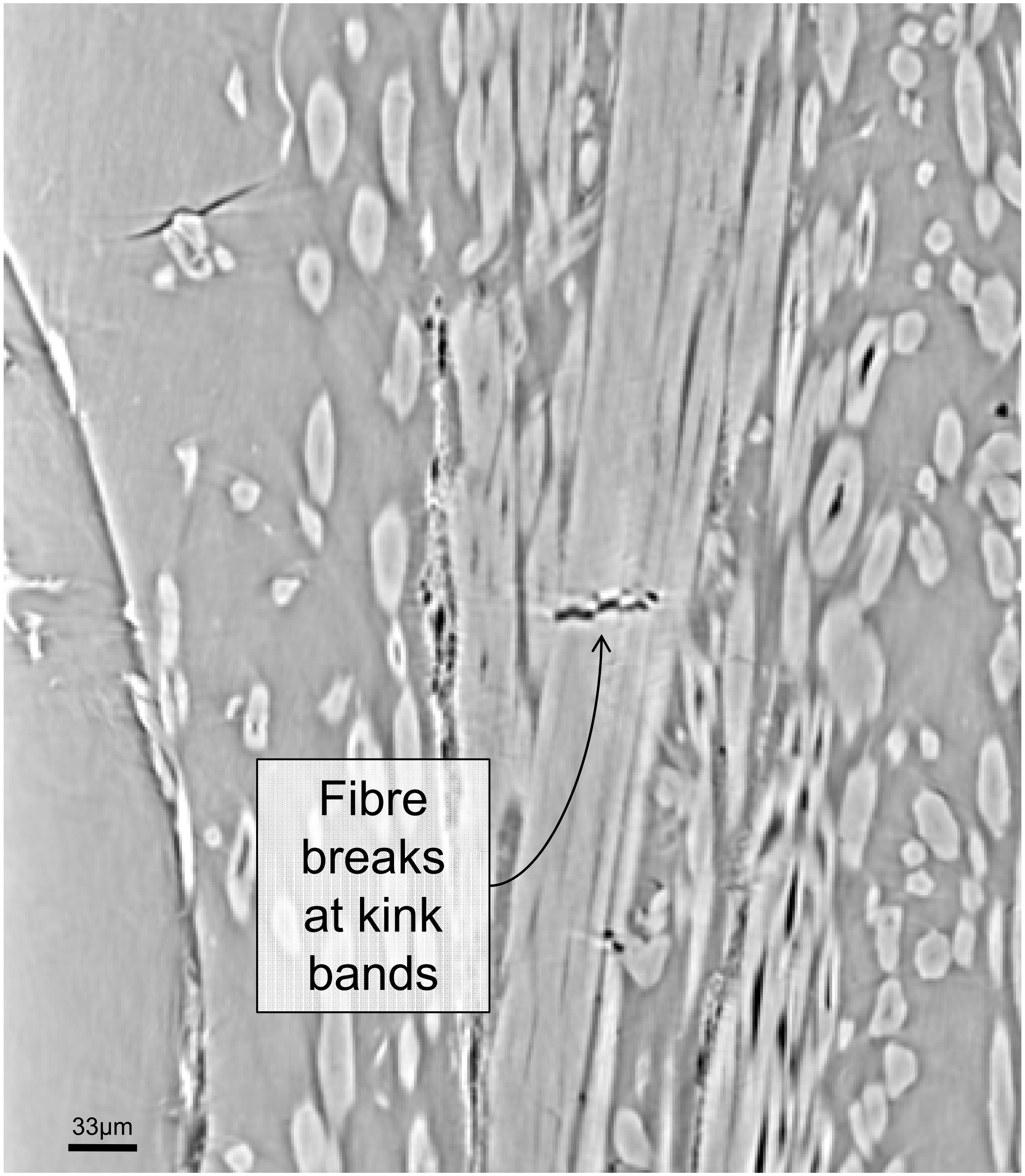
- Large break-away
- Path dictated by fibre/matrix interfaces



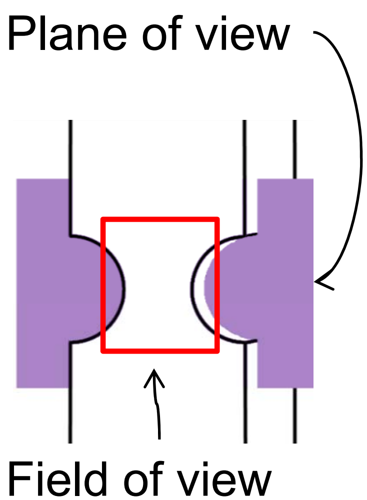



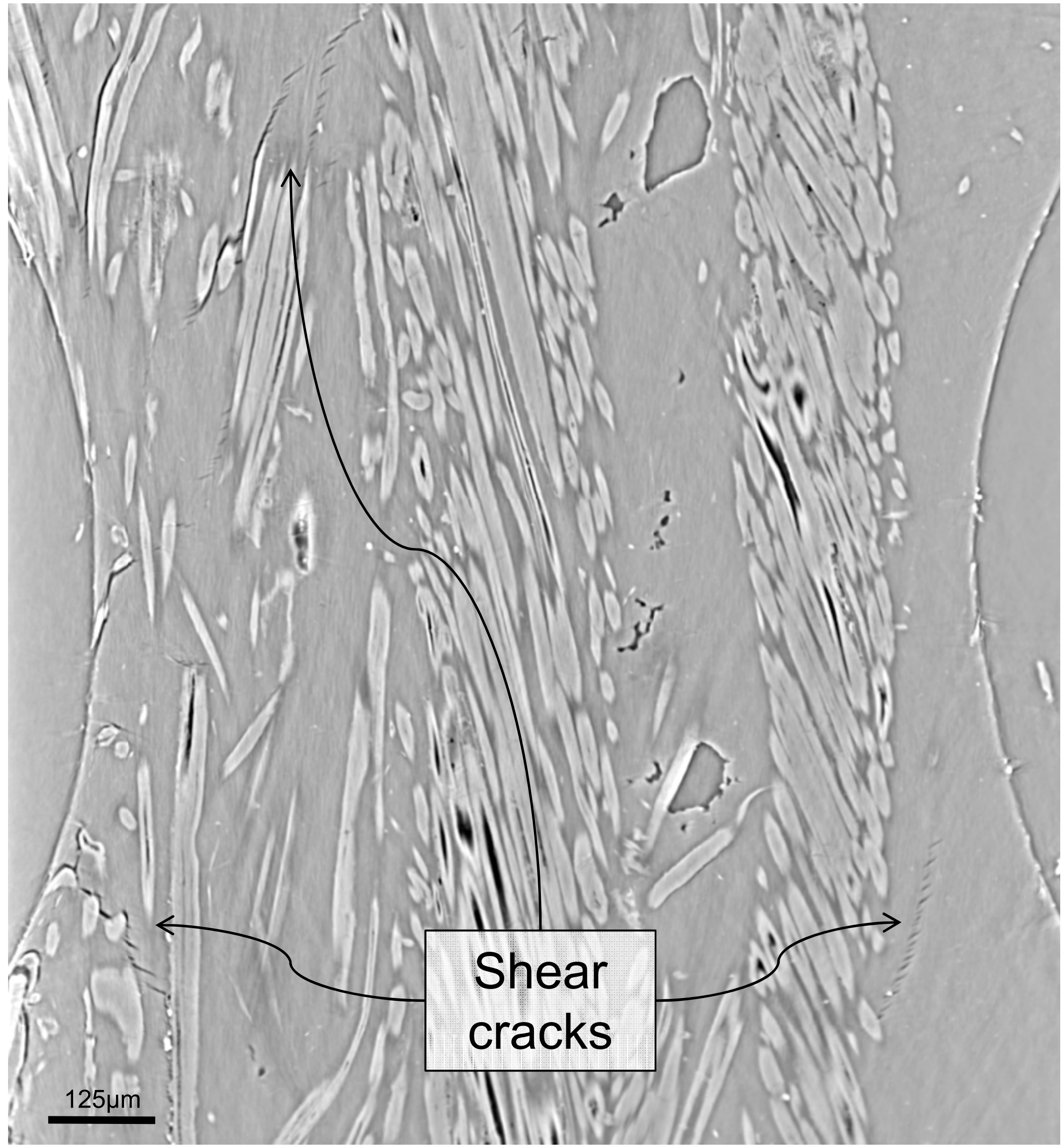
- Fibre breaks at weak bands in fibres
- Breaks at three neighbouring fibres. No weak band seen in middle fibre – failure by stress transfer?

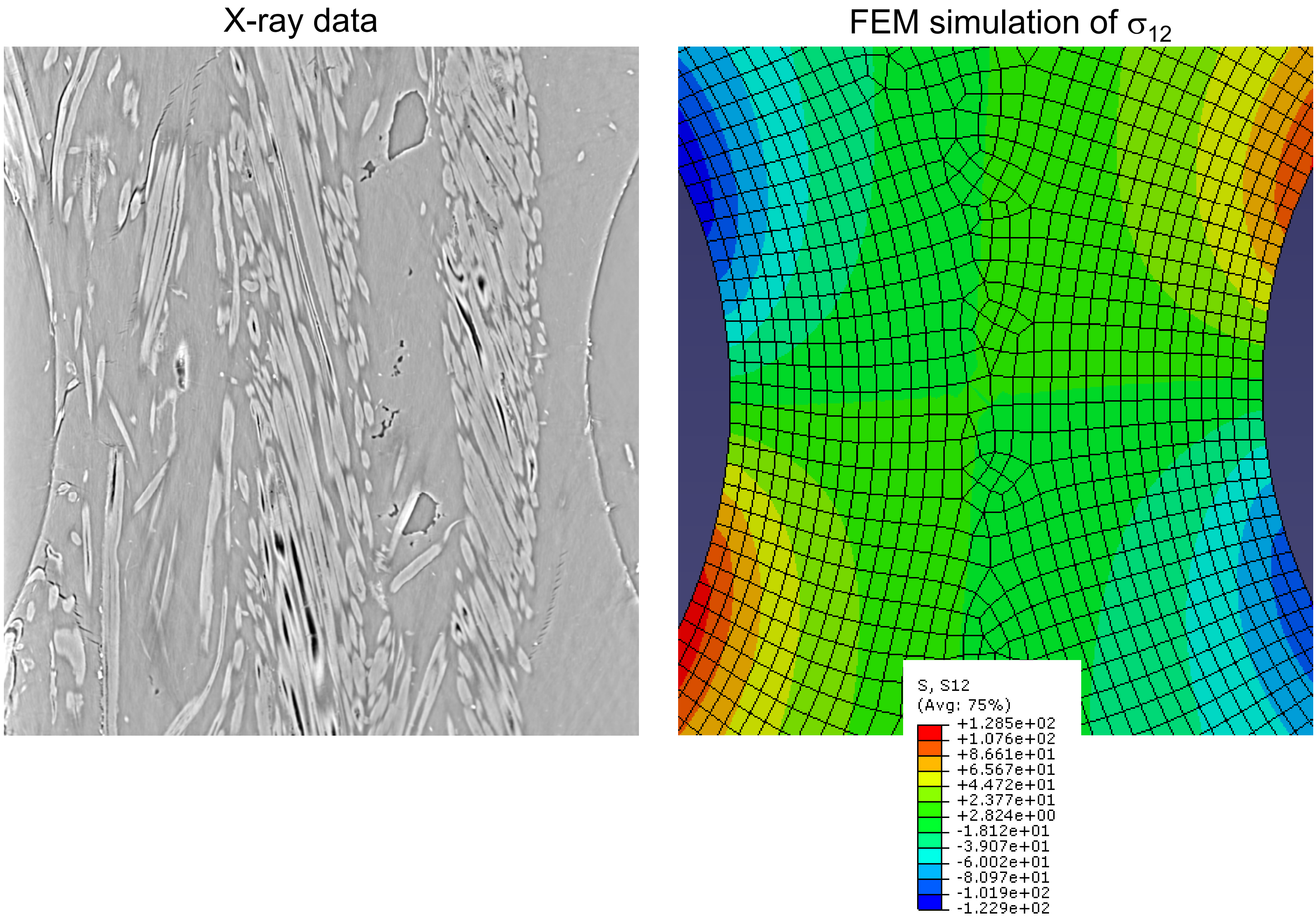


- Shear cracks symmetric in position and direction?





X-ray data
FEM simulation of σ12
S, S12
(Avg: 75%)
+1.285e+02
+1.076e+02
+8.661e+01
+6.567e+01
+4.472e+01
+2.377e+01
+2.824e+00
-1.812e+01
-3.907e+01
-6.002e+01
-8.097e+01
-1.019e+02
-1.229e+02

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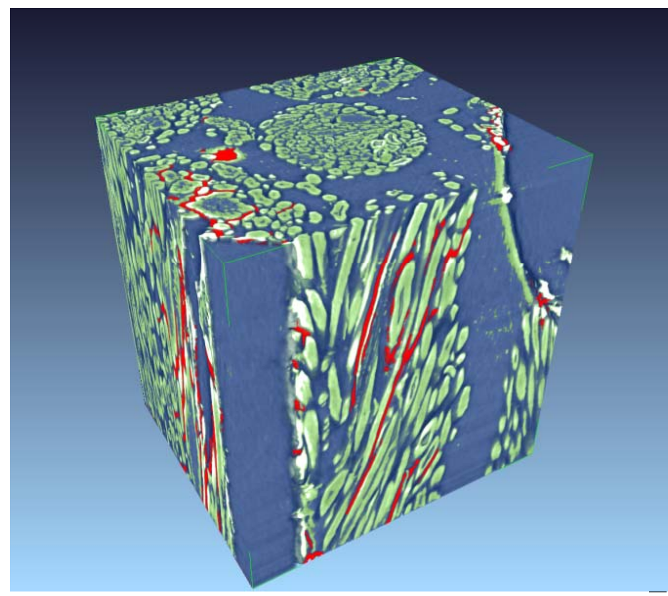
- **Conclusions**

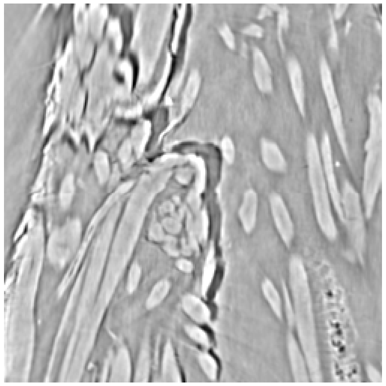
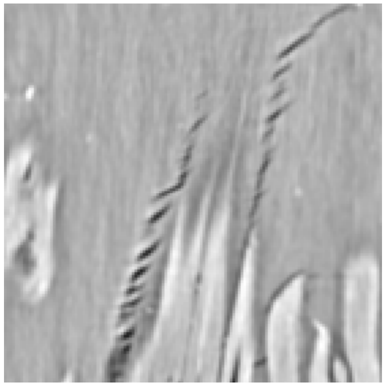
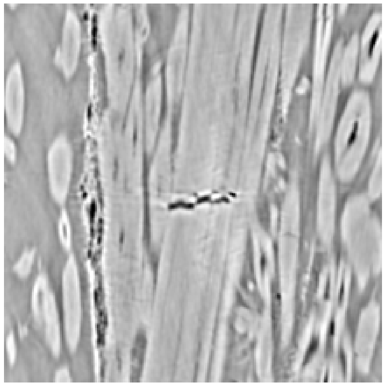


# Conclusions

- Damage mechanisms
  - Splitting cracks driven by interfaces
  - Shear cracks
  - Fibre breaks

→ Microstructure has a large influence on damage evolution

- How to take these observations to the next level?
  - FEM simulation?
  - Displacement image correlations?
  - …

# Acknowledgment


- The research leading to these results has received funding from the European Comunity's Seventh Framework Programme (FP7/2007-2013) under grant agreement no 214467 (NATEX)
- Tomcat beamline at Swiss Light source
- Professor Ian Sinclair, University of Southhampton, for providing loading fixture