


KUNSTSTOFF TECHNIK LEOBEN

WERKSTOFFKUNDE UND PRÜFUNG DER KUNSTSTOFFE


Correlating crack density, stiffness degradation and dissipated energy during fatigue loading of ±45° GFRP laminates

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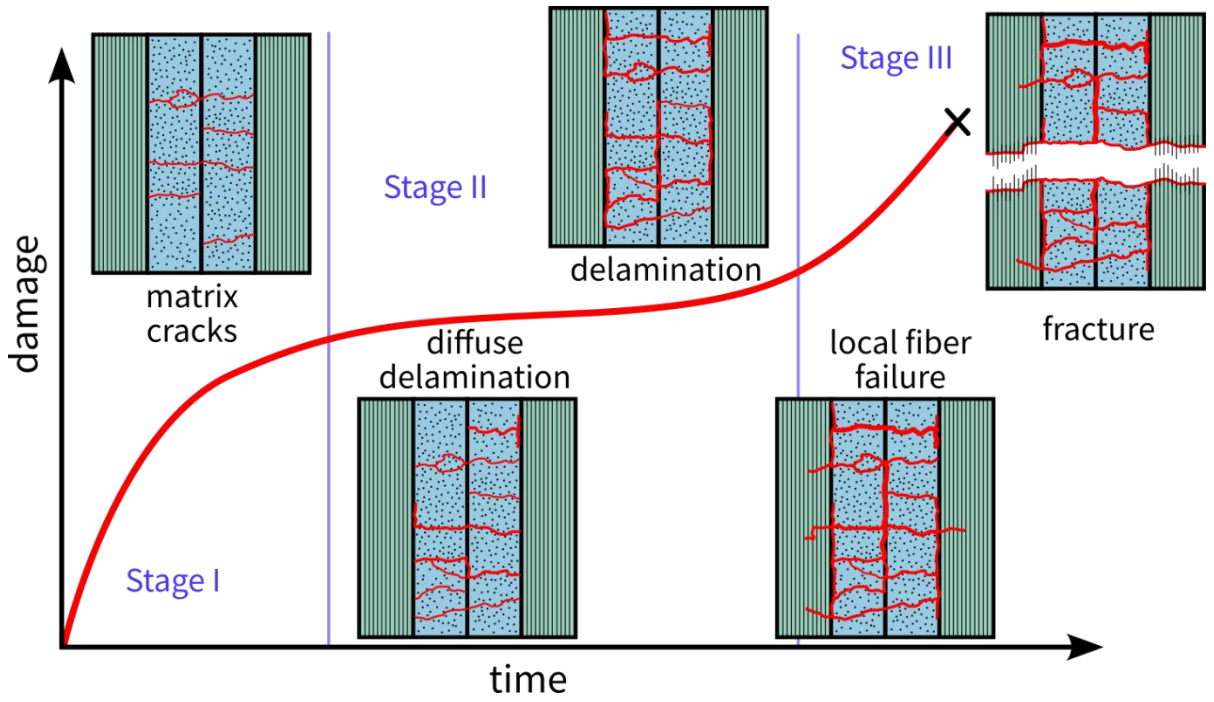
23rd INTERNATIONAL CONFERENCE ON COMPOSITE MATERIALS (ICCM23)

30.07. – 04.08.2023, Belfast

ICCM 23 BELFAST 2023

Fatigue of composites



Progressive fatigue damage model for Stage I

➔ Predicts stiffness degradation based on crack density

Experimental characterization for calibration

➔ Quantification of crack density and resulting mechanical properties

K. L. Reifsneider "*Fatigue of Composite Materials*". no. 4 in Composite materials series, Elsevier, 1991.
M. Drvoderic, M. Pletz, C. Schuecker "Modeling Stiffness Degradation of Fiber-Reinforced Polymers Based on Crack Densities Observed in Off-Axis Plies". Journal of Composite Science, Vol. 6, No. 1, 2021.

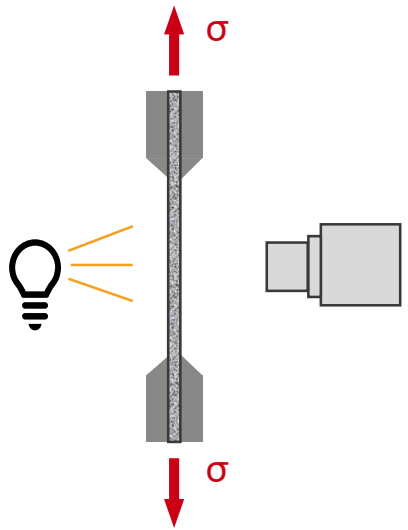
Fatigue characterization

– **Crack density**

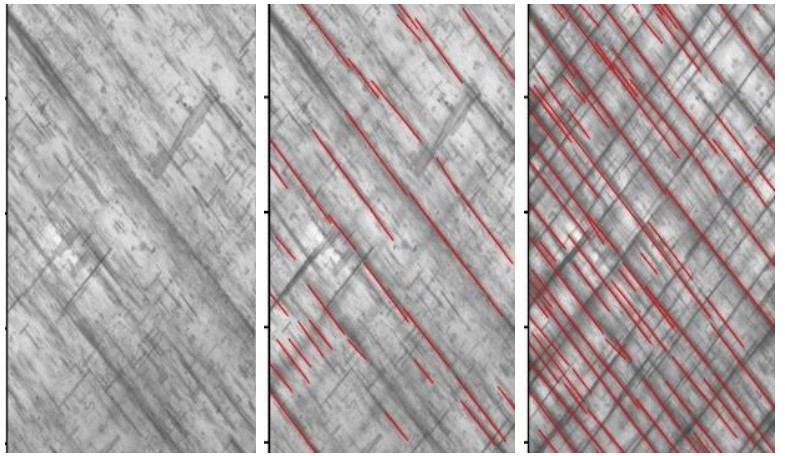
➔ Automated crack detection with open-source software **CrackDect**

$$\rho = \frac{\sum_{i=1}^{n} l_i}{A}$$

l_i length of the ith crack
A area of interest



Material has to be semi-transparent:



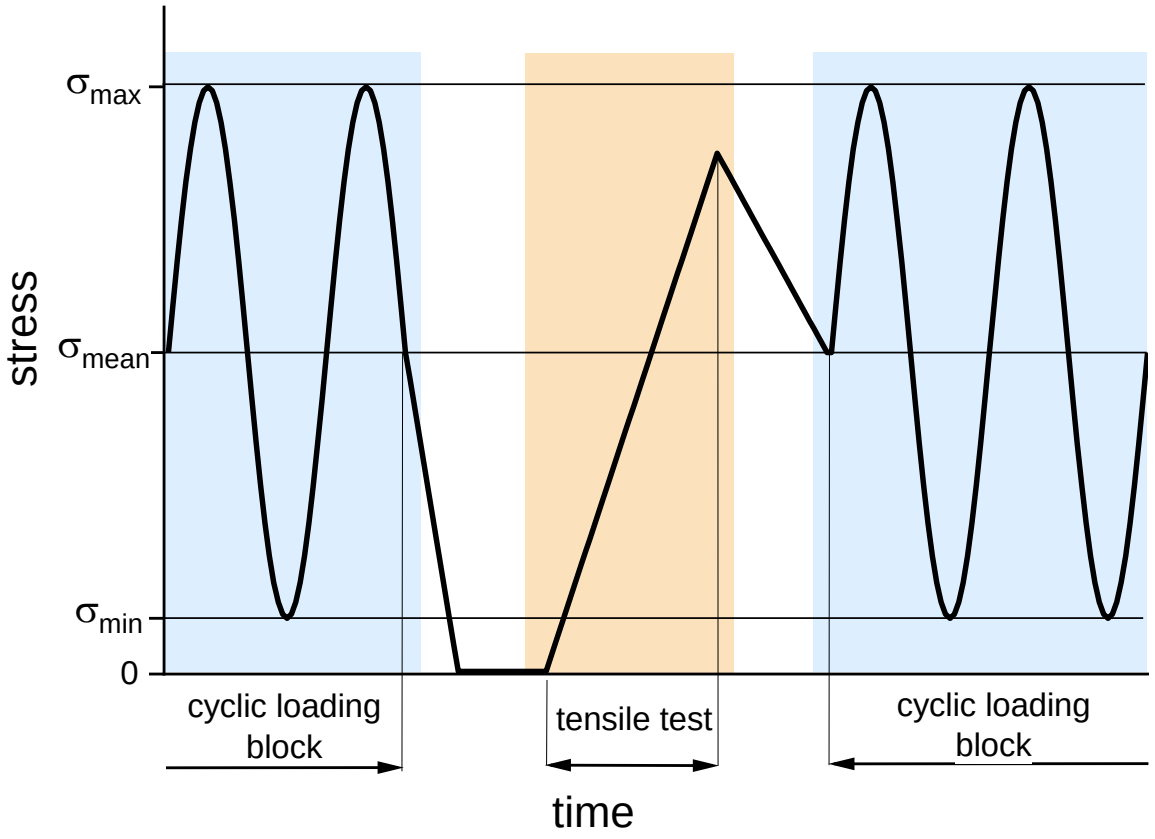
±45° glass-epoxy laminate

– **Stiffness degradation**

– **Dissipated energy**

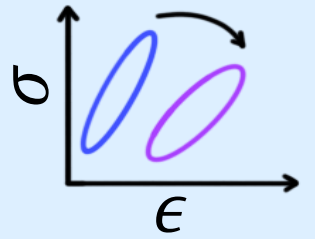
M. Drvoderic, M. Rettl, M. Pletz, C. Schuecker “CrackDect: Detecting crack densities in images of fiber-reinforced polymers”. SoftwareX, Vol. 16, 10083, 2021.

Testing procedure



Cyclic loading blocks:

– Dissipated energy

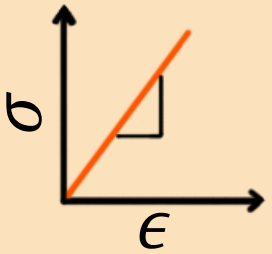


Quasi-static tensile tests:

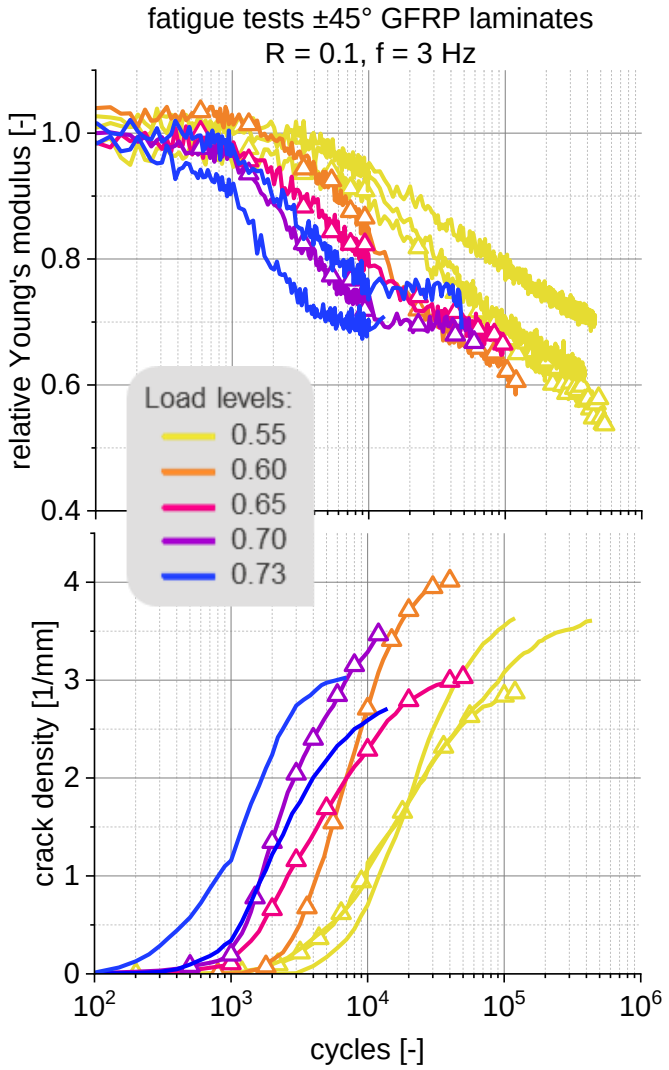
➔ Interruption of cyclic loading after defined intervals

– Stiffness

– Crack density

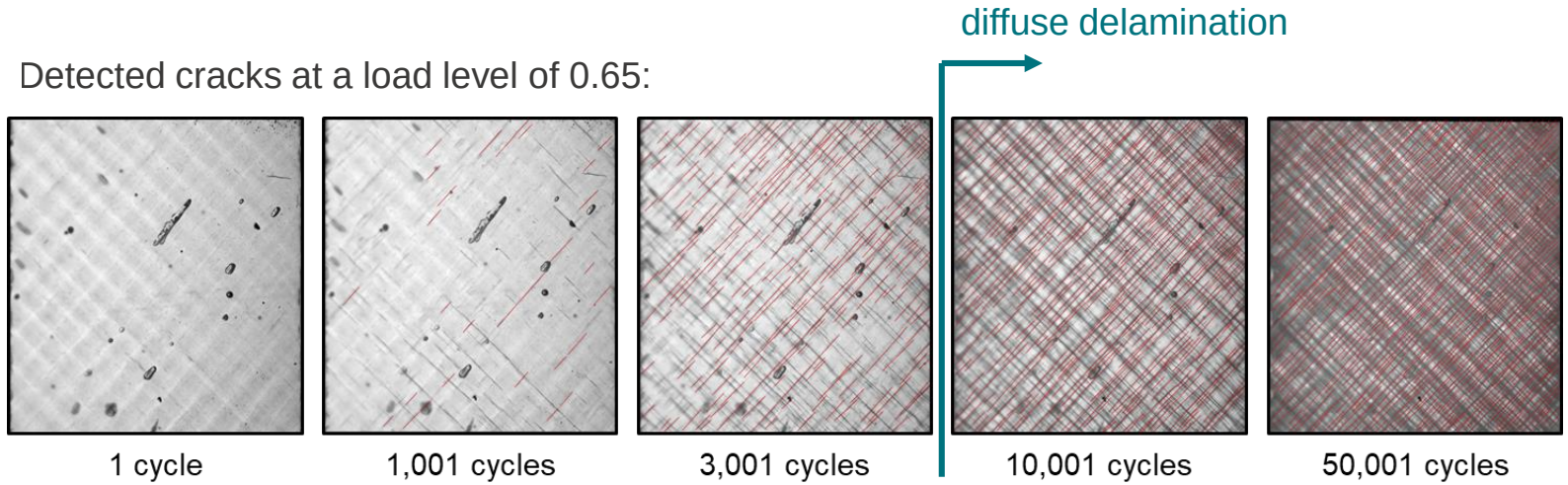


Stiffness / crack density



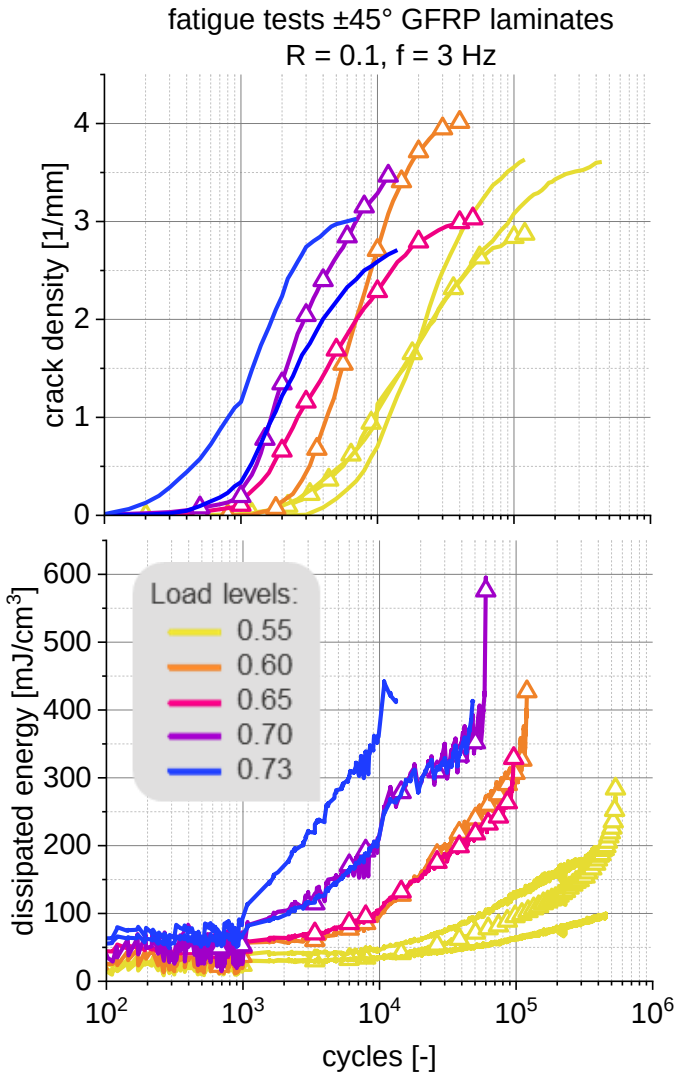
- Stiffness decrease and crack initiation happen simultaneously
- Higher load levels ➔ earlier start of stiffness degradation / crack initiation
- Off-axis cracks grow in number and size over the fatigue life
- Crack growth rate slows down when diffuse delamination starts to occur

Detected cracks at a load level of 0.65:



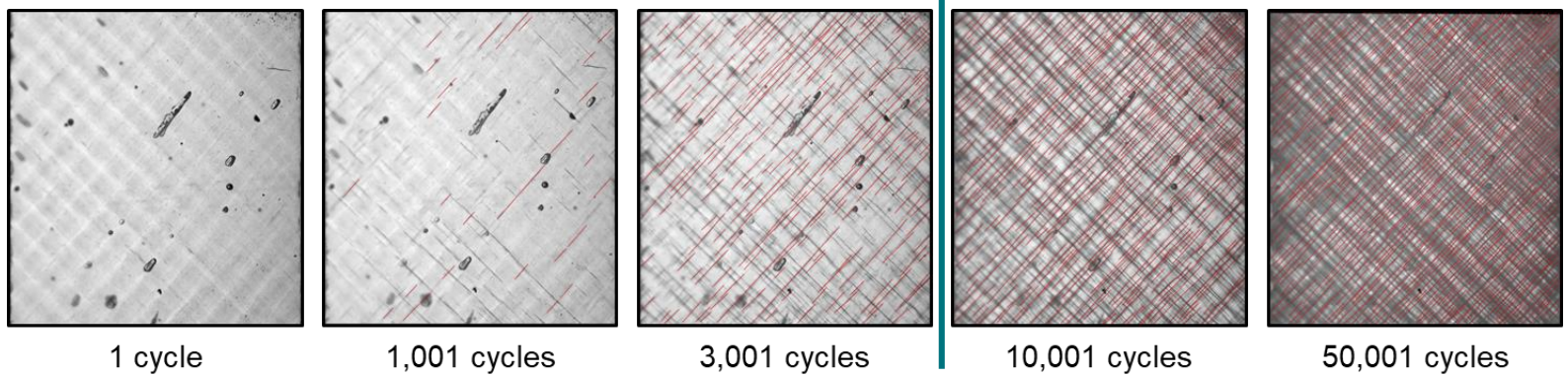
Data marked with Δ are published in: M. Drvoderic, M. Gfrerrer, J. Wiener, G. Pinter, M. Pletz, C. Schuecker “Comparing crack density and dissipated energy as measures for off-axis damage in composite laminates”. International Journal of Fatigue, Vol. 169, 107486, 2023.

Crack density / dissipated energy



- Higher load levels ➔ earlier increase of dissipated energy
- Dissipated energy…
  - … increases later in time compared to crack density
  - … continues to increase after crack saturation
  - ➔ Result of other mechanisms (e.g. delamination) or internal friction
  - ➔ Not a good measure for off-axis damage

Detected cracks at a load level of 0.65:



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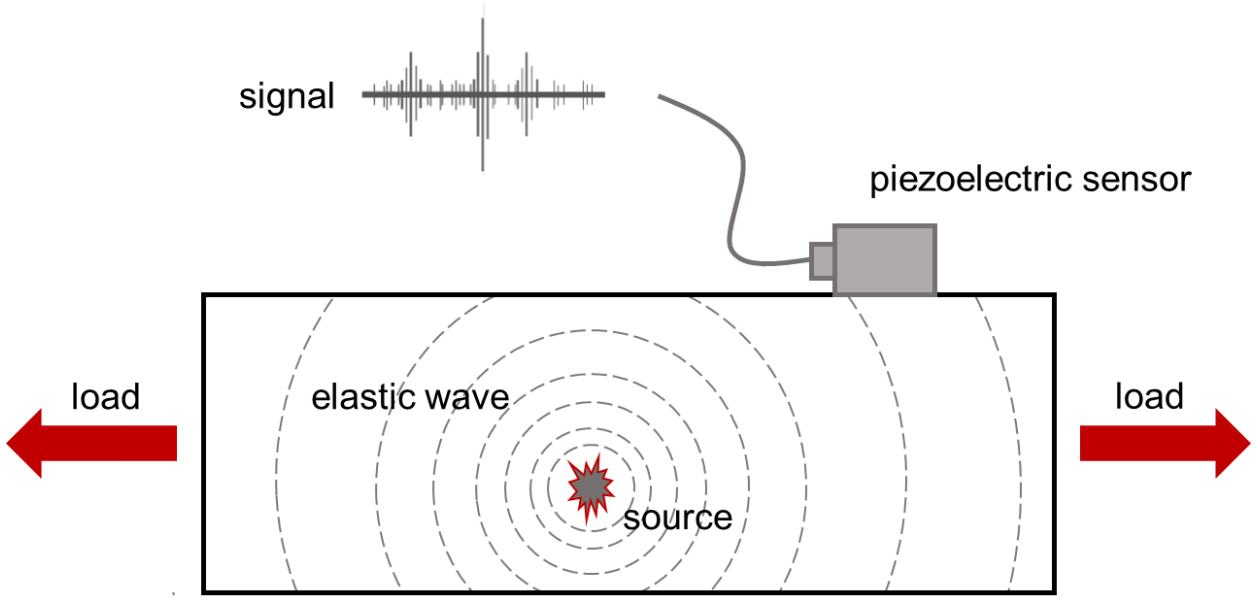
Fatigue characterization with acoustic emission

New test series with different laminate:

- Crack density
- Stiffness degradation
- Dissipated energy
- **Acoustic emission (AE)**



… optical crack detection is limited to semi-transparent laminates

AE as alternative method for crack detection applicable to non-transparent materials?

M. G. R. Sause "*In Situ Monitoring of Fiber-Reinforced Composites: Theory, Basic Concepts, Methods, and Applications*". Springer International Publishing AG, 2016.

Fatigue characterization with acoustic emission

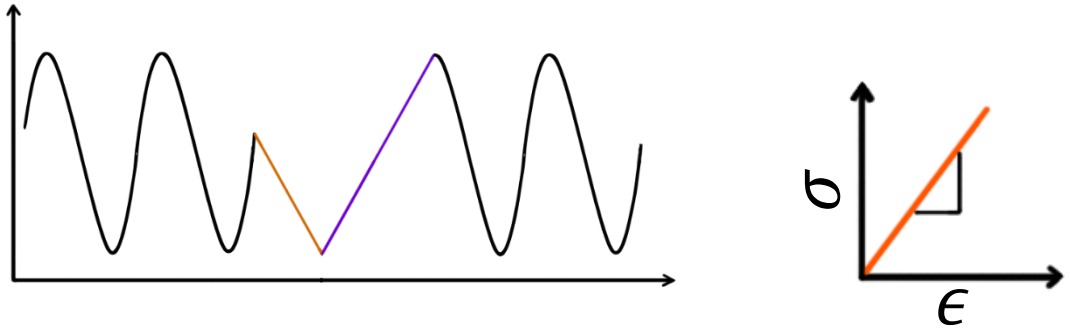
1st series

UD glass fabric (10% weft yarns) + epoxy matrix

Cyclic loading + tensile tests

➔ Classic Young`s modulus

Good correlation of quasi-static modulus and dynamic modulus was found

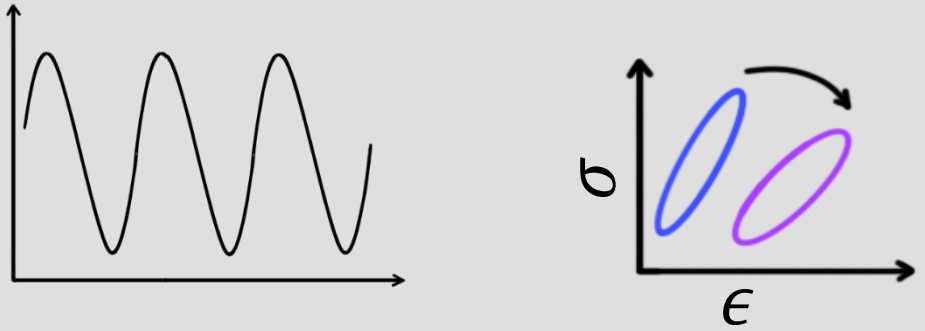


2nd series

UD glass-epoxy prepreg

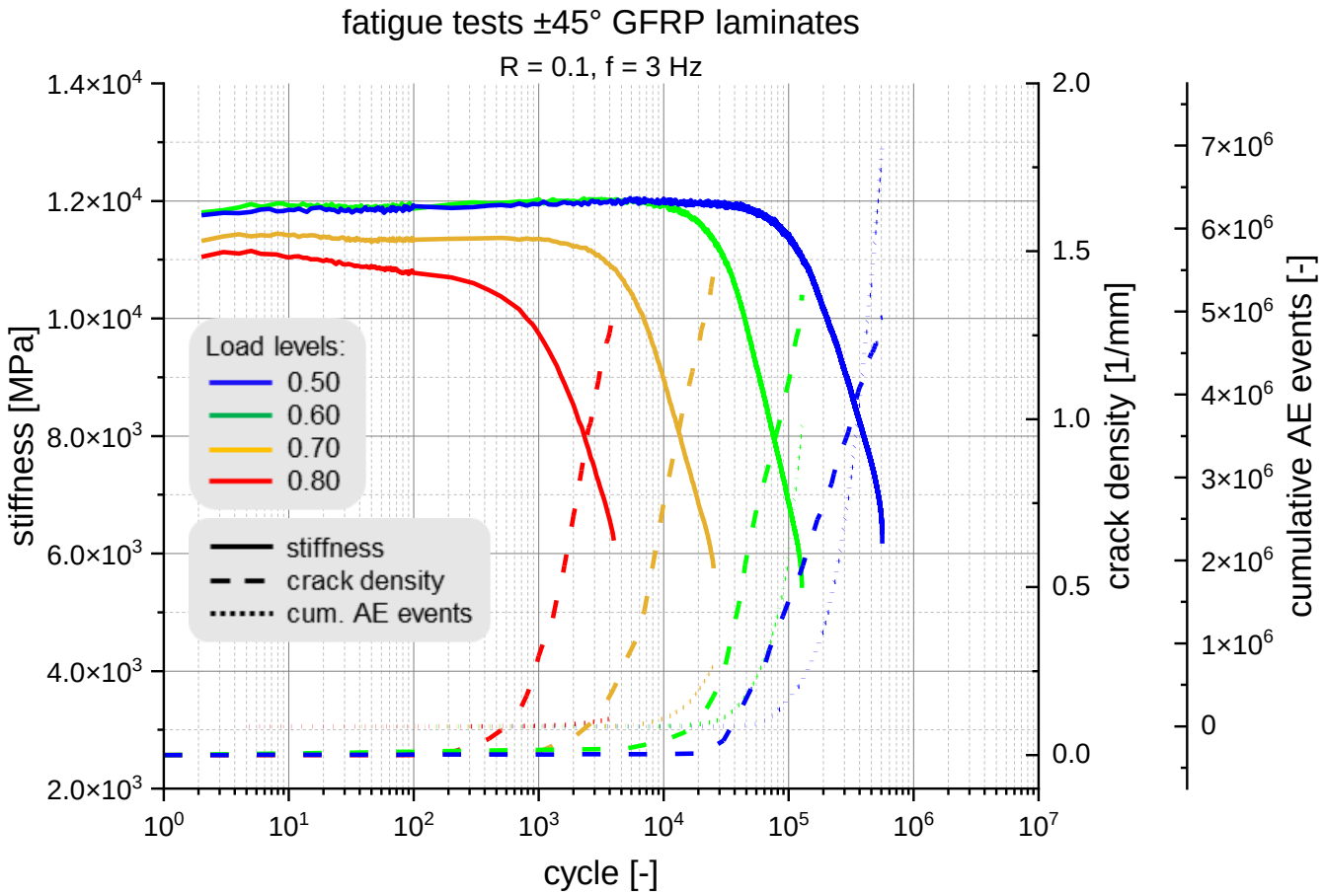
Reduction of test complexity: Cyclic loading

➔ Dynamic modulus from hysteresis



M. Drvoderic, M. Gfrerrer, J. Wiener, G. Pinter, M. Pletz, C. Schuecker “Comparing crack density and dissipated energy as measures for off-axis damage in composite laminates”. International Journal of Fatigue, Vol. 169, 107486, 2023.

Stiffness / crack density / AE events



No crack saturation

Cumulative AE events significantly increase later in time compared to crack density

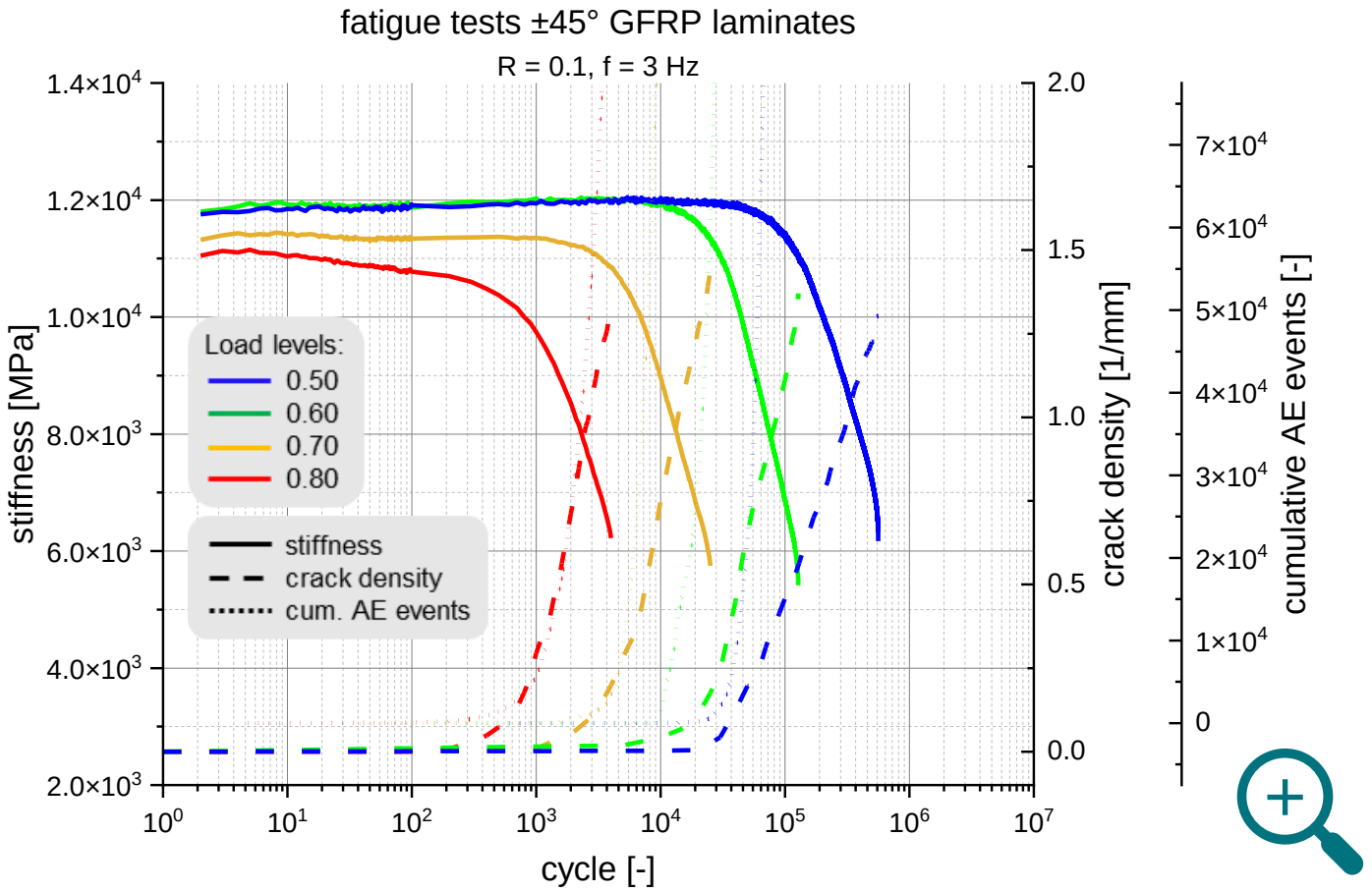
➔ Result of other mechanisms (e.g. delamination) or internal friction

More AE events detected for lower load levels

➔ higher number of cycles

➔ more AE signals due to friction

Stiffness / crack density / AE events



First detected AE signals correlate with crack initiation

Conclusion

Correlation of crack density with

- **Stiffness degradation**
  - Stiffness decrease and crack initiation happen simultaneously
- **Dissipated energy (hysteresis loops)**
  - Increases later in time compared to crack density
  - Continues to increase after crack saturation
- **AE events**
  - Significantly increase later in time compared to crack density
  - More AE events detected for lower load levels
  - Crack initiation can be detected (depends on AE measuring parameters)

Result of other mechanisms or internal friction

Higher number of cycle
More signals due to friction

Detailed analysis of AE signal parameters: Differentiation between source mechanisms?

CrackDect

Crack Density Comparison

Thank You!