Investigating 3D fatigue damage progression in fibre composites by combing X-ray tomography with trans-illuminated white light imaging

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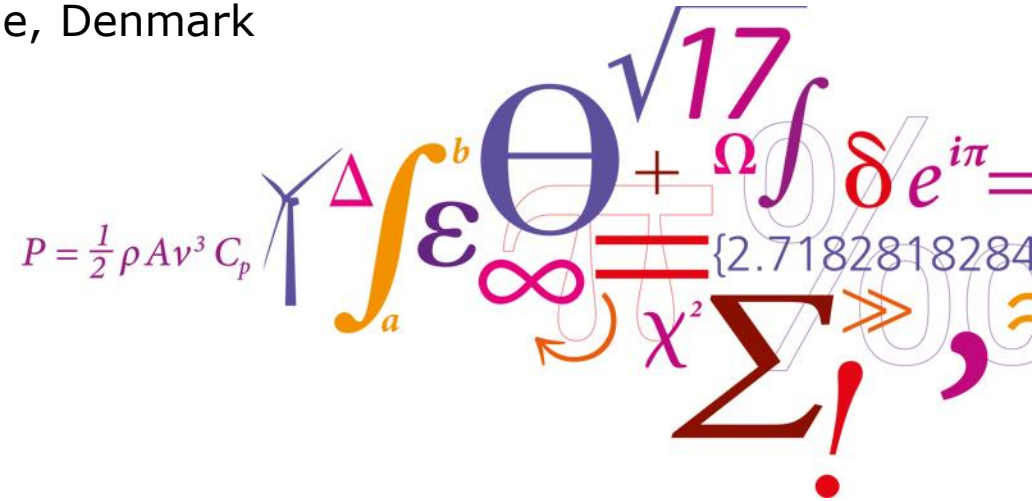
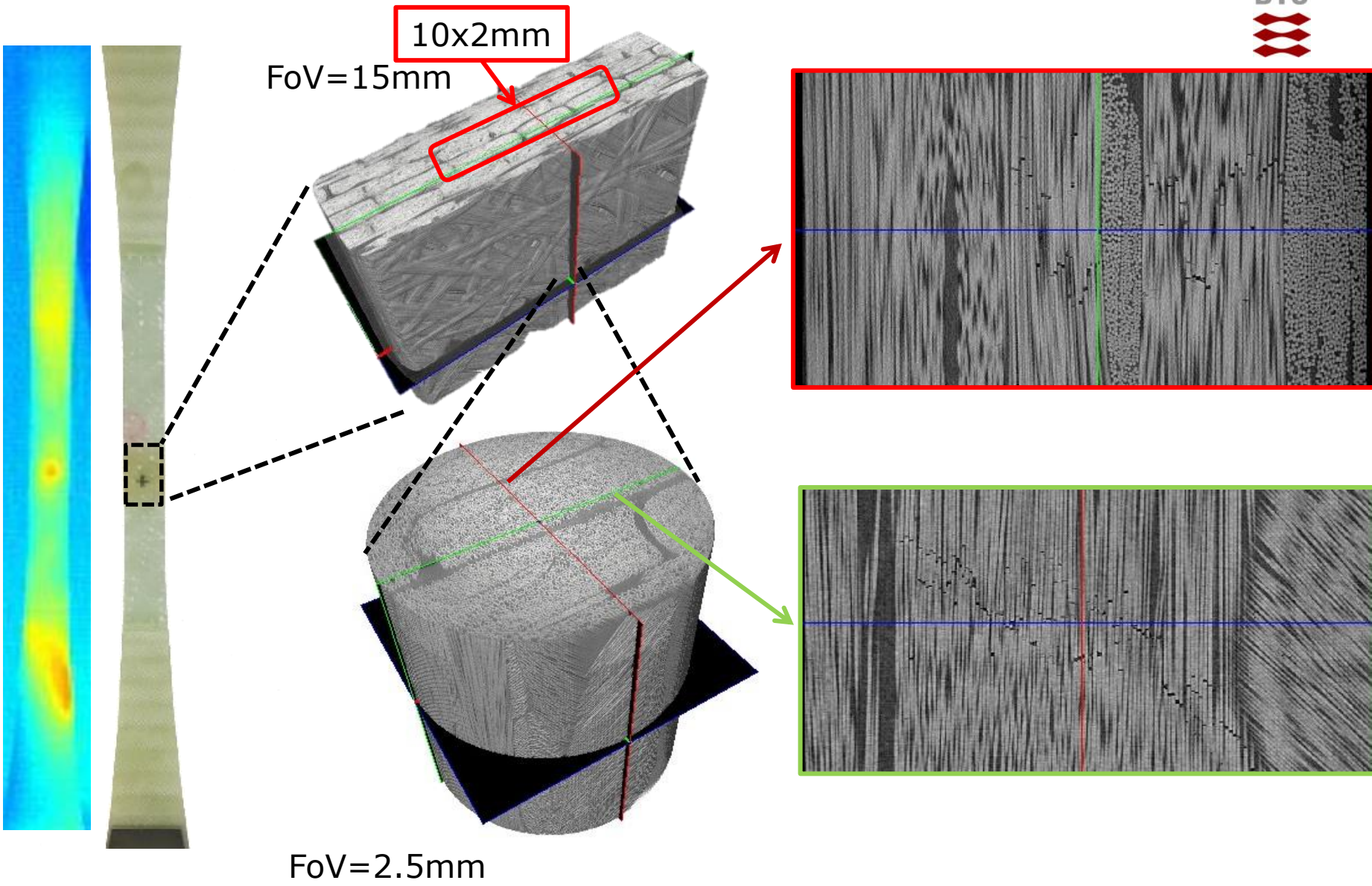


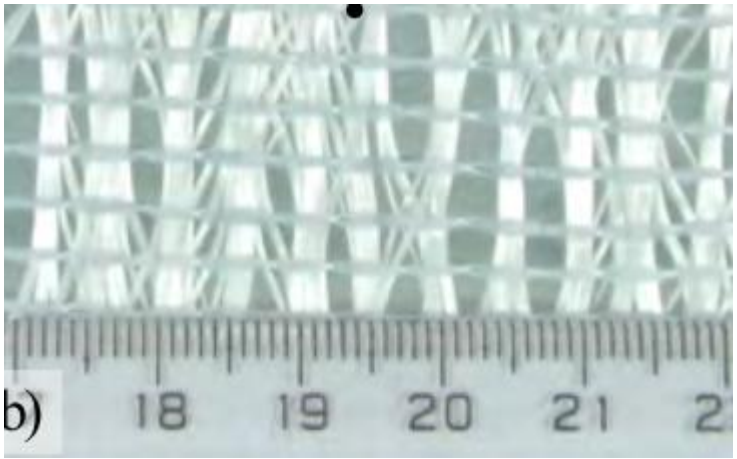
Now at Waseda University, Japan

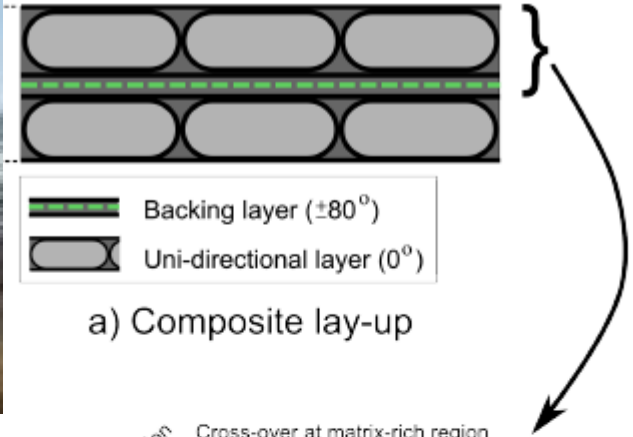
DTU Vindenergi
Institut for Vindenergi

Representative volume (15mmx4mm)

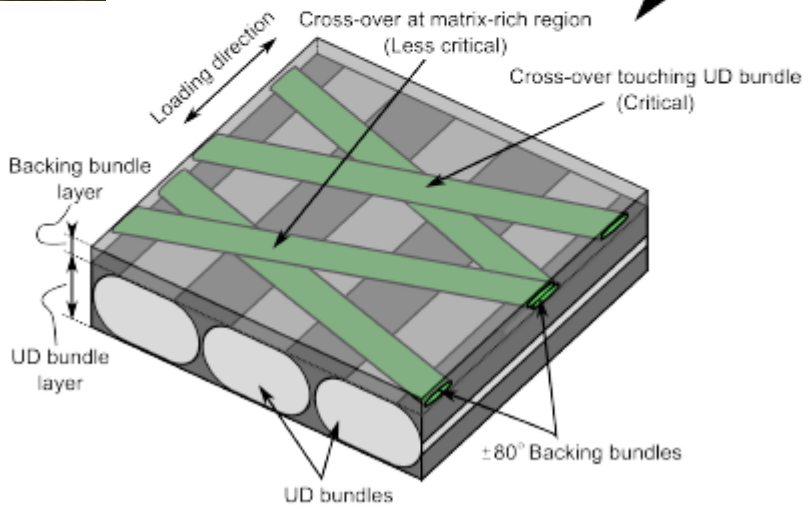


Material system: [0/±80/0]





a) Composite lay-up

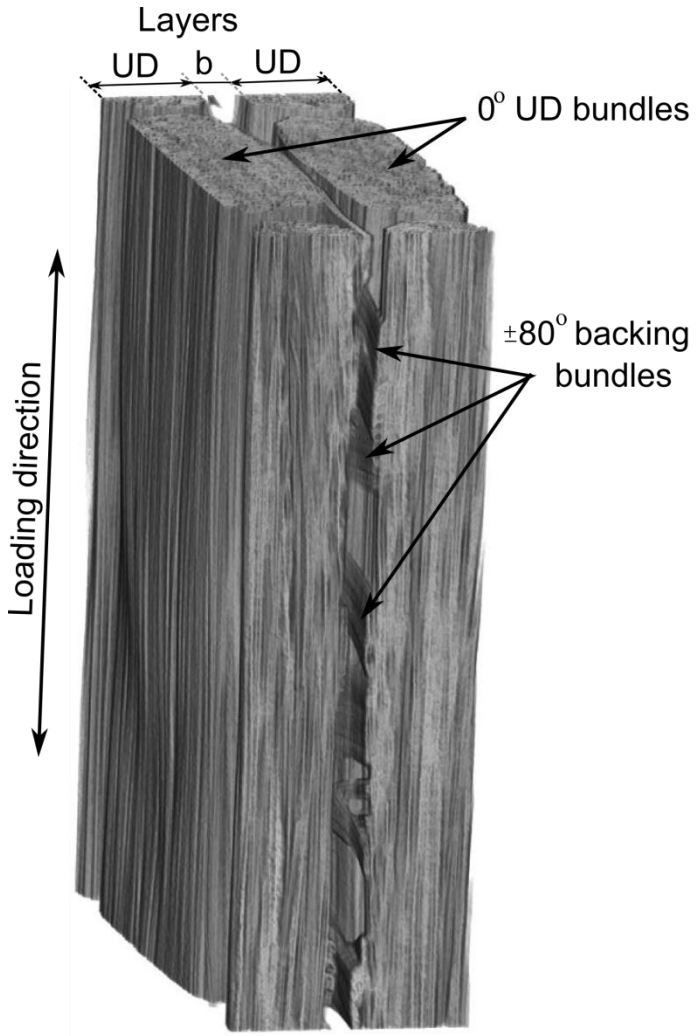


b) One UD fabric layer with backing

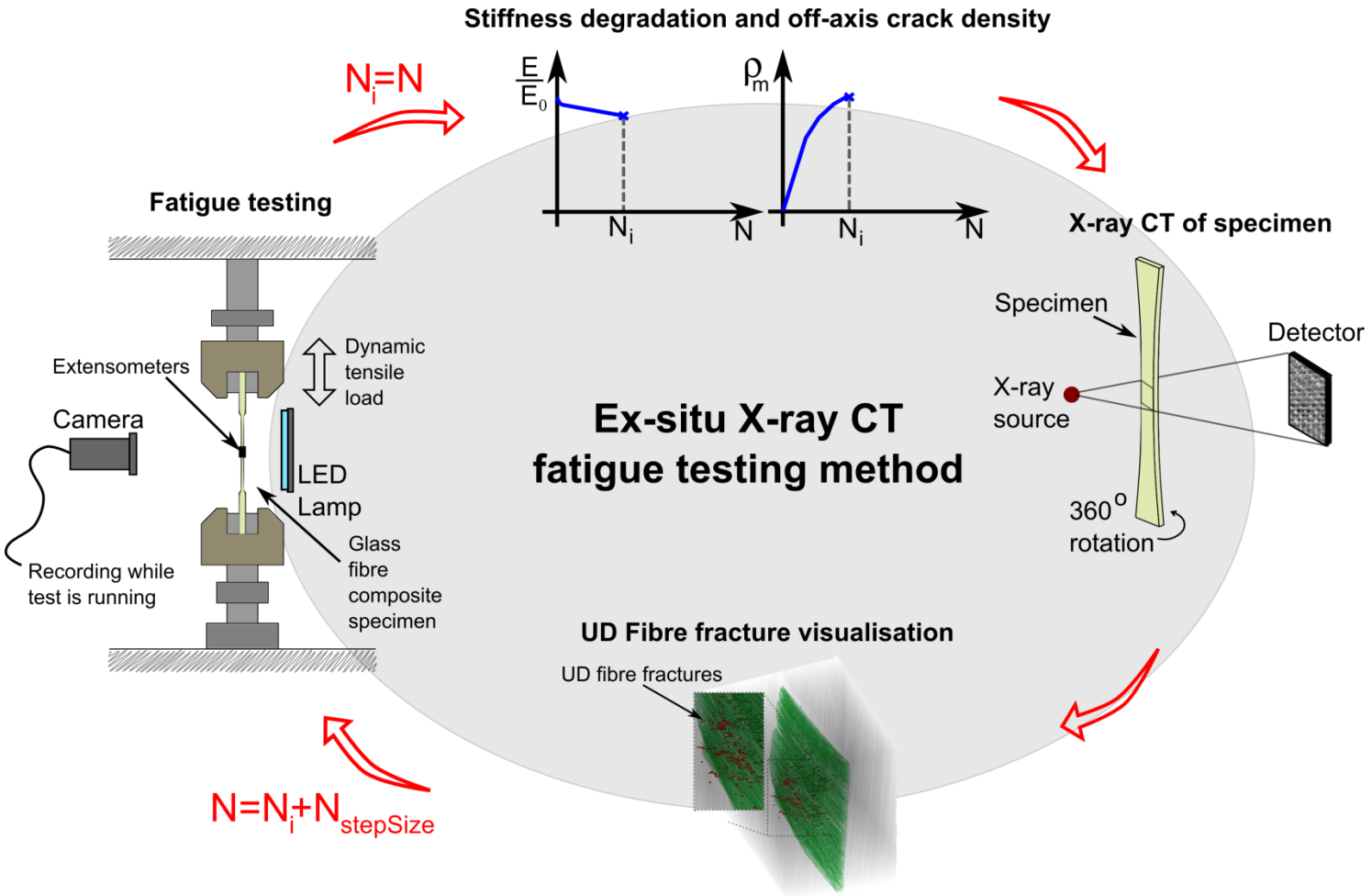
Studying the isolated effect of one layer of backing between two layer of UD bundles

- One layer of backing bundles in between two UD bundle layers
  - Two layers of fabric
  - Backing fibre bundles removed from one of the layers

Transverse cracking not surface cracks but located central in the specimen.



Combining ex-situ X-ray CT approach with trans-illuminated white light imaging



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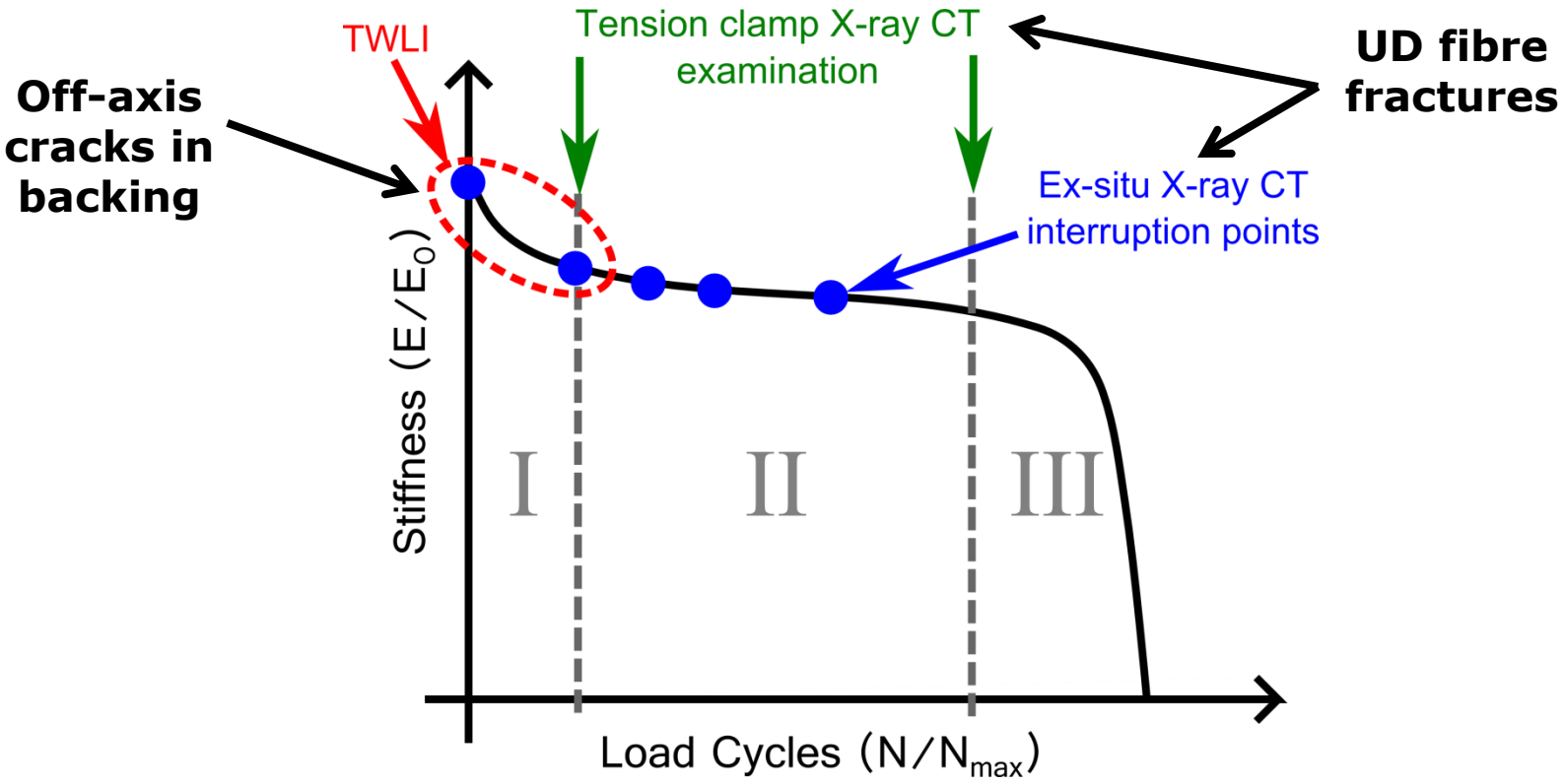
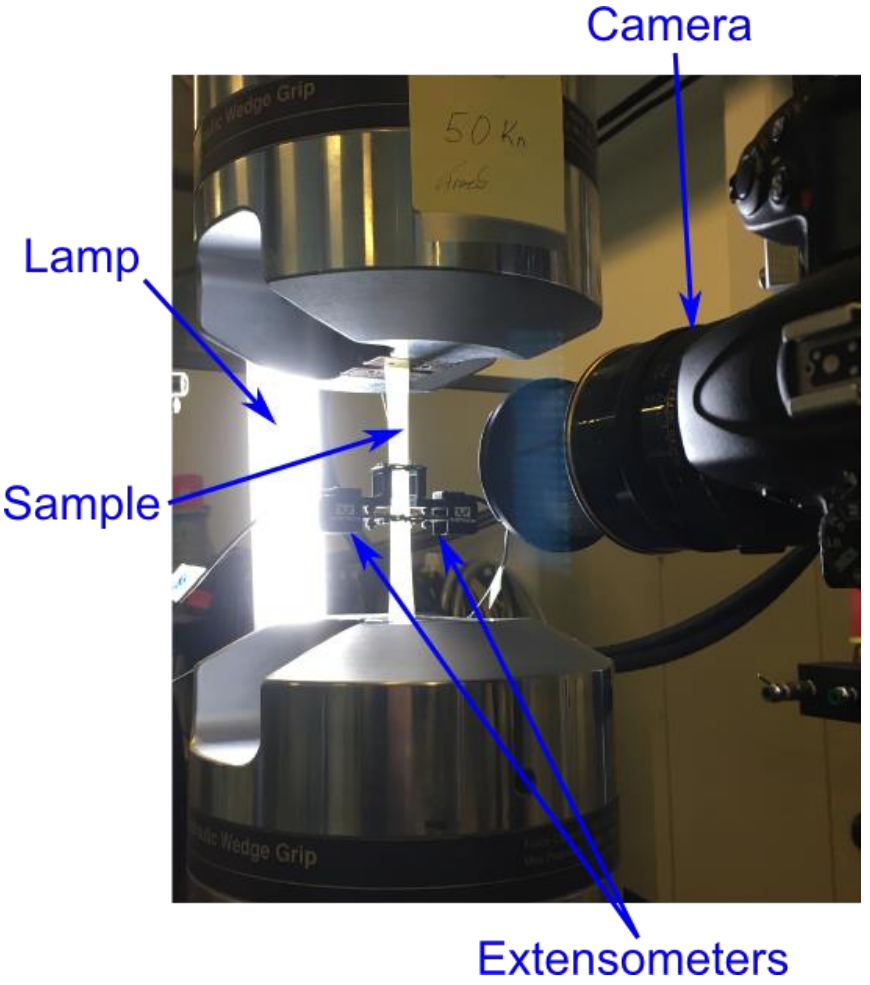


In-situ trans-illuminated white light imaging

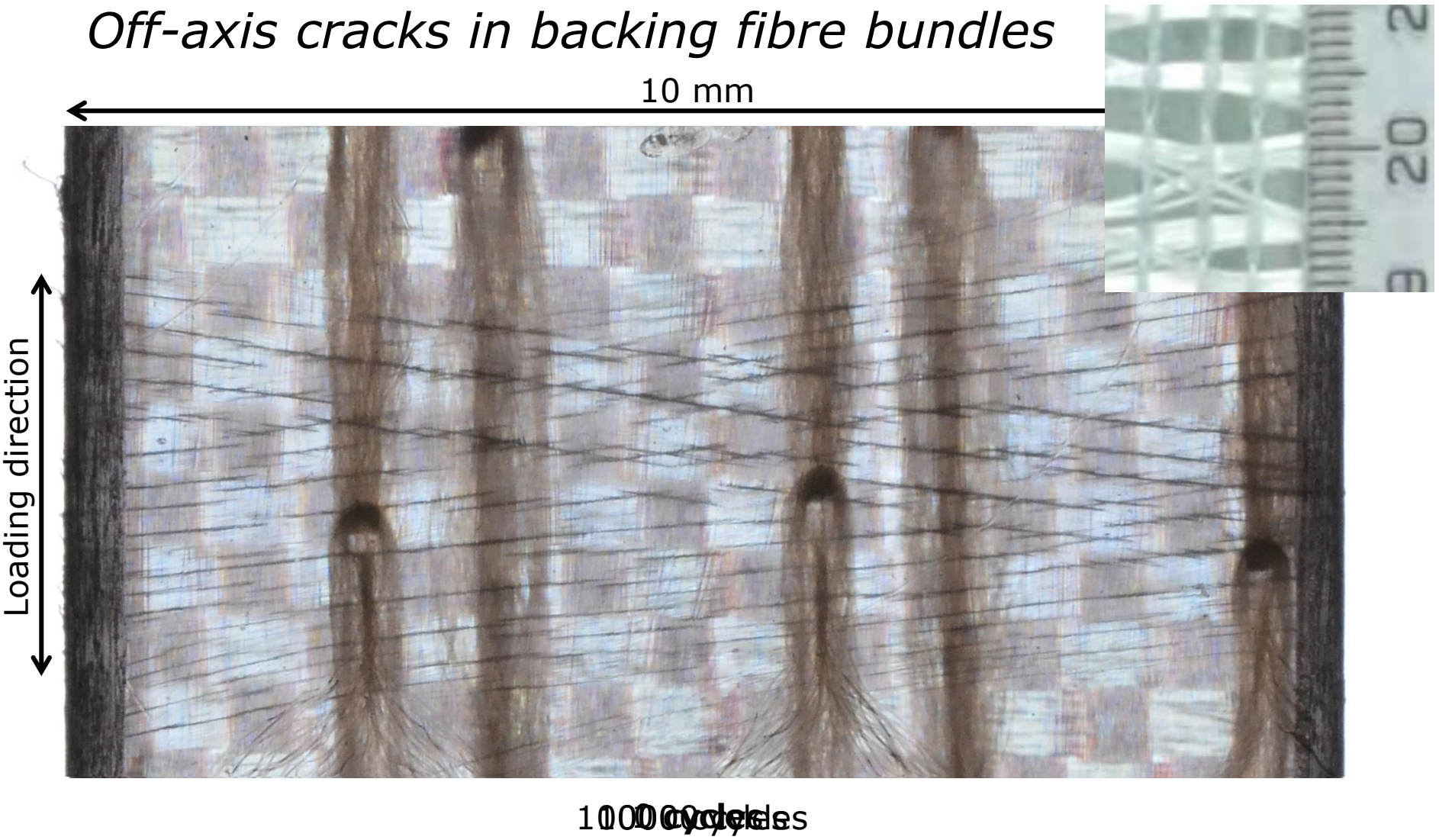
Off-axis cracks in backing fibre bundles

- Using TWLI off-axis cracks in backing bundles are visible in 2D. Camera synchronised with the test machine
- Fatigue tests performed at different strain levels
- Strain is measured by extensometers in the same region monitored by camera



In-situ transilluminated white light imaging

Off-axis cracks in backing fibre bundles



Backing bundle area

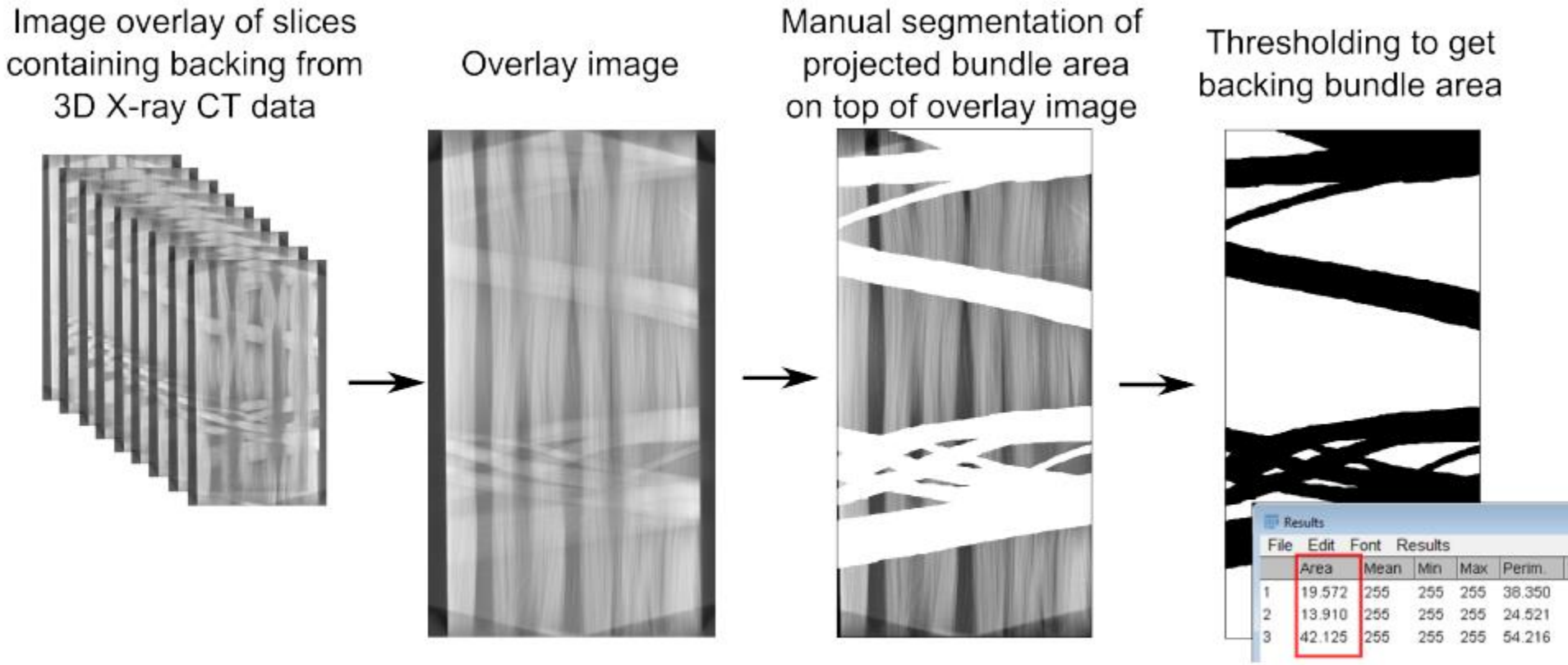
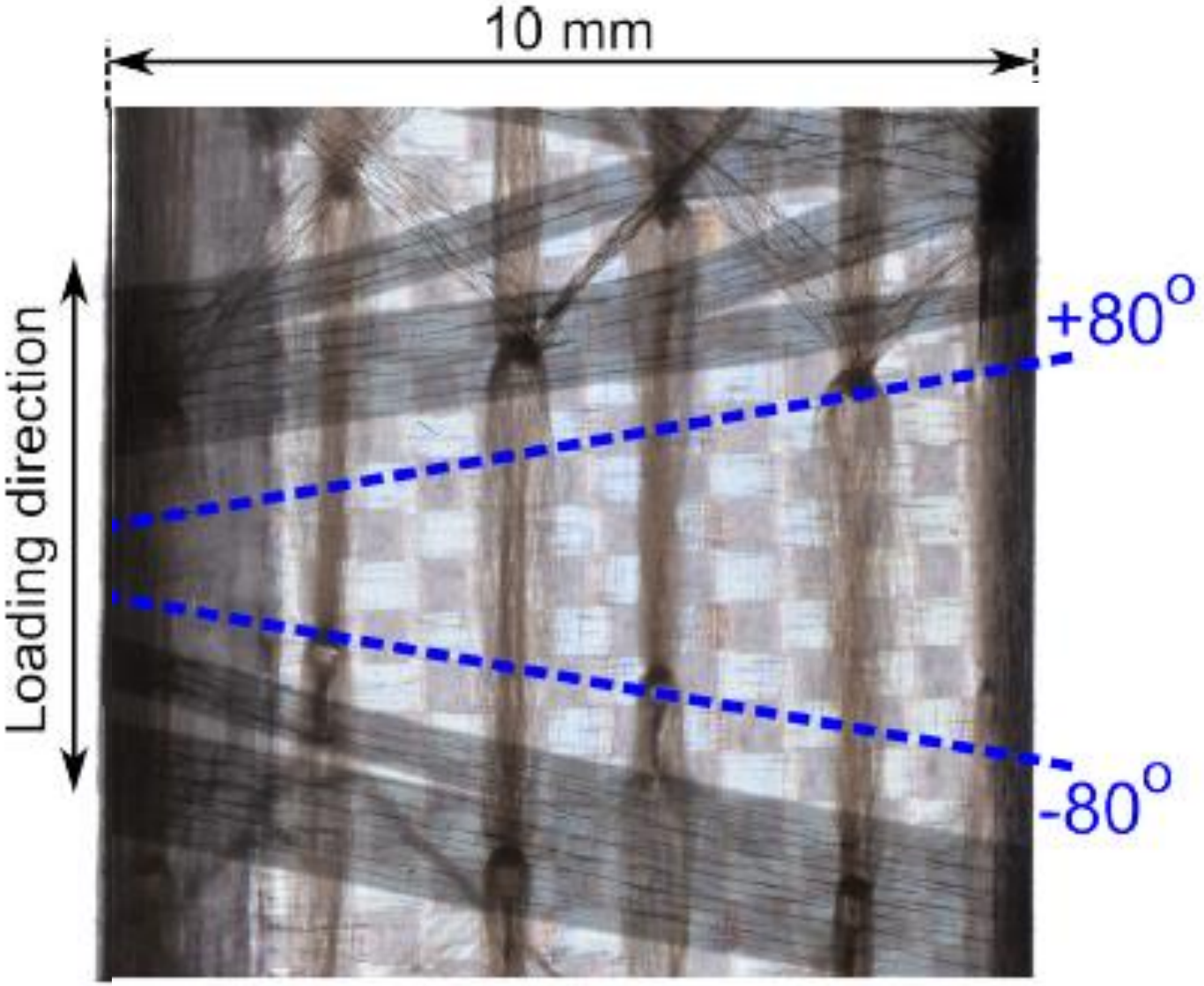


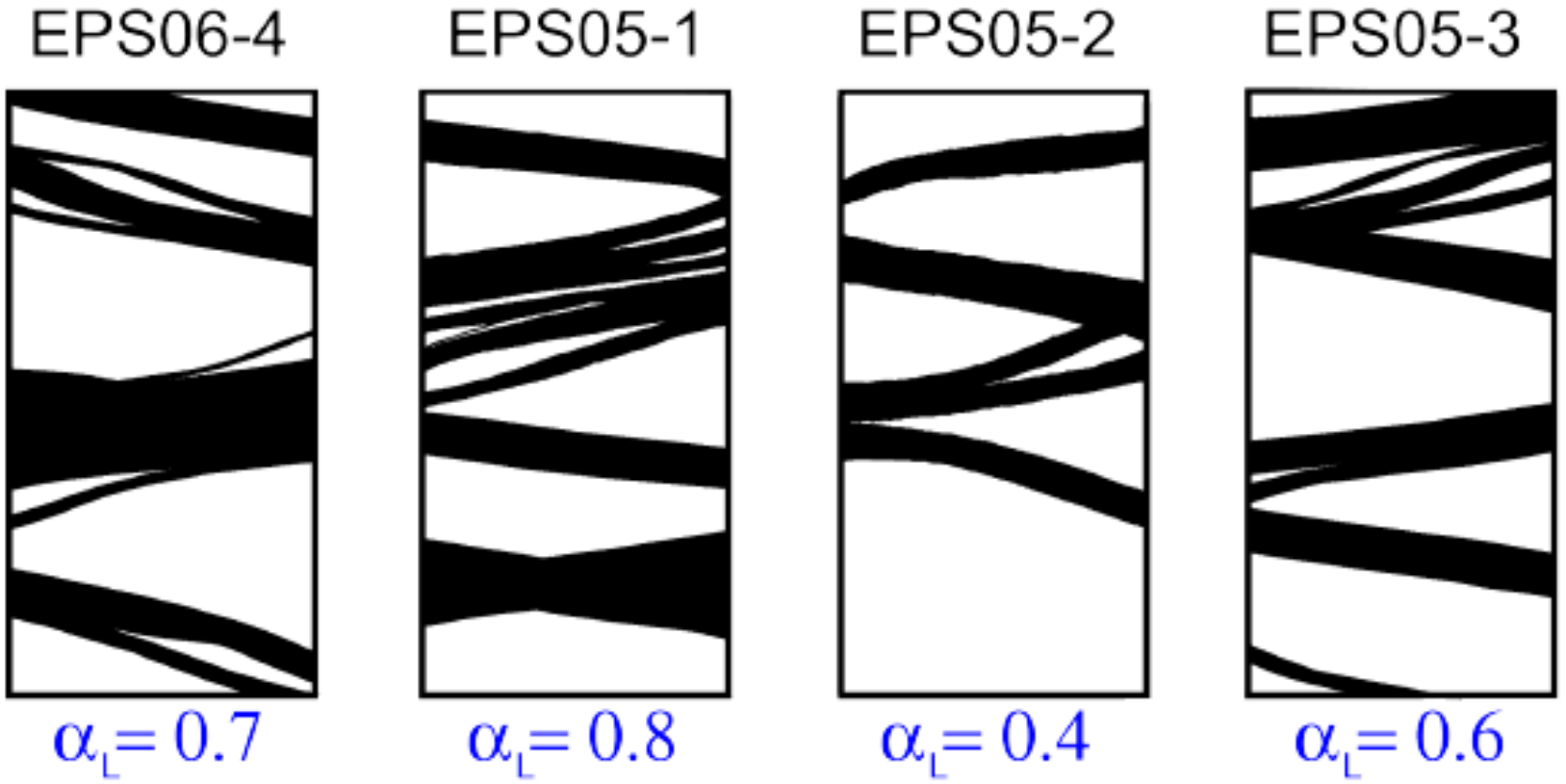
Figure 7: Sketch of principle for segmentation of projected backing bundle area

Backing bundles area



Backing bund area

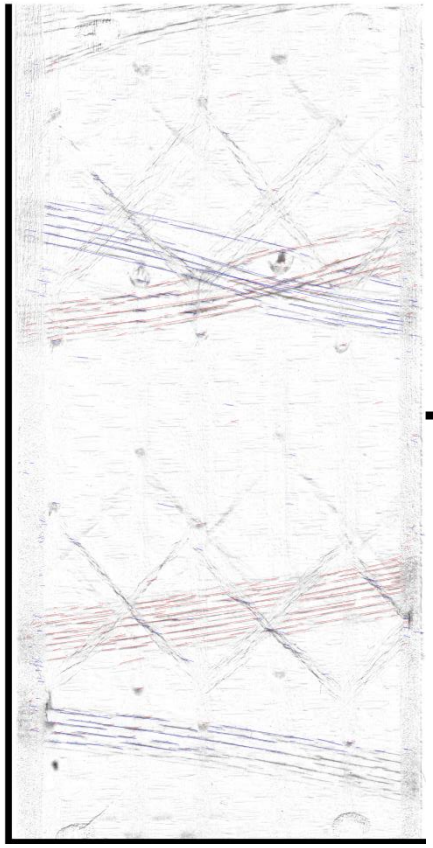
$$\alpha_L = \frac{A_{bb}}{A_{tot} - A_{bb}}$$



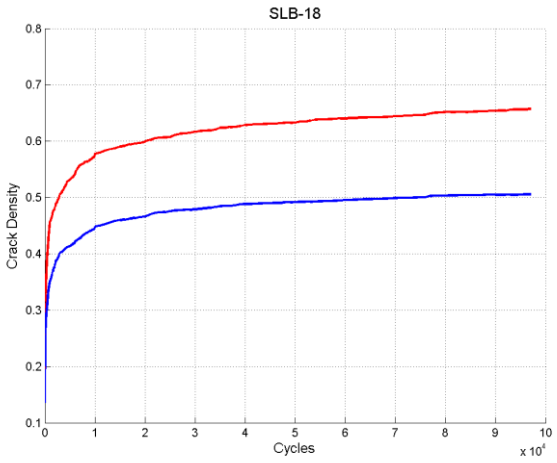
Automatic quantification of off-axis crack relative to 'projected backing bundle area'

Photo with cracks

Counted cracks



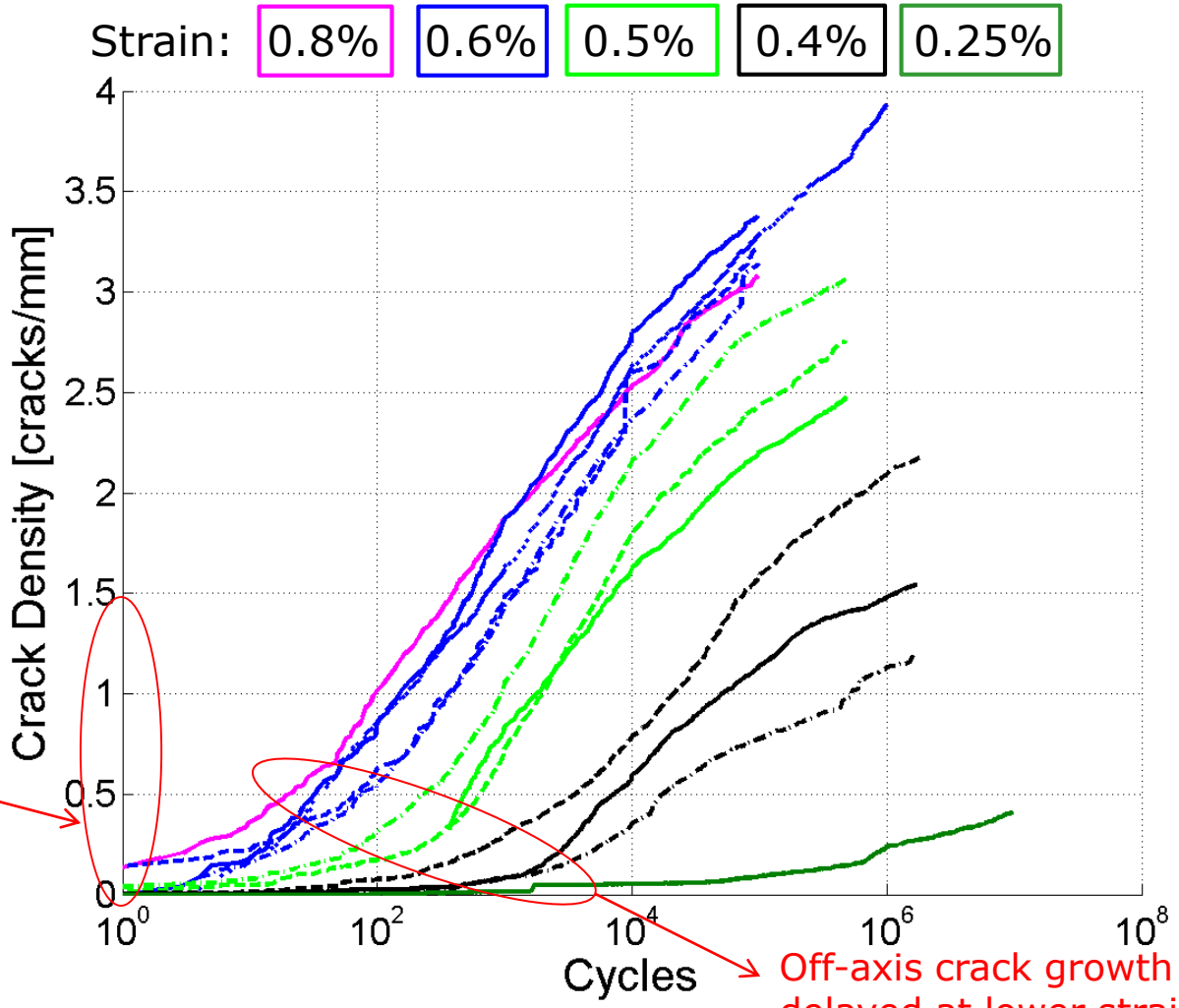
Crack density vs cycles



$$\rho = \frac{\sum_{i=1}^{N} L_i}{A_{bb}}$$

Ref: Glud, J. A., Dulieu-barton, J. M., Thomsen, O. T., & Overgaard, L. C. T. (2016). Automated counting of off-axis tunnelling cracks using digital image processing. *Composites Science and Technology*, *125*, 80–89.

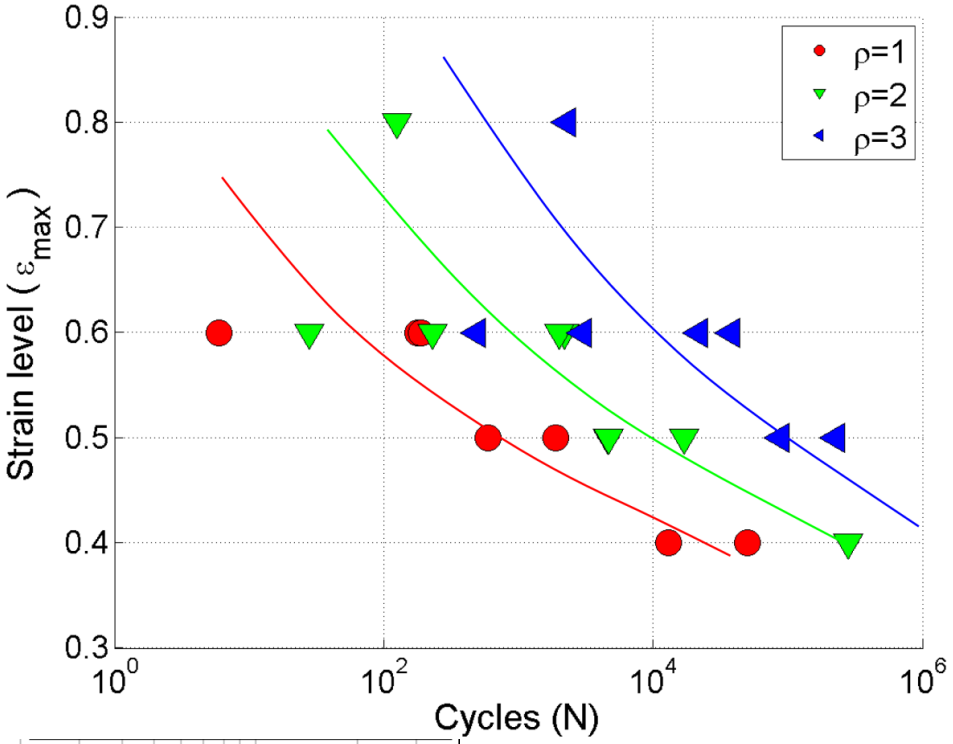
Strain level affects the off-axis crack behaviour

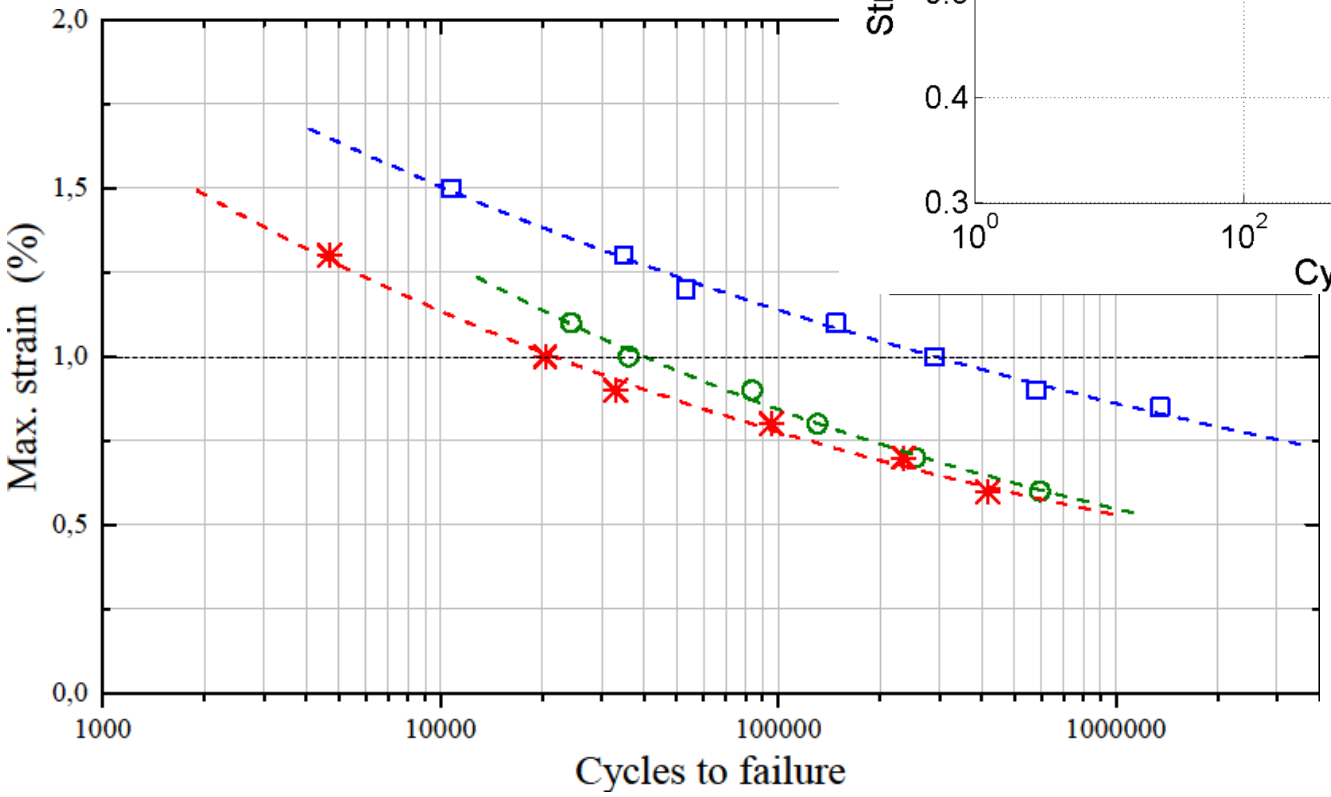


Cracks initiated already after 1 cycle

Off-axis crack growth delayed at lower strain levels

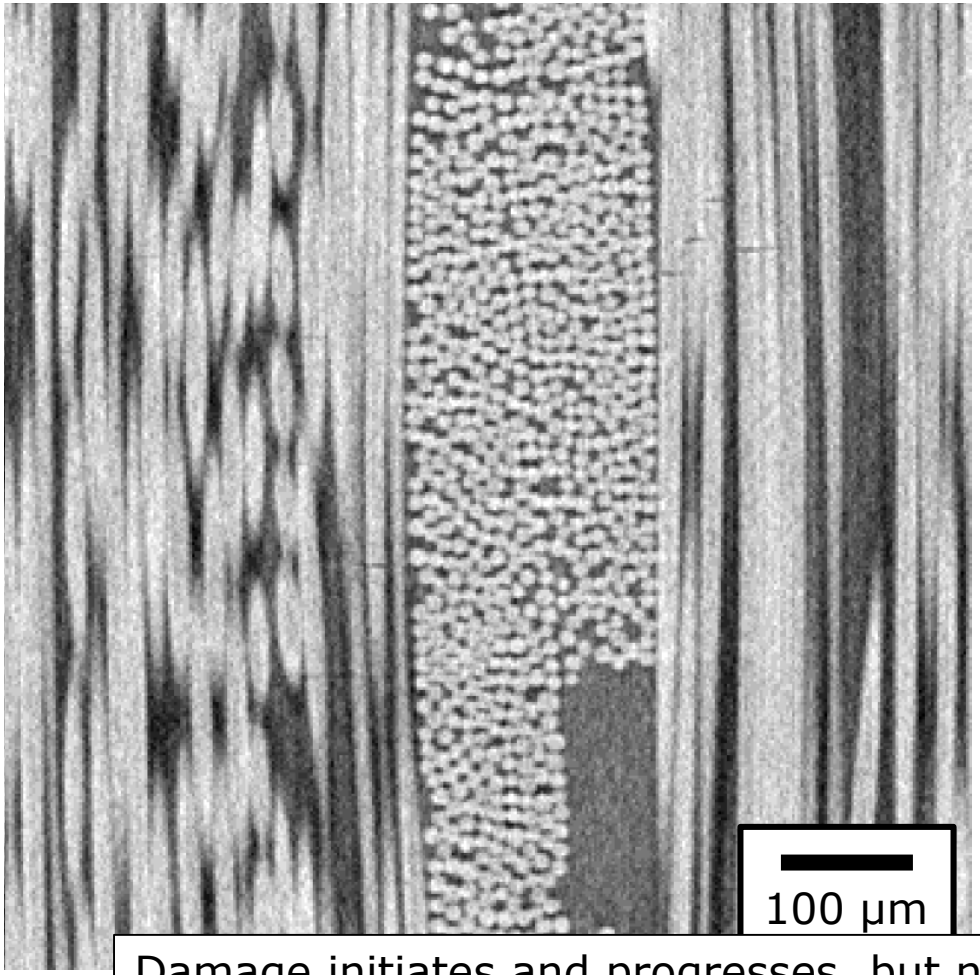
Use off-axis crack density as indication of overall fatigue damage state



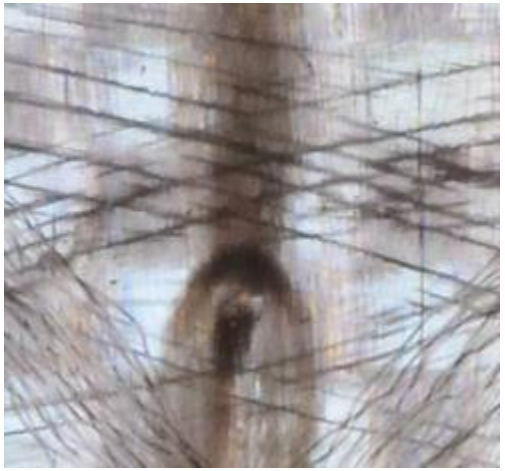


Ex-situ X-ray CT results

UD fibre fractures



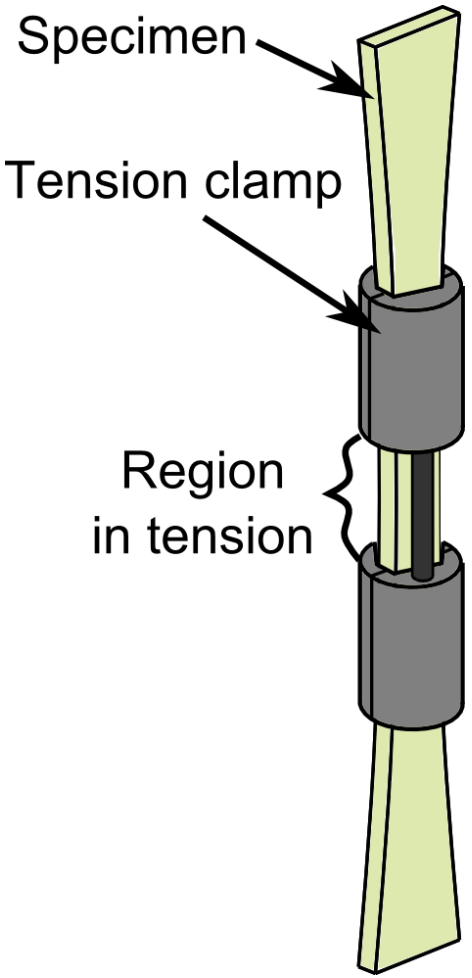
TWLI of X-ray CT region

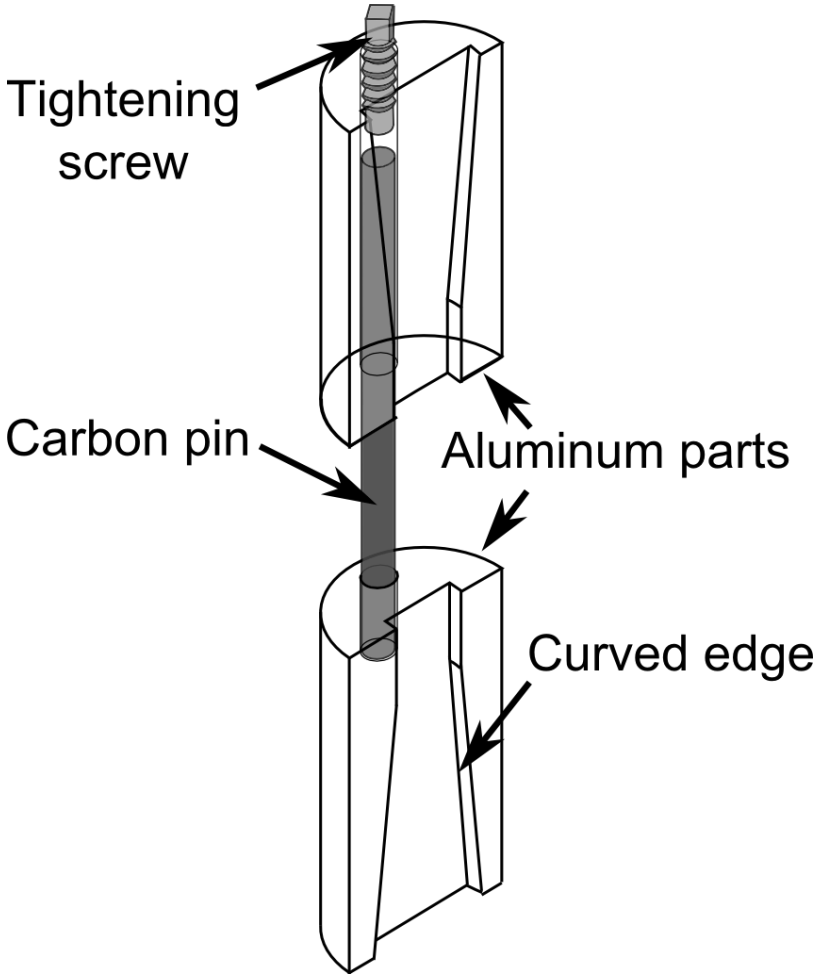


150000 cycles

Damage initiates and progresses, but not very visible. Off-axis cracks present in TWLI images but not visible

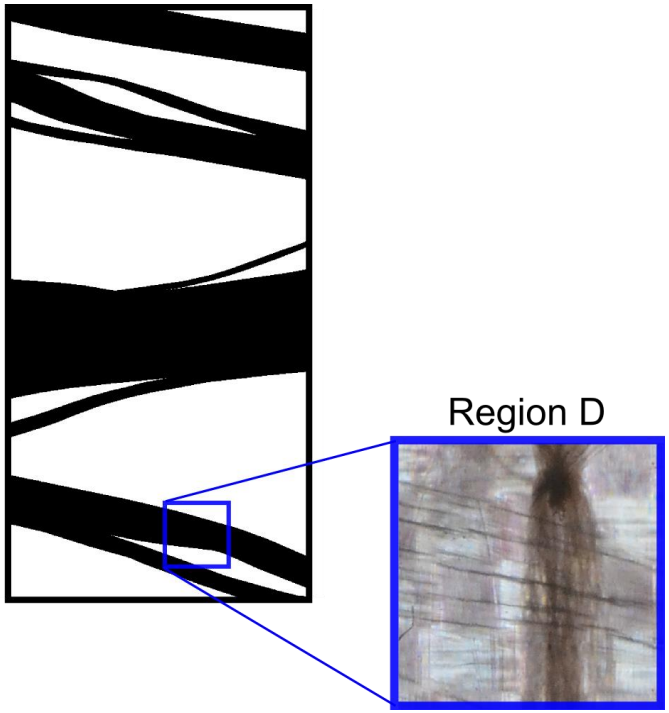
Applying tension to the sample during scan

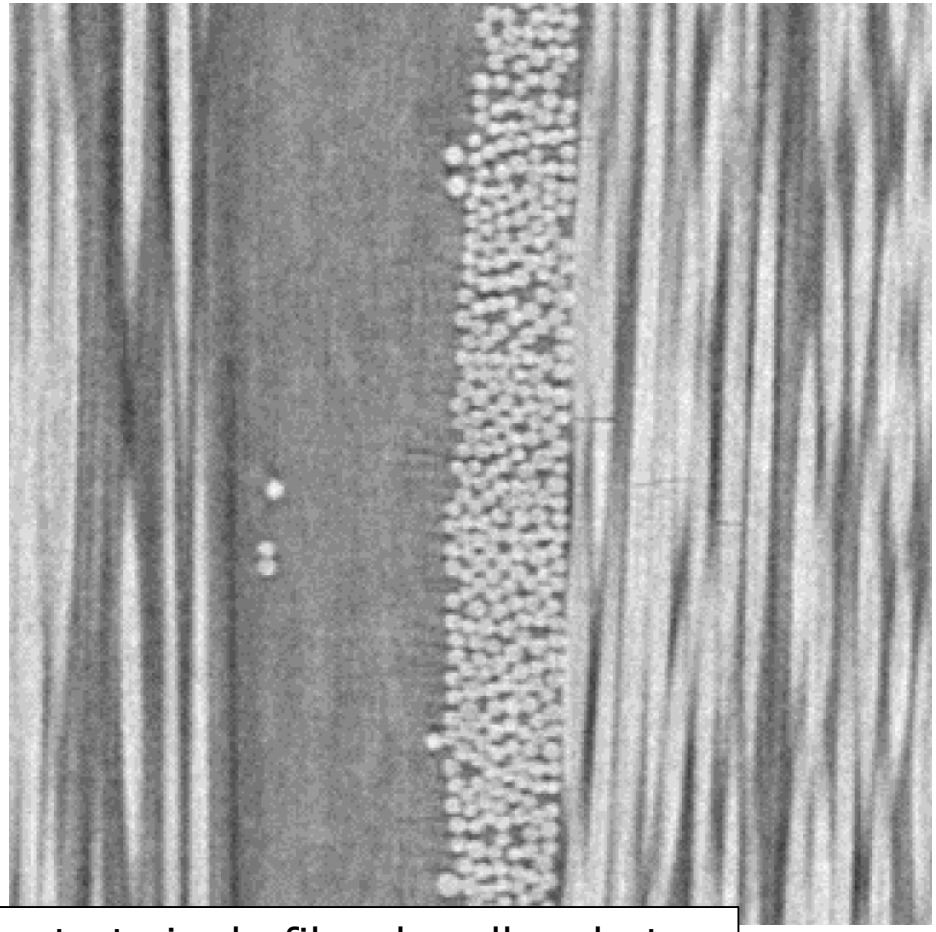




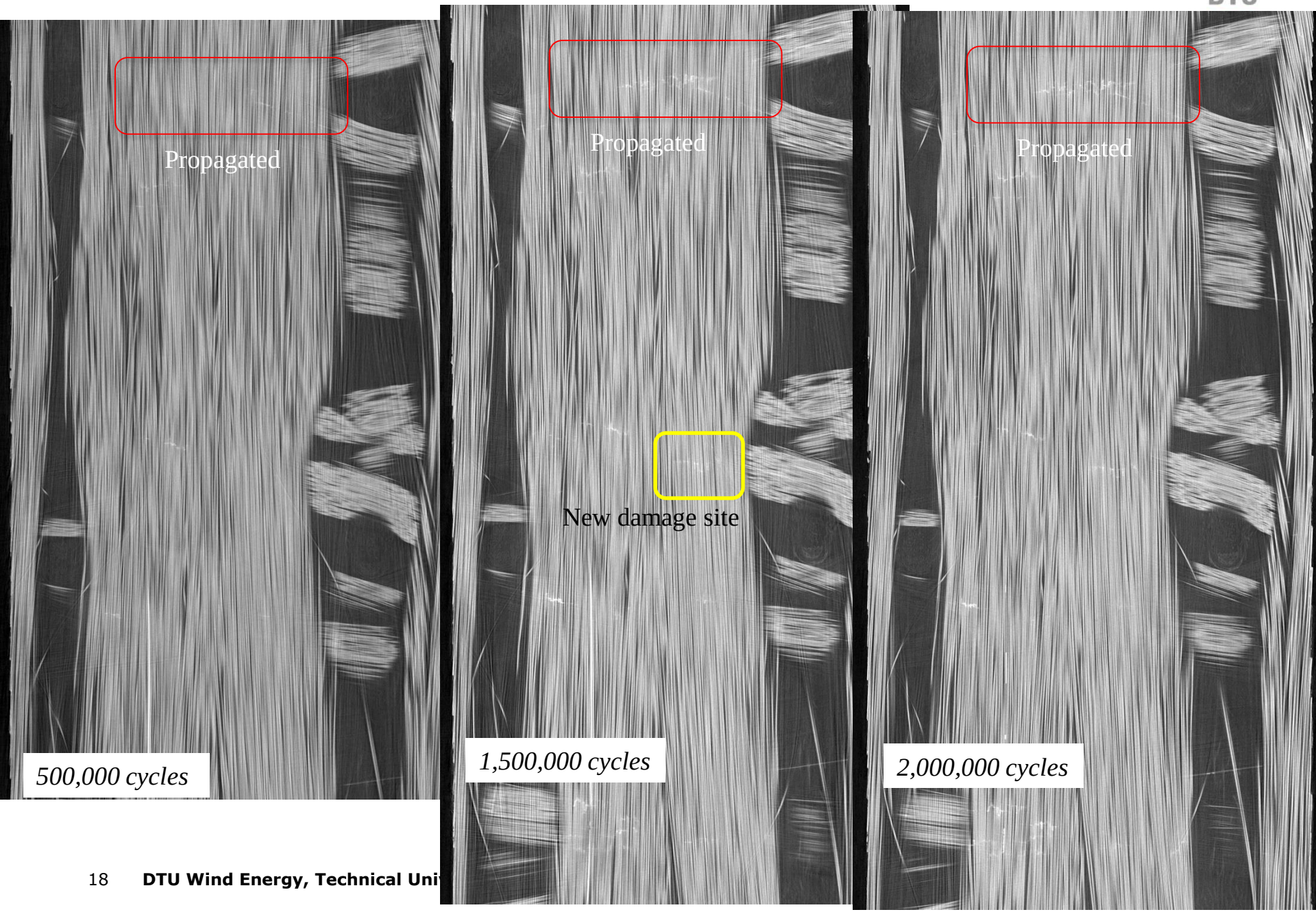
Applying tension during scanning

Relatively late in fatigue life (1,000,000 cycles)

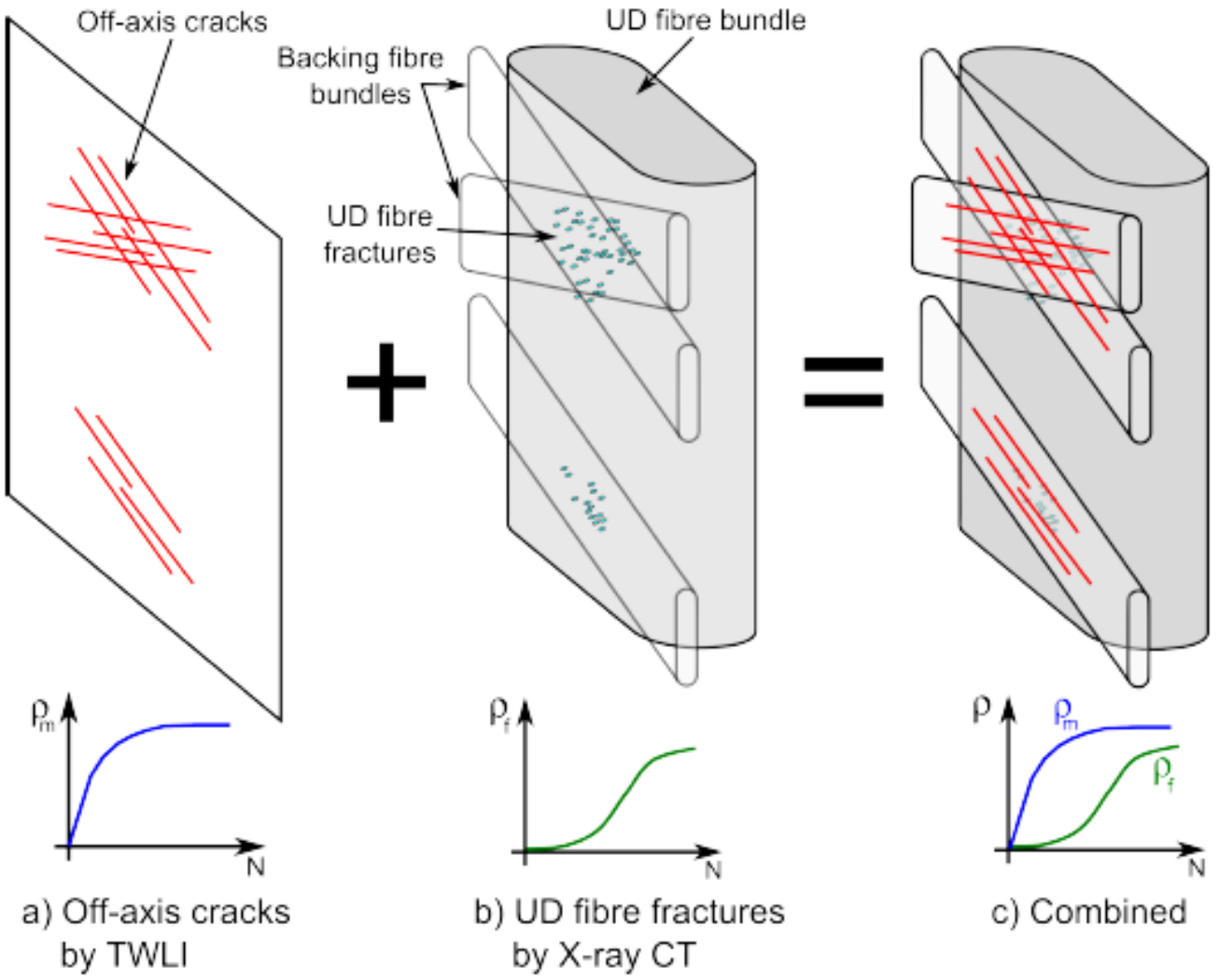




UD fibre fractures present at single fibre bundles, but seem to arrest at large matrix regions


Propagated
Propagated
New damage site
Propagated
500,000 cycles
1,500,000 cycles
2,000,000 cycles

Combination of TWLI and X-ray CT



Questions?

Acknowledgements

- CINEMA: the allianCe for ImagiNg of Energy MAterials
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- LM Wind Power for manufacturing of the test laminates