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3D X-ray CT of fatigue damage in fibre composites

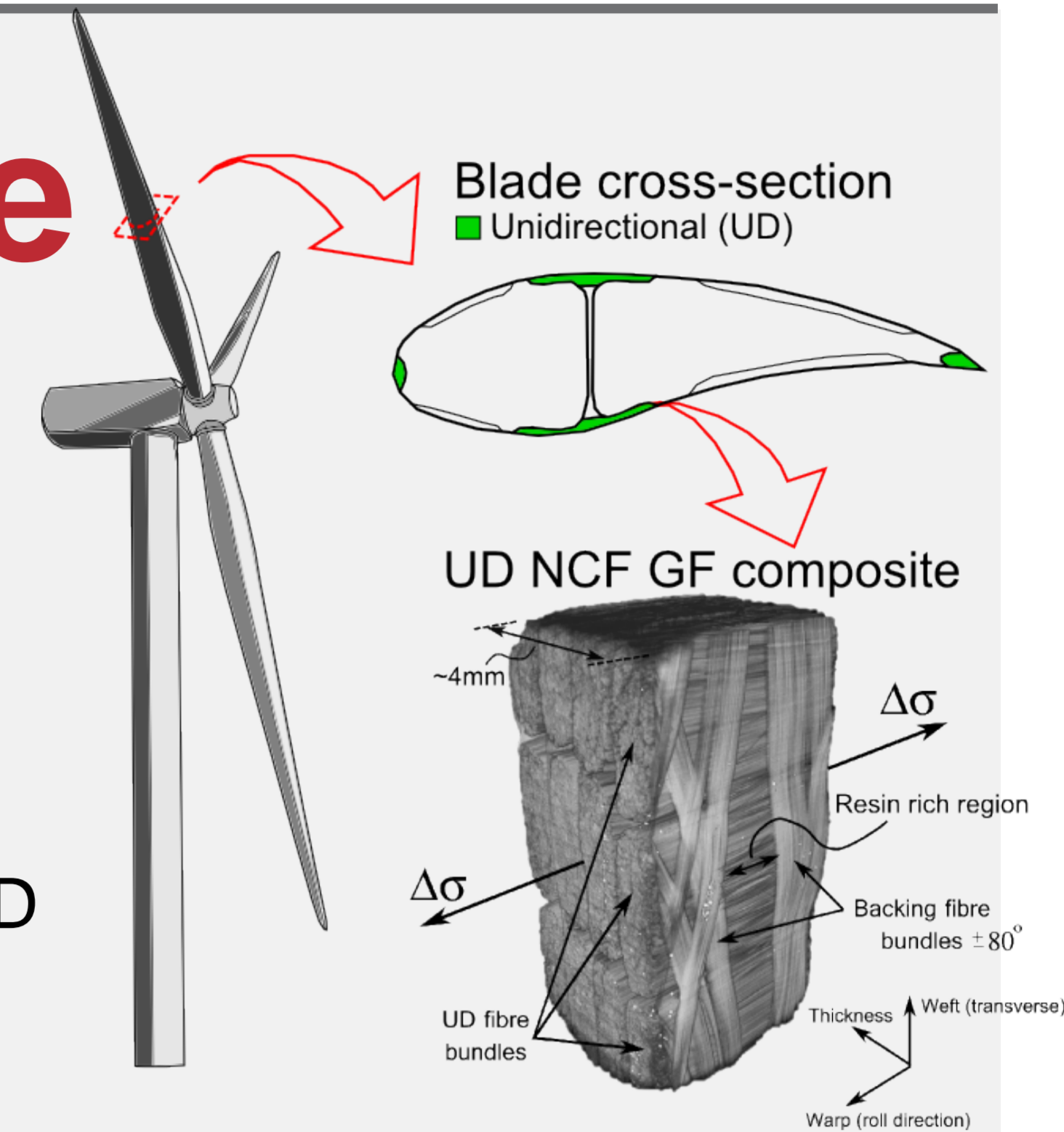
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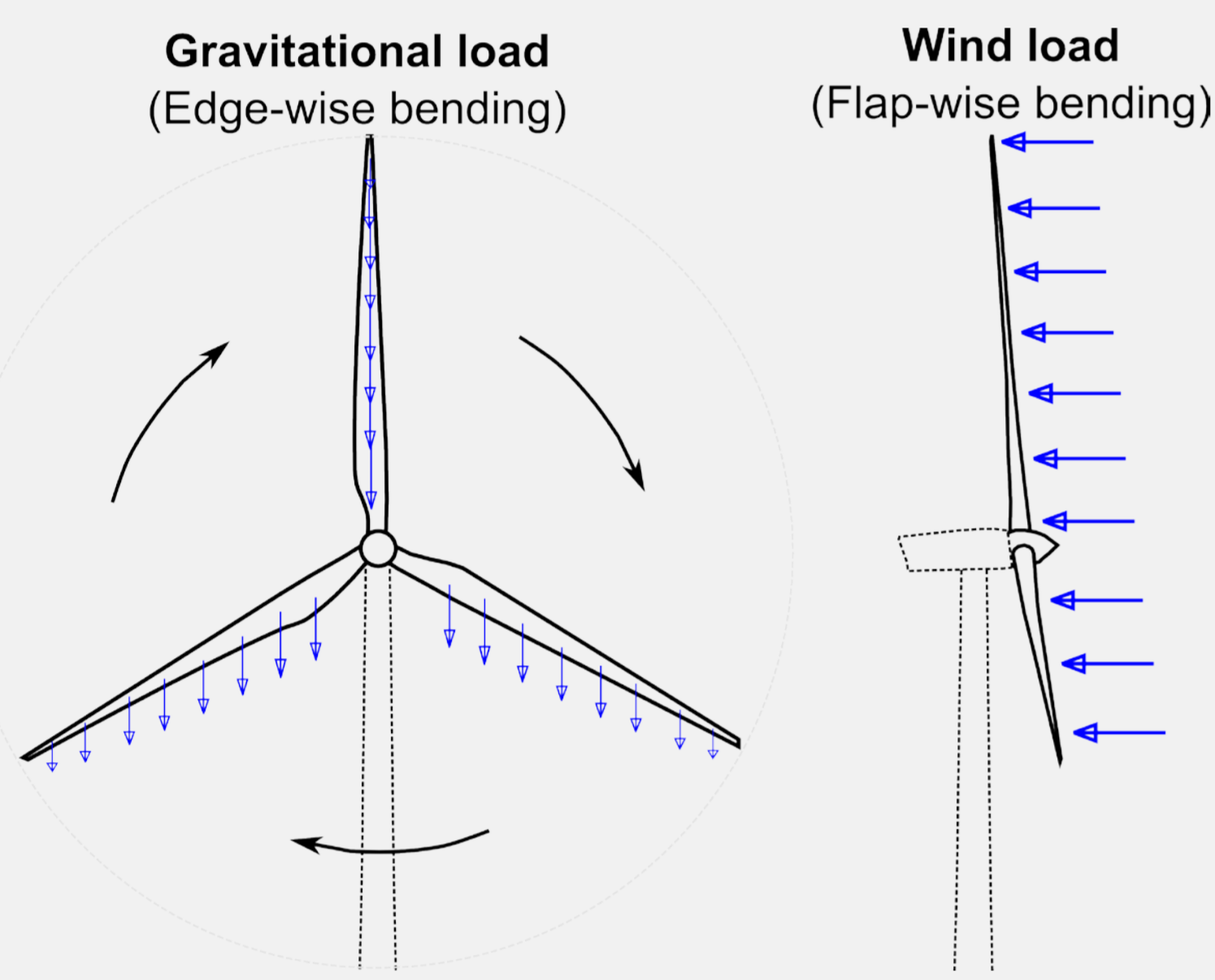
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A uni-directional (UD) glass fibre composite made from a non-crimp fabric (NCF) was investigated by 3D X-ray computed tomography (CT) to study the fatigue damage at different stages of the fatigue life. The damage was found to appear as local UD fibre fracture regions close to the so-called supporting backing layer, which seemed to have an important role in the location of the damage initiation. Furthermore, the damage appeared as 3D regions containing both clusters and chains of fibre fractures, and it was concluded that considering this problem in 3D seemed to be important in order to obtain realistic results.



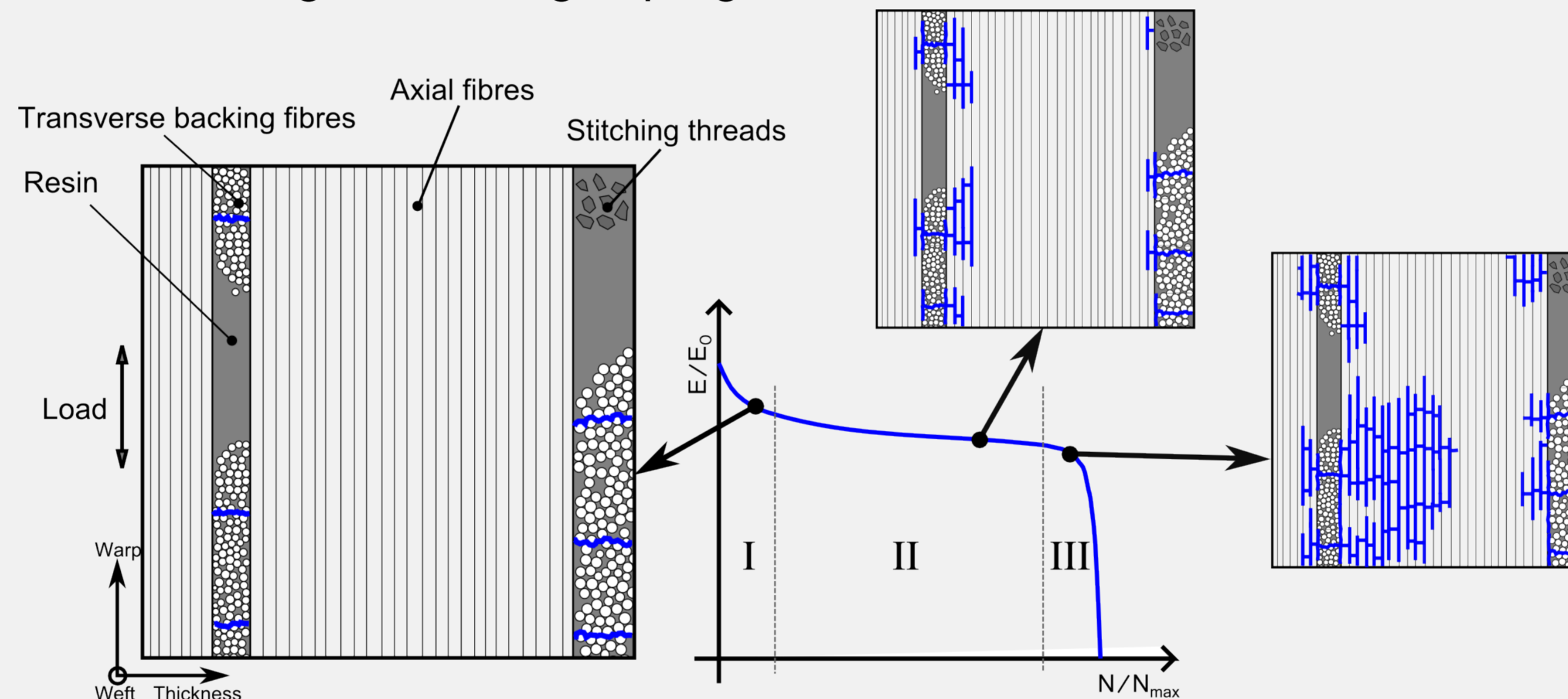
UD glass fibre composite material is used for the load carrying parts of the wind turbine blade considered (marked with green). The glass fibres are gathered in bundles which are held in place by stitching them to a backing layer. The glass fibres are in the range of 17-21 microns in diameter and are surrounded by a polyester resin.



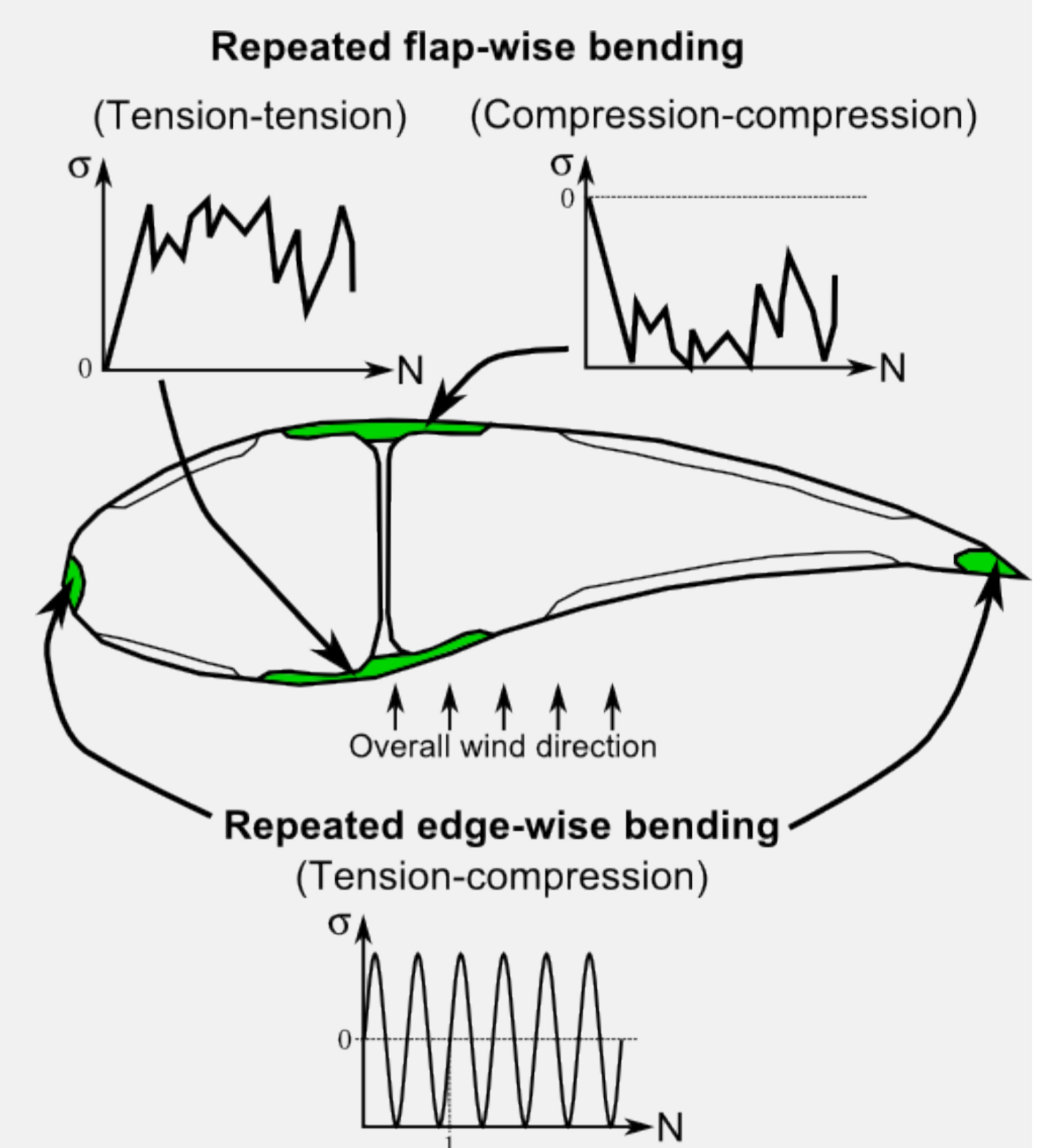
The above figure shows the main loads on wind turbine blades. The rotation of the blade causes the gravitational load on the blade to change direction twice (two load cycles) during a single rotation. Furthermore, the wind variation causes repeated loading with high variation.

Fatigue damage in wind turbine blade materials

With a lifespan of around 20 years, a wind turbine blade experiences repeated loading in the order of 10^8 cycles, which is much higher than for most other structures. Therefore fatigue is one of the main limiting factors when designing long blades. However, the main load carrying parts of the blades are made from UD NCF composite and their fatigue damage mechanism is complex and not well understood. To improve the materials and decrease safety factors, it is important to gain understanding on the fatigue progression behaviour.



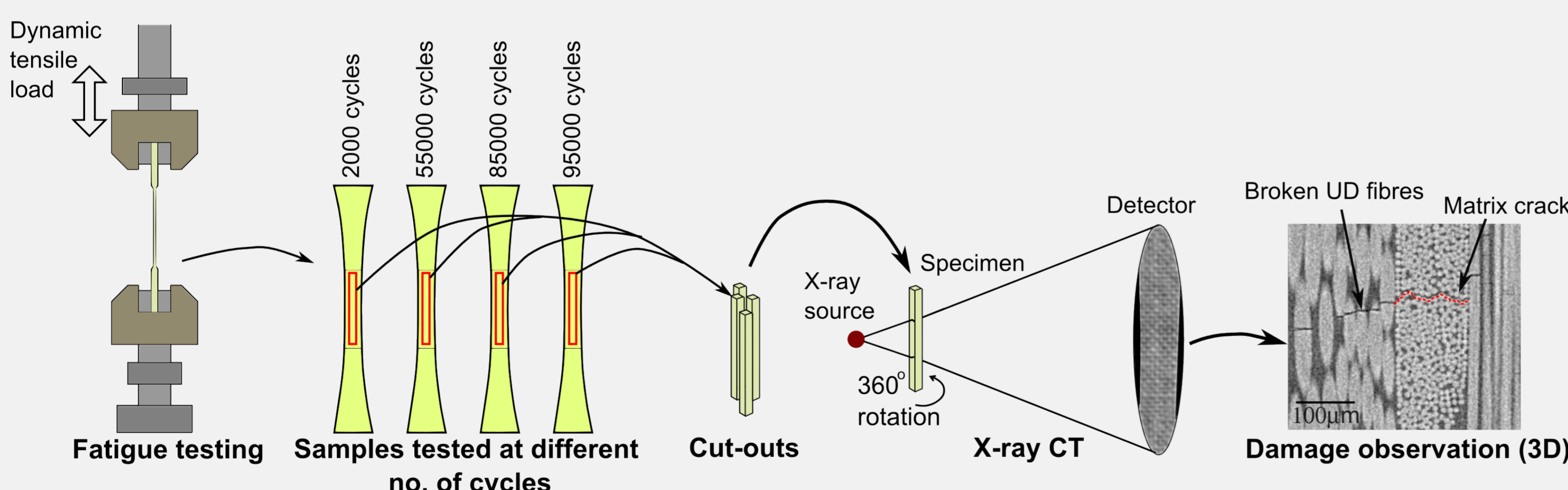
The above figure shows the typical stiffness degradation behaviour and damage progression postulate for considered UD composite based on 2D SEM observation [2]. Off-axis cracks are said to initiate in the supporting backing bundles causing an initial stiffness drop. UD fibre fractures then cause the stiffness to gradually decrease with increasing cycles until final failure.



The above figure shows an example of a blade cross-section and an indication of the predominant loading types acting on the main beams made from UD glass fibre composite (green).

Experimental method

Fatigue tests ($R=0.1$) were carried out on four 410mm long butterfly shaped specimens and stopped at different number of cycles. X-ray CT experiments were performed on a Zeiss X-radia Versa 520. As the image resolution in X-ray CT scans is decreasing for increasingly large cross-sections, cut-outs are considered to obtain high resolution ($1.2 \mu\text{m}$ voxel resolution). This results in a small field of view (2.4mm), however high resolution is necessary to see individual UD fibre fractures.

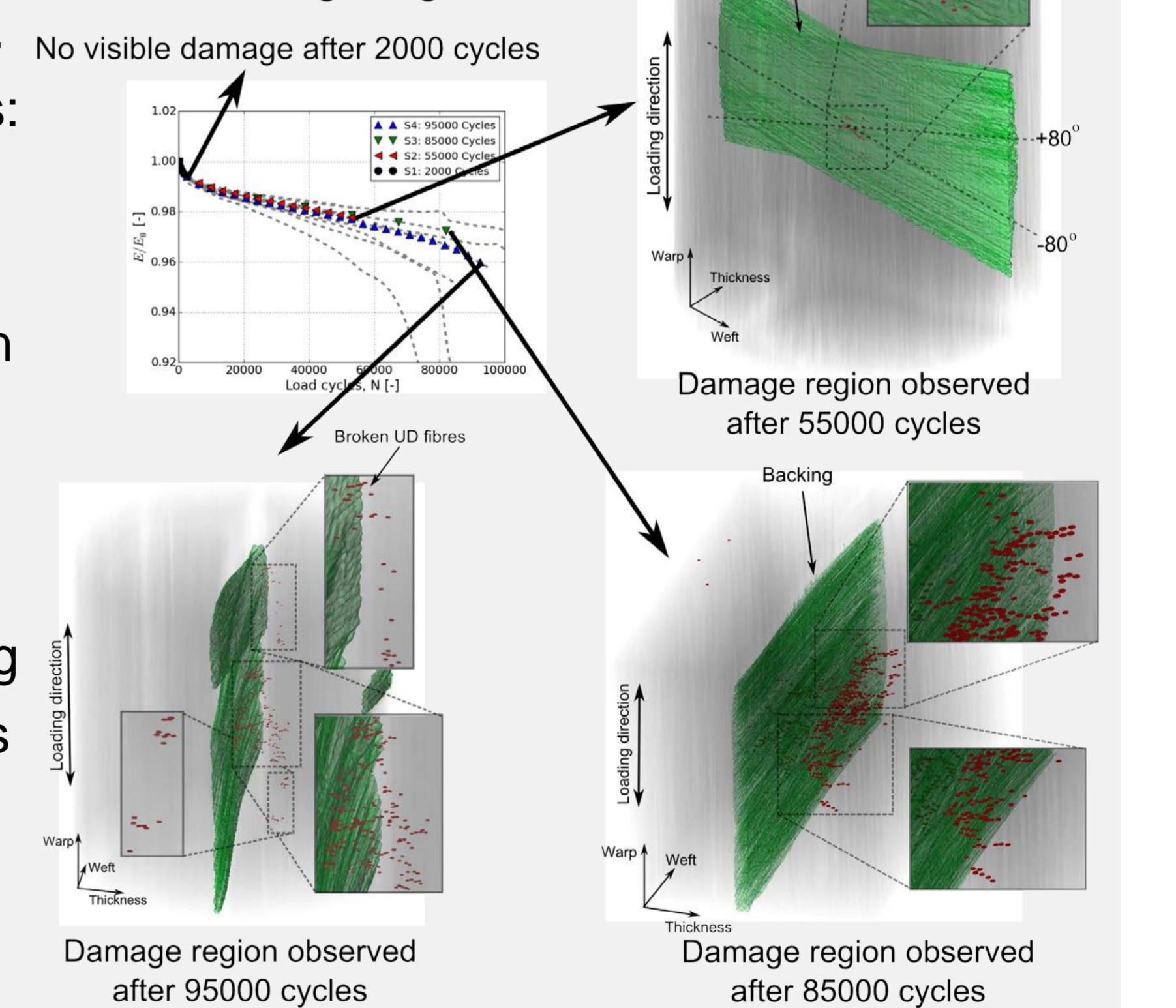


Observed damage in 3D

The UD fibre fractures were individually marked and shown in 3D. The main observations are as follows:

- UD fibre fracture regions are only seen where backing bundles intersect and at the same time is in contact with the UD bundle
- Damage is clearly a 3D phenomenon and there 2D observations might give misleading results and furthermore 2D models will be overly conservative

Segmentation of UD fibre fractures at different damage stages



Acknowledgements

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