

Faculty of Mechanical Engineering Department of Materials Test Engineering (WPT)

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Charakterisierung des temperaturspezifischen Ermüdungs- und Schädigungsverhaltens von glasfaserverstärktem Polyurethan und Epoxidharz der Luftfahrtindustrie

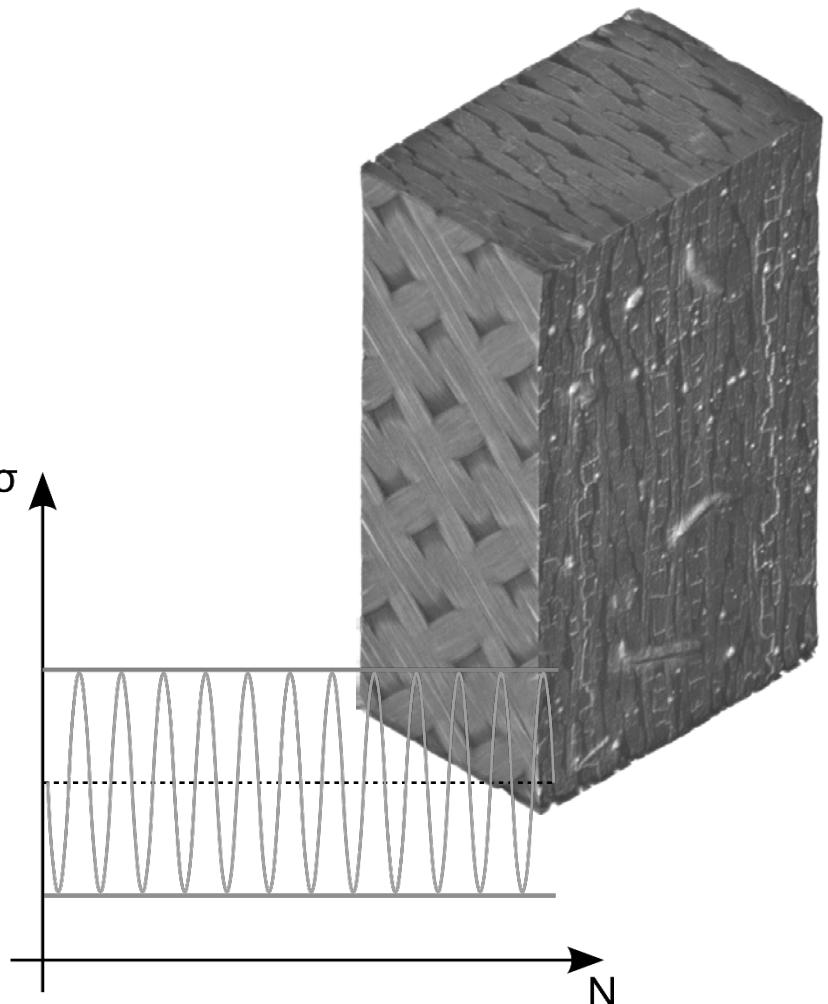
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Chapter

- 1 **Introduction of the department**
- 2 An energy approach for reproducible fatigue testing
- 3 Temperature-dependent fatigue behavior
 - Strength-based
 - Stiffness-based
- 4 In situ computed tomography for damage analysis
- 5 Conclusions



Competence fields



Steels

Light Metals

Composites

Additive Manufacturing

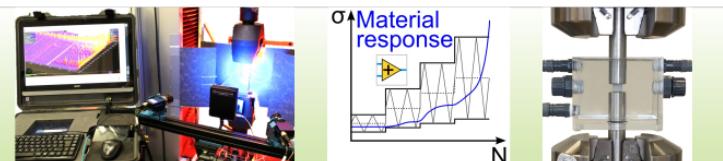
Structural Analysis

In situ
2D and 3D Analyses
Multiscale



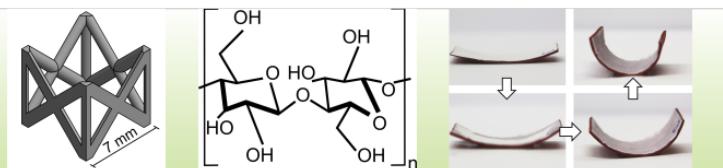
Measurement and Test Engineering

Innovative Measurement Development
LabVIEW-based Programming
Biomimetic Testing Solutions



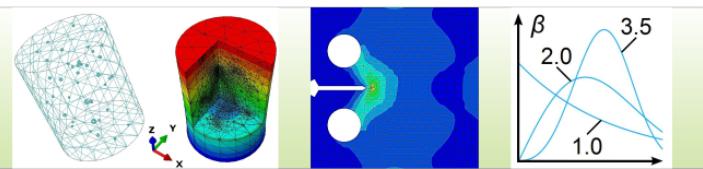
Biomaterials

Bio-Inspired Structures
Biopolymers
Multi-Functional Materials



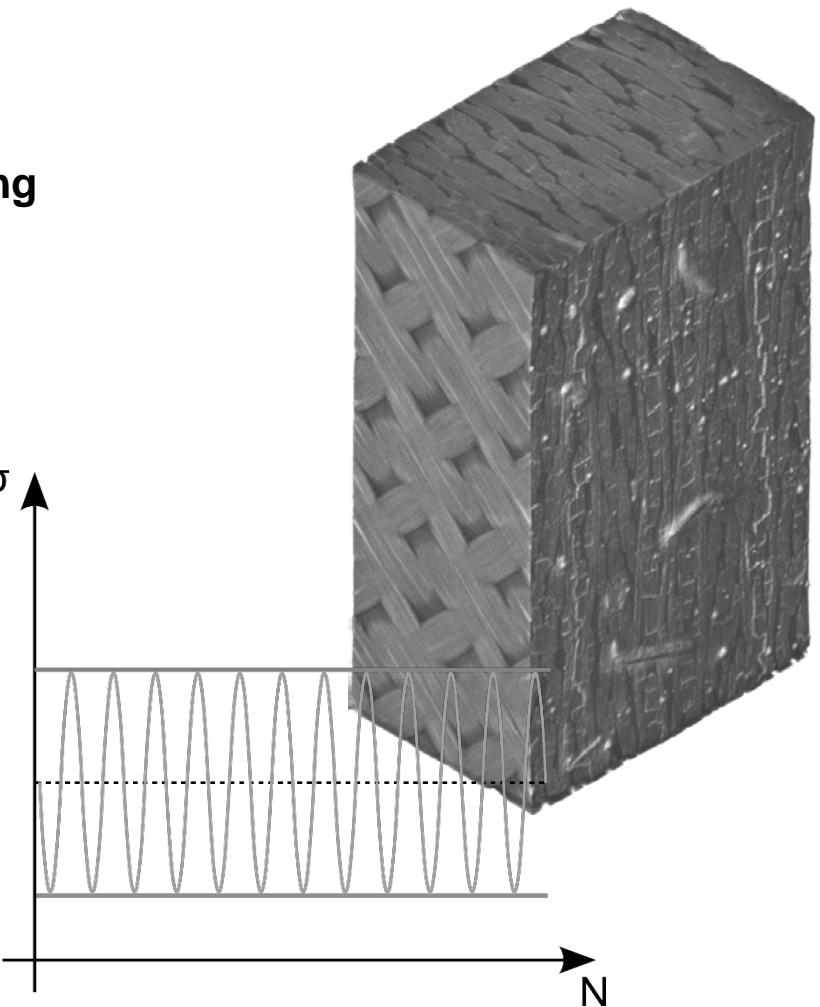
Modelling and Simulation

Cyclic Deformation
Crack Initiation and Propagation
Probability and Statistics



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Test frequencies for fatigue testing of FRP

ISO 13003

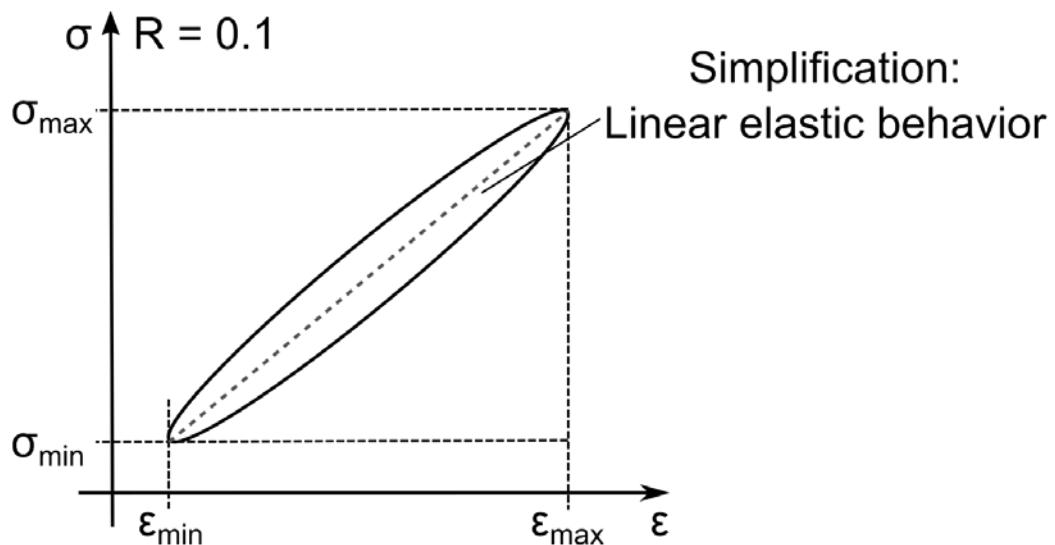
8 Conditioning and test environments
8.1 Conditions
Unless otherwise specified (e.g. to investigate the effect of humidity, oil, chemical environments, other types of pressure or temperature), use standard specimens as prescribed in ISO 281.
8.2 Test atmosphere
The test shall be carried out in a standard atmosphere chosen from ISO 281 unless otherwise specified.
If other conditions are to be agreed between the parties, record full details in the test report.
NOTE
In tests involving the use of different types of conditioned specimen may change unless it is mentioned in the conditioning environment during the test.
9 Procedure
9.1 Measurement of dimensions of test specimens
Measure the dimensions as specified in the test method used.
9.2 Test Frequency
Although normally only one specimen is tested in the specimen holder, the test frequency may be increased if the test is being carried out in the specimen holder immediately after loading or heating. The frequency shall be measured with an accuracy of $\pm 2\%$.
NOTE
The temperature of the specimen surface is normally limited to 15°C but it is recommended that the sensitivity of the test is not affected by the temperature of the specimen surface. If the temperature of the specimen surface is higher than 15°C it is to be noted for the test results. For some dependent materials, the results can be sensitive to the temperature of the specimen surface.
9.3 Conduct of the test
9.3.1 Consideration of the test conditions
Carefully read the test conditions to be used with the guidance of Annexes A and B, or review the equivalent test conditions for other test methods.
9.3.2 Alignment
Carefully align the specimen in the loading frame in accordance with the standard for the test method used.
9.3.3 Monotonic tests
Test five specimens and determine the mean static (standard) properties in accordance with the test method standard used. For loading rate dependent materials, repeat the tests at the fatigue loading rate.
9.3.4 Fatigue tests
Select the four fatigue levels in accordance with the material under test and the maximum fatigue life of interest, alternatively, the range of stress versus interest.

ASTM 7991-12

$$1 < f < 25 \text{ Hz}$$
$$\Delta T \text{ max. } 10 \text{ K}$$

$f < 5 \text{ Hz}$

Hypothesis:
A constant induced energy rate
leads to reproducible temperature increase



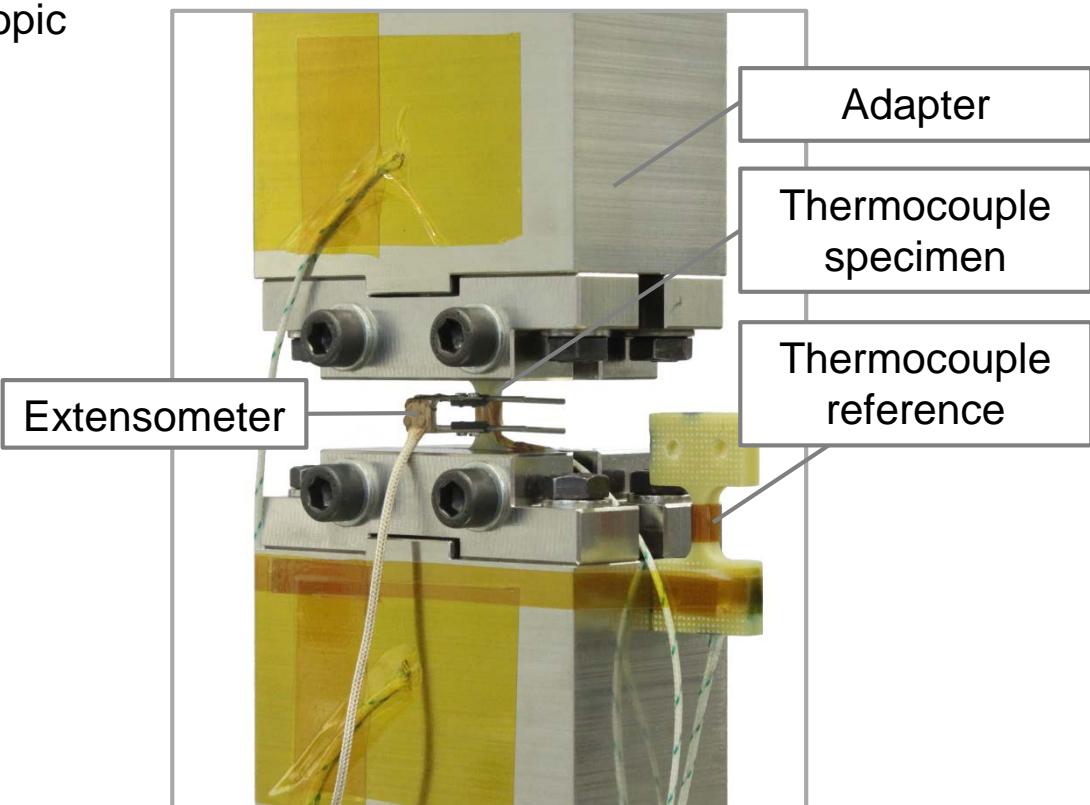
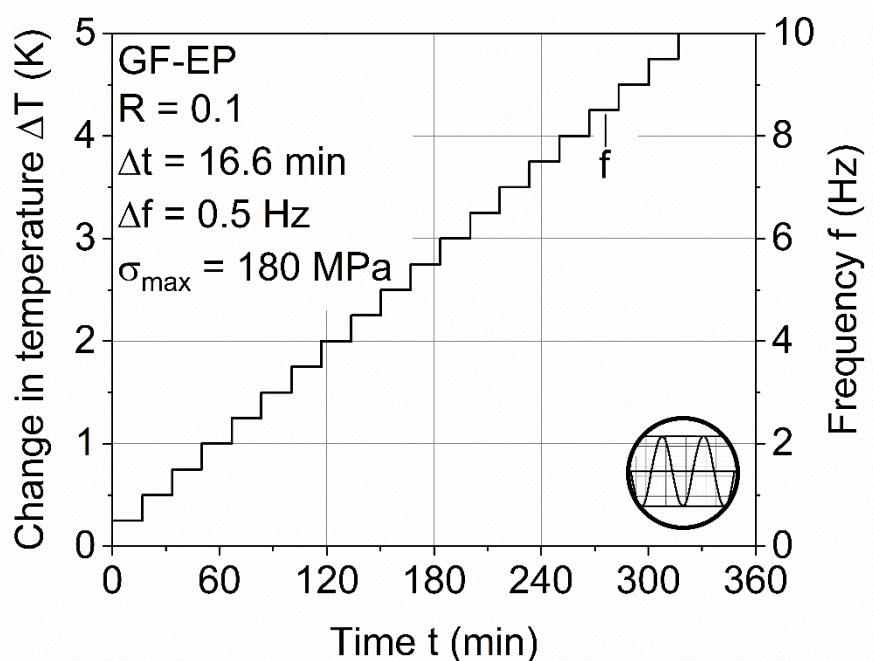
Induced energy rate E_{ind} :

$$\dot{E}_{\text{ind}} = \frac{E_{\text{ind}}}{0,5 \cdot t_i} \quad t_i = \frac{1}{f}$$

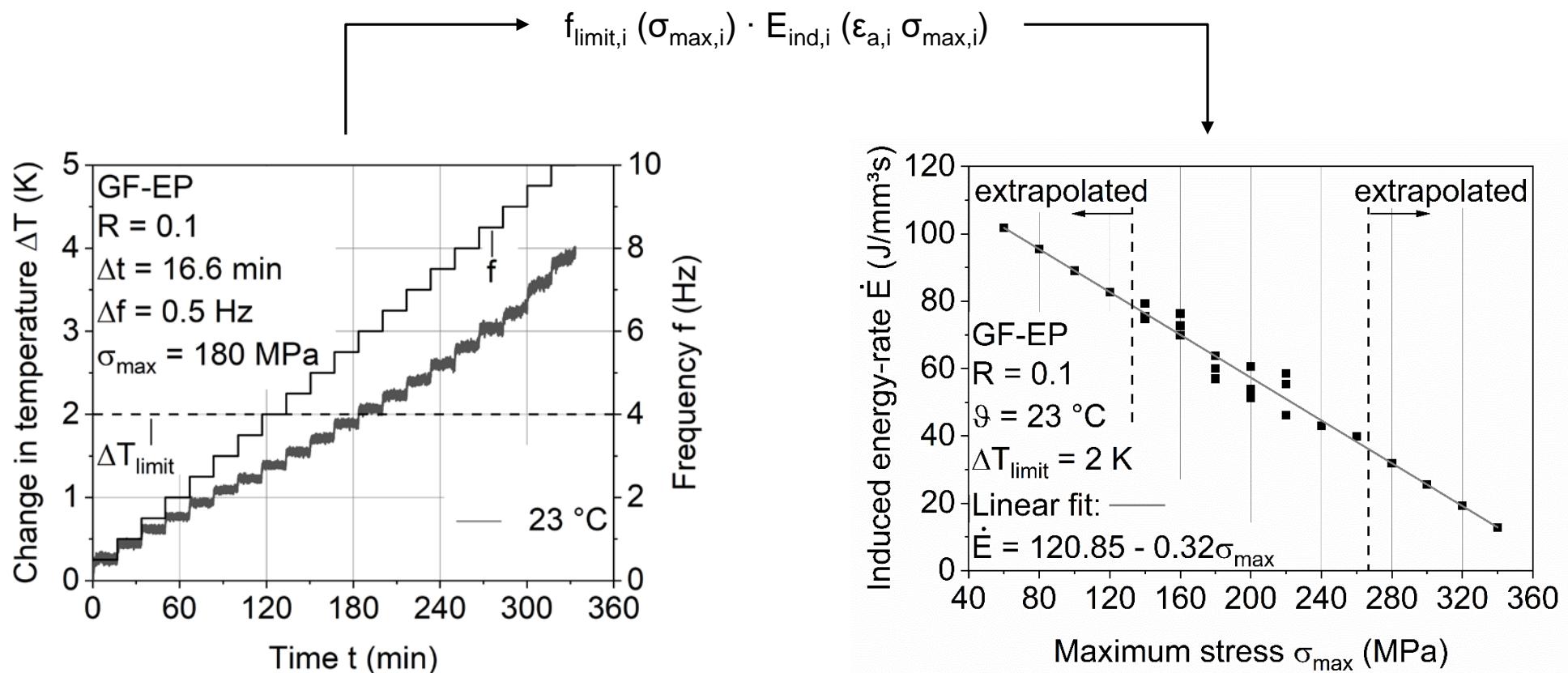
Principle of frequency-increase tests



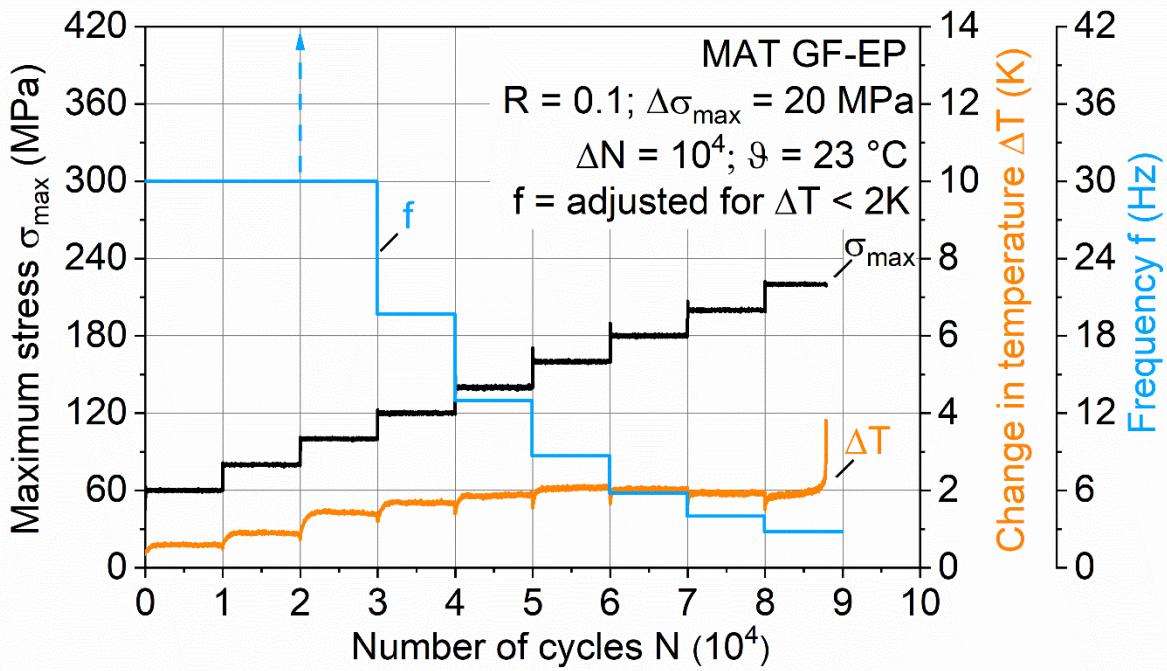
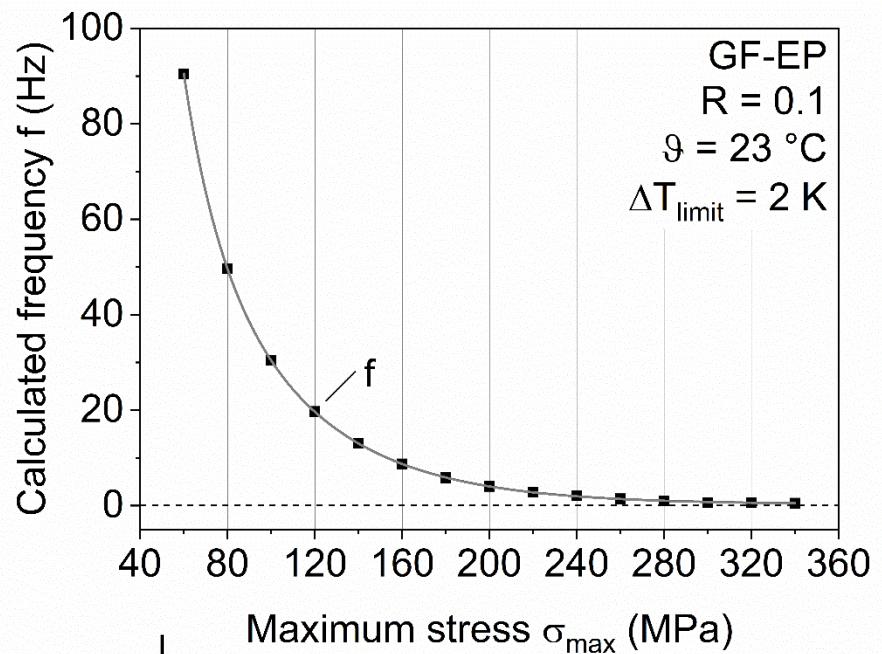
Layer setup:
 $[45, -45, 0, 90]_{2S} \longrightarrow$ quasi-isotropic



Determination of stress-dependent induced energy rate



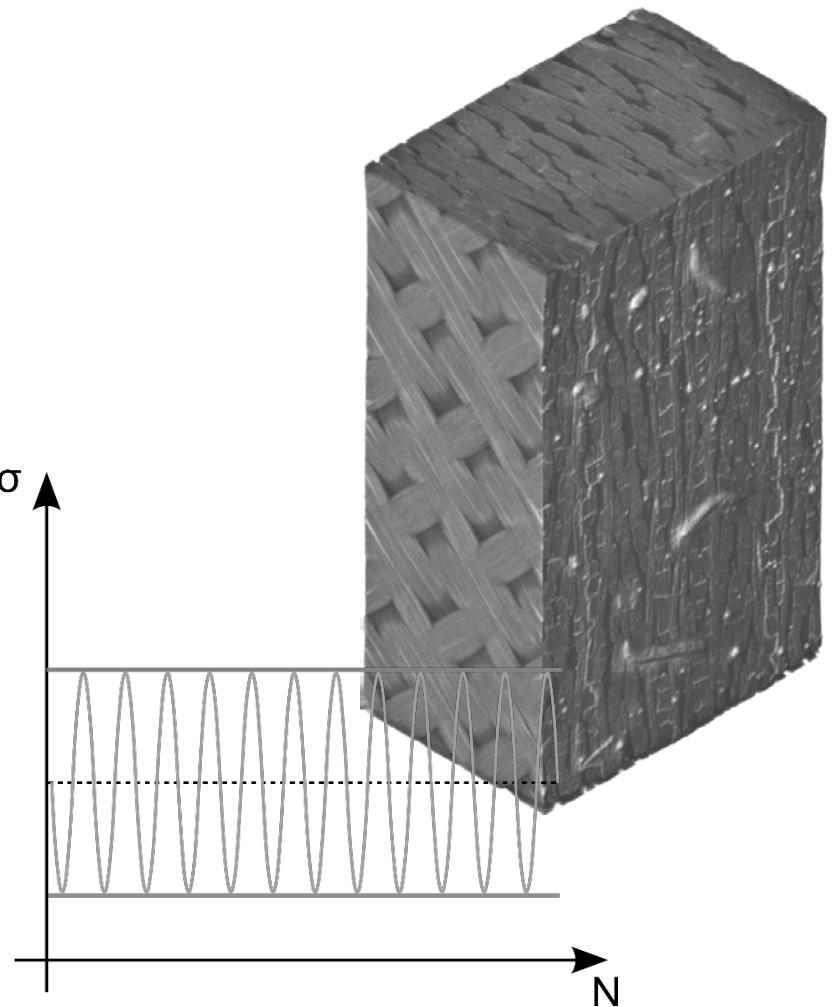
Determination of suitable test frequencies



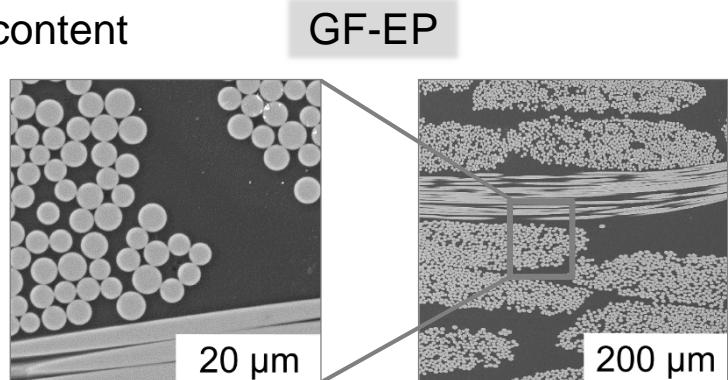
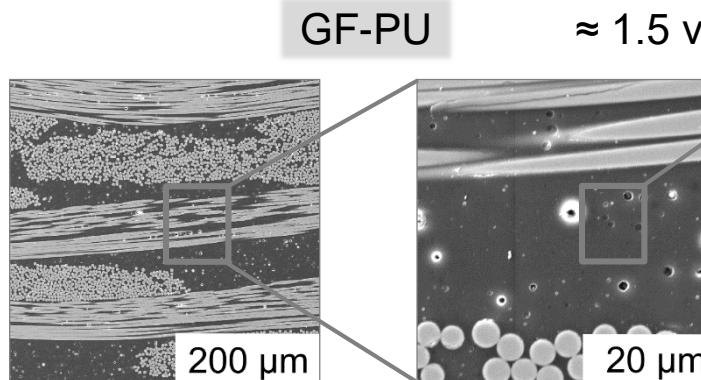
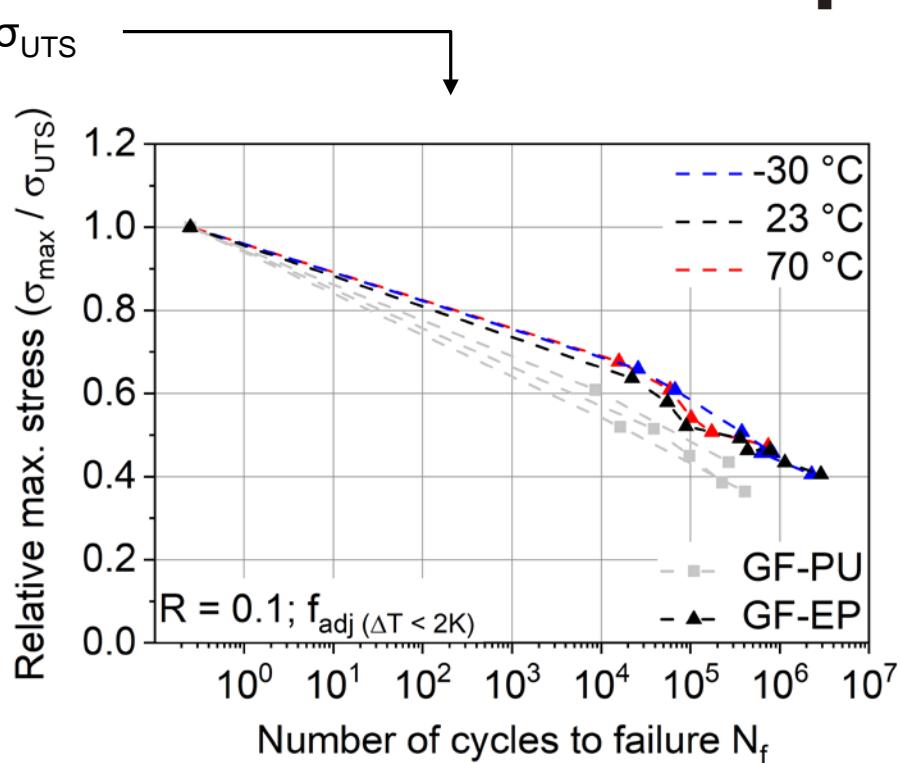
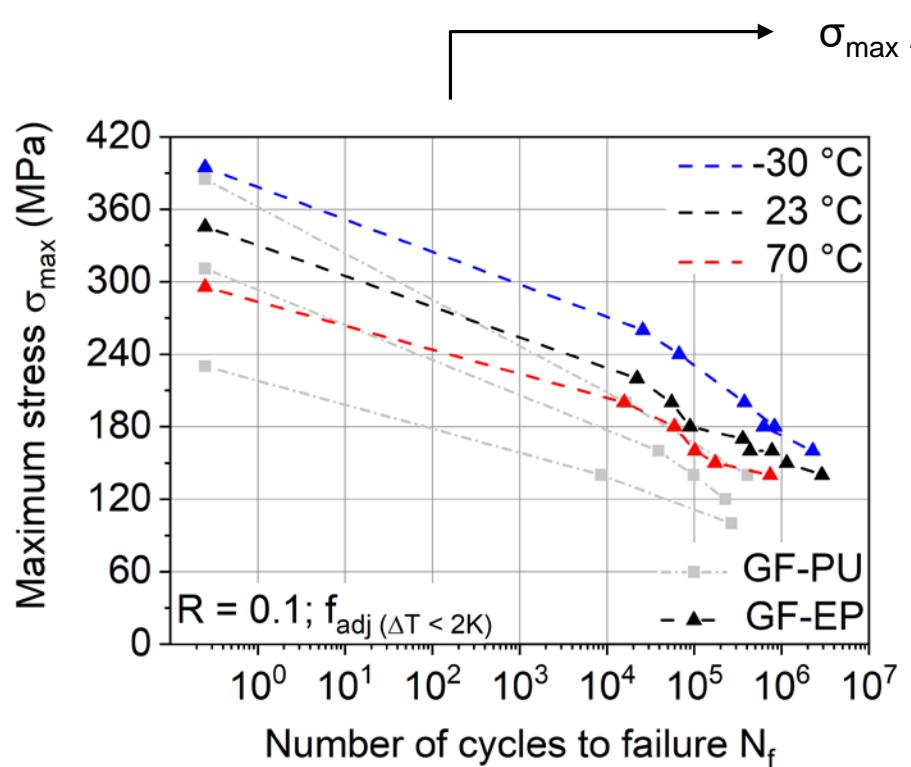
σ_{\max} (MPa)	f (Hz)	σ_{\max} (MPa)	f (Hz)	σ_{\max} (MPa)	f (Hz)
60	90.1	120	19.7	180	5.8
80	48.2	140	11.2	200	4.0
100	30.7	160	8.7	220	2.8

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S/N-curves

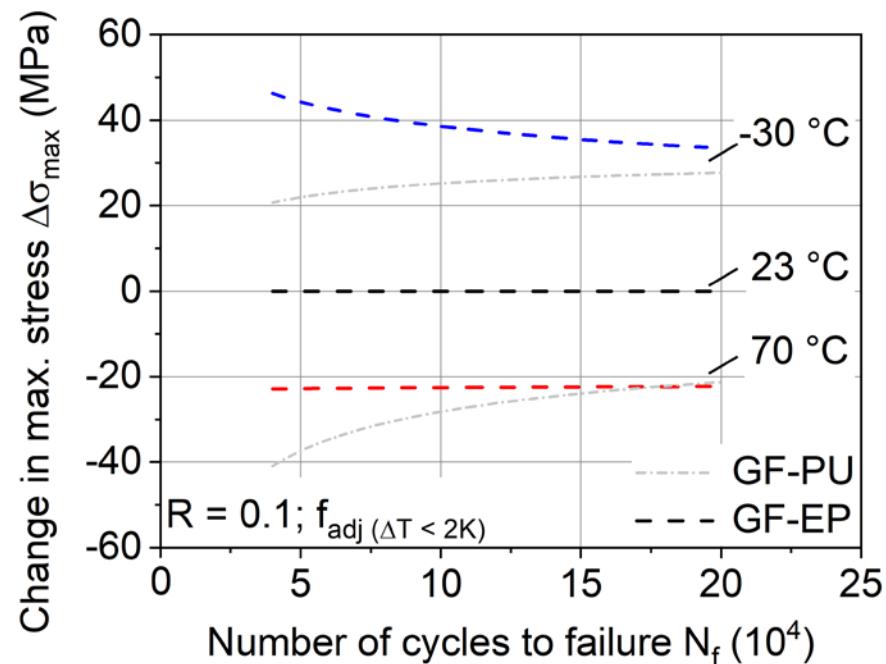
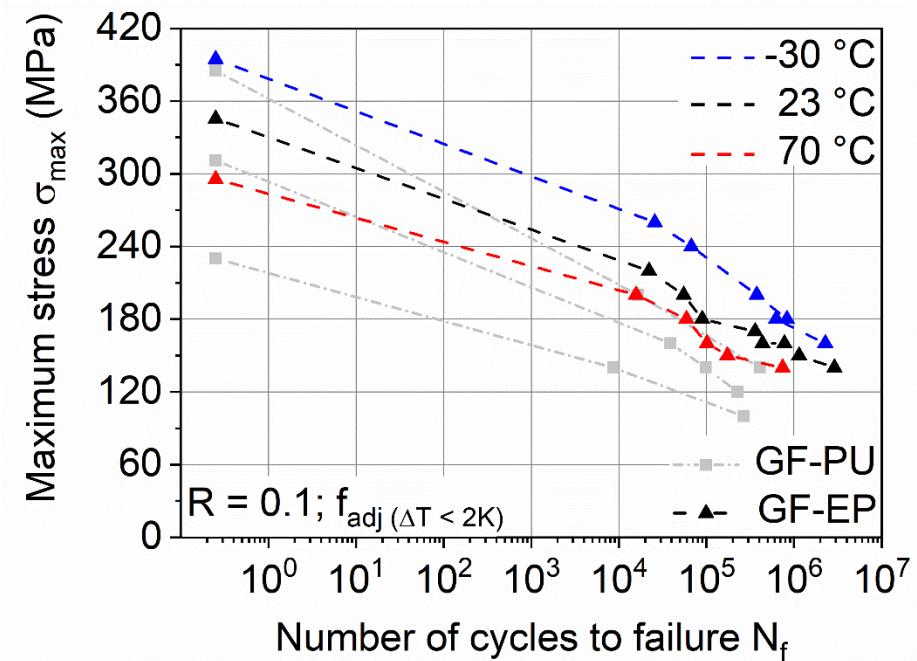
-30 °C**23 °C****70 °C**

Influence of temperature on fatigue strength

-30 °C

23 °C

70 °C



GF-EP

$$\sigma_{\max, T=-30^\circ\text{C}} = 802.77 \cdot (N_f)^{-0.11} \text{ MPa}$$

$$\sigma_{\max, T=23^\circ\text{C}} = 535.57 \cdot (N_f)^{-0.091} \text{ MPa}$$

$$\sigma_{\max, T=70^\circ\text{C}} = 529.91 \cdot (N_f)^{-0.101} \text{ MPa}$$

$$\Delta\sigma_{\max, T=-30^\circ\text{C}} = 394.56 \cdot (N_f)^{-0.202} \text{ MPa}$$

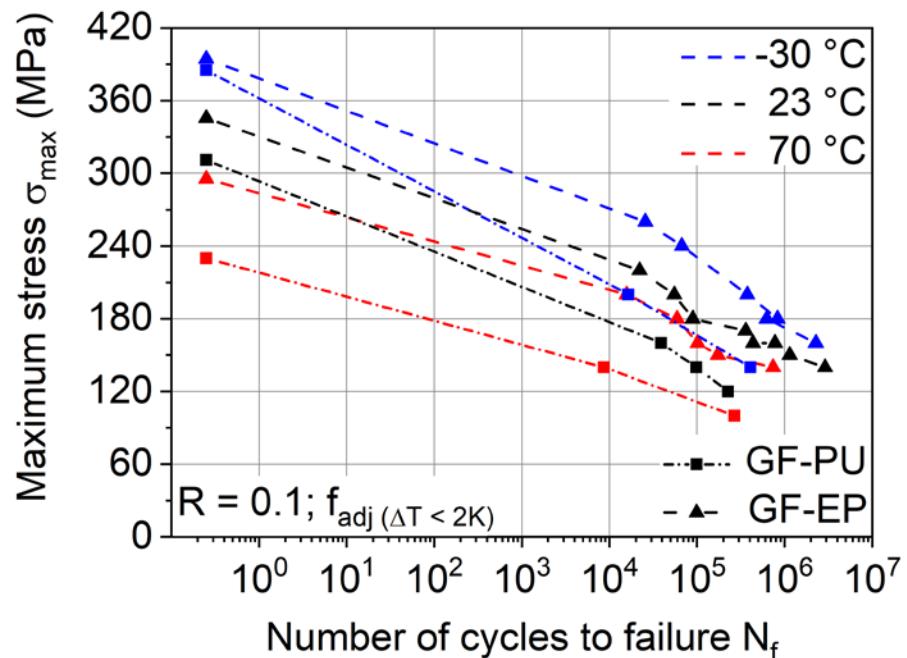
$$\Delta\sigma_{\max, T=70^\circ\text{C}} = -27.122 \cdot (N_f)^{-0.016} \text{ MPa}$$

Influence of temperature on fatigue strength

-30 °C

23 °C

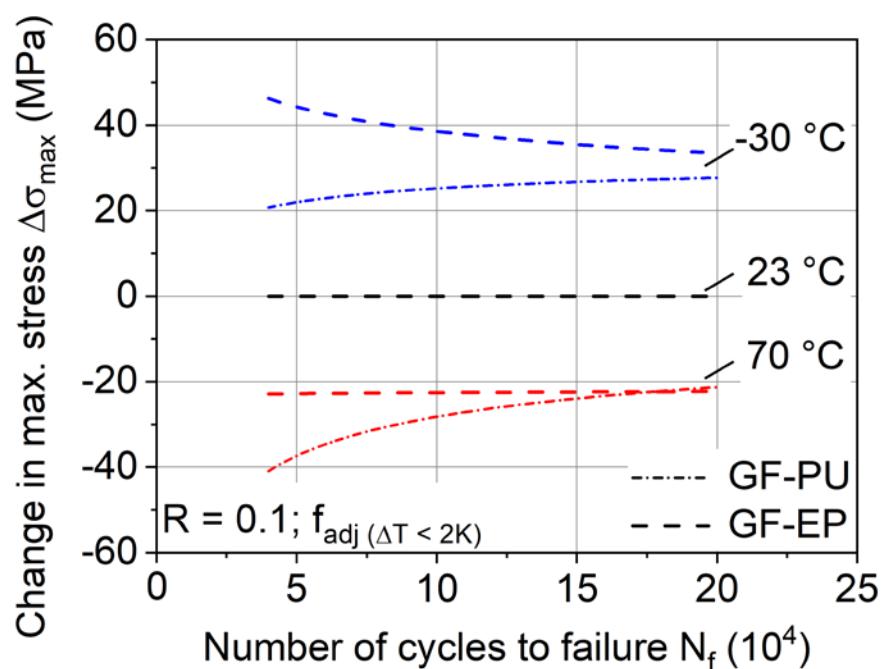
70 °C



GF-PU

Glass transition
temperature t_g

130 °C



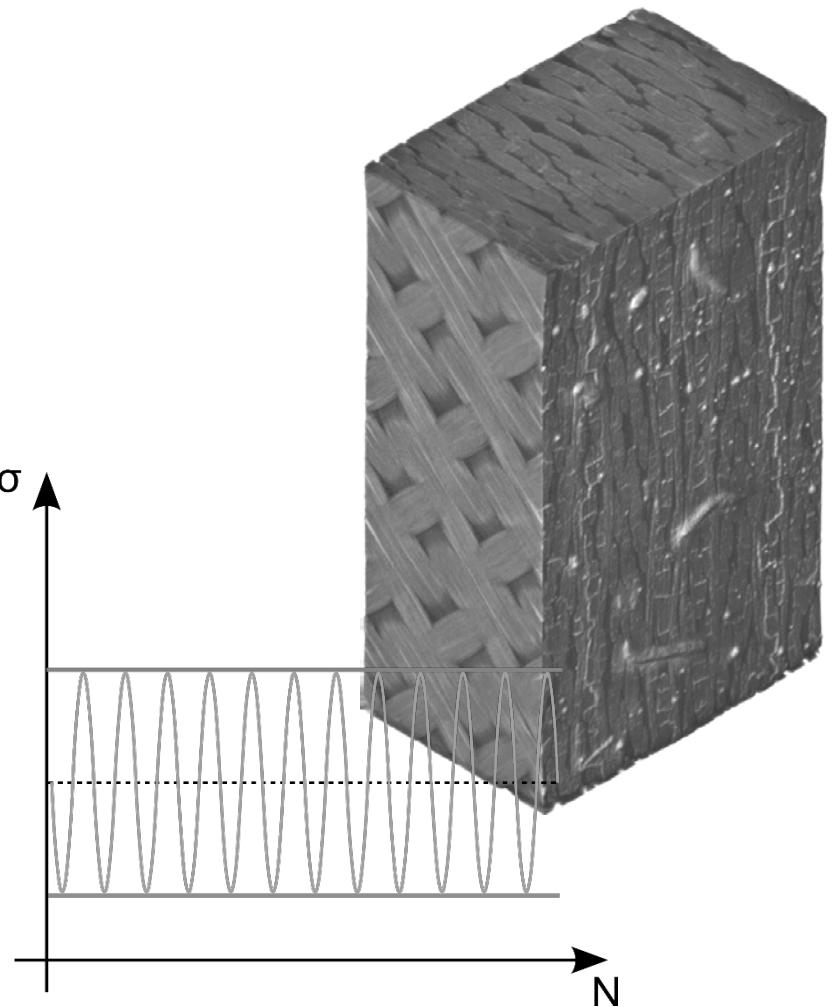
GF-EP

Glass transition
temperature t_g

190 °C

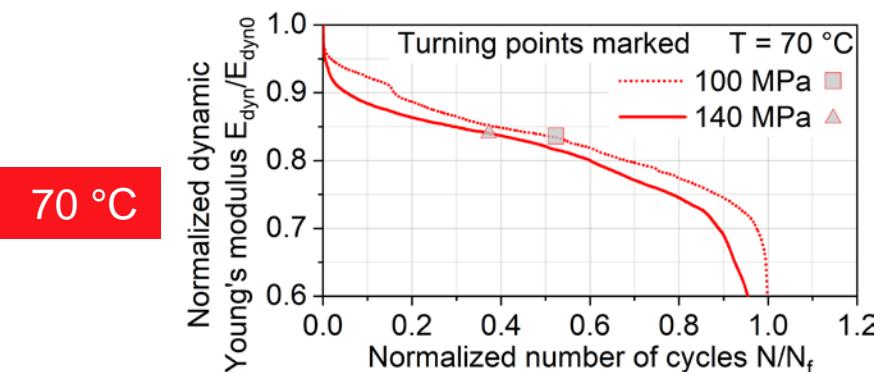
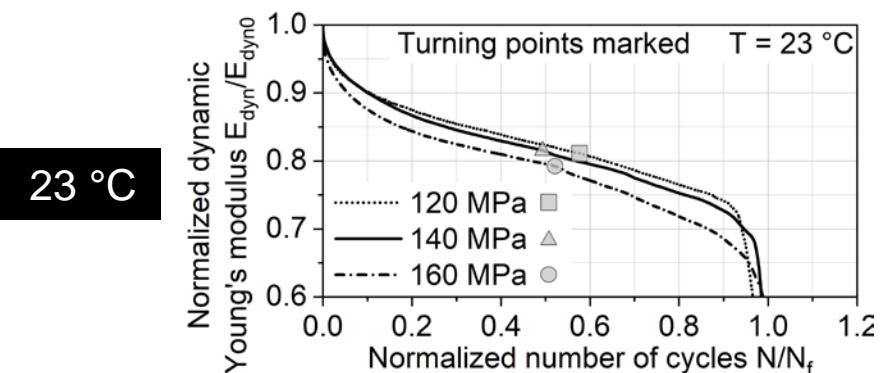
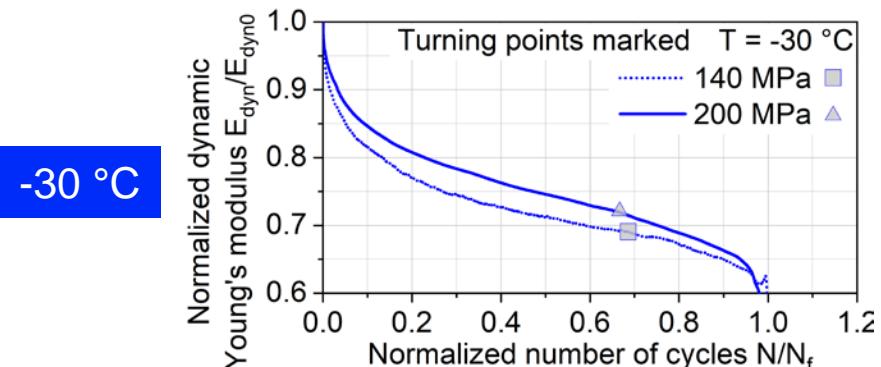
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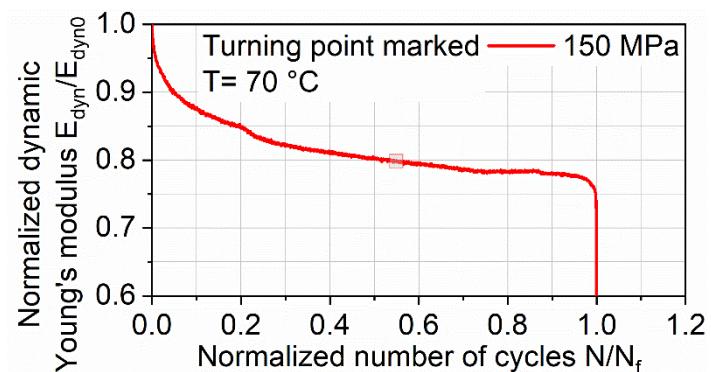
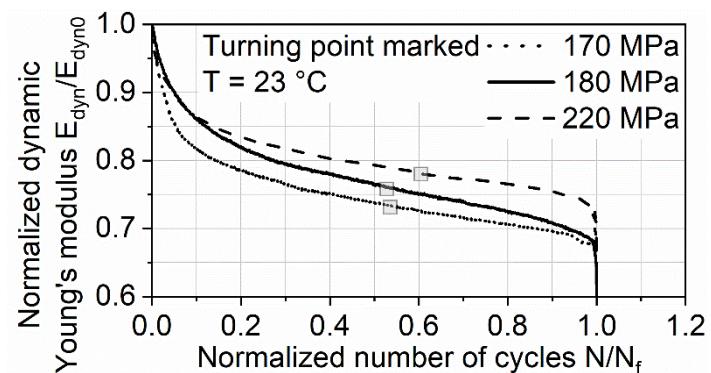
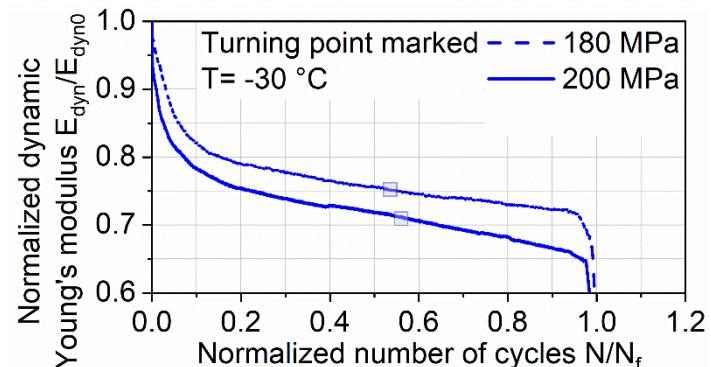


Influence of temperature on stiffness degradation

GF-PU

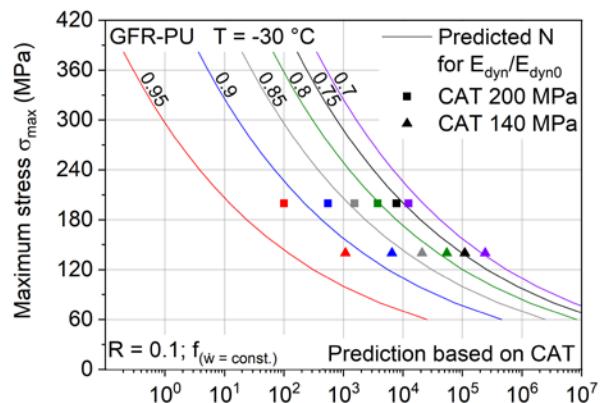


GF-EP



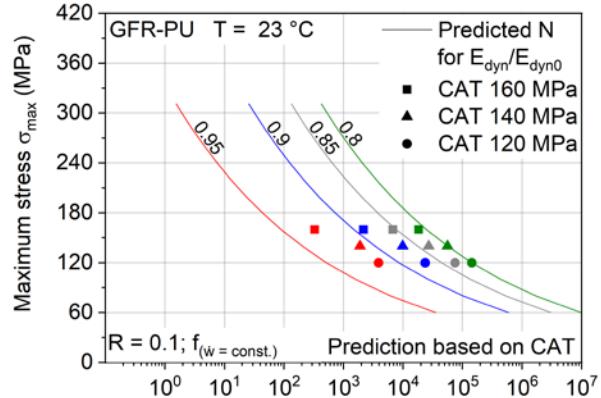
Stiffness-based lifetime estimation via Ogin

-30 °C



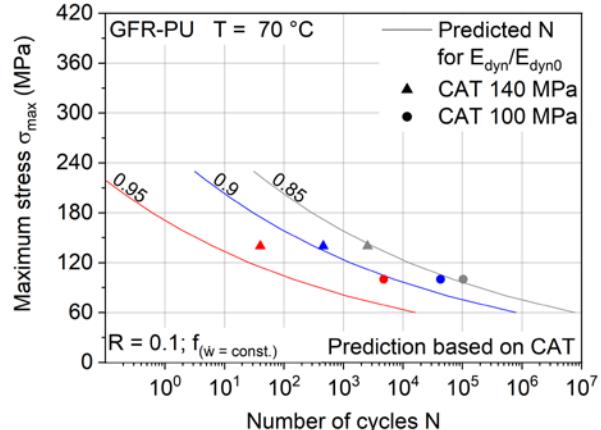
-30 °C

23 °C

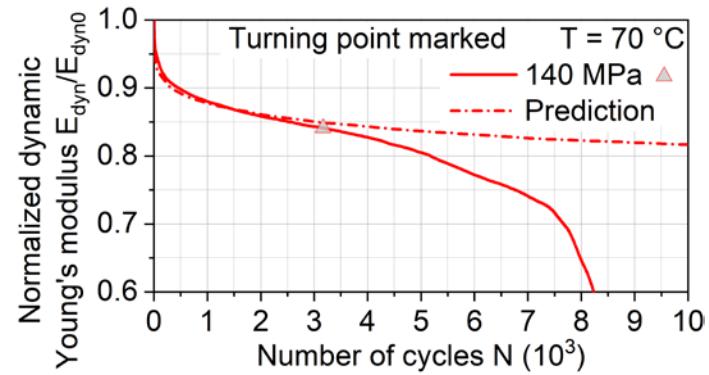
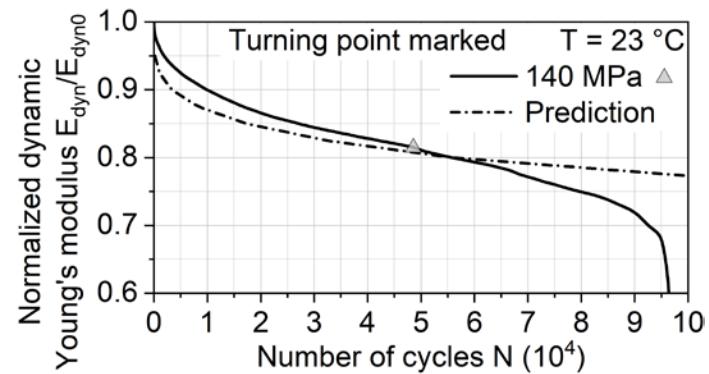
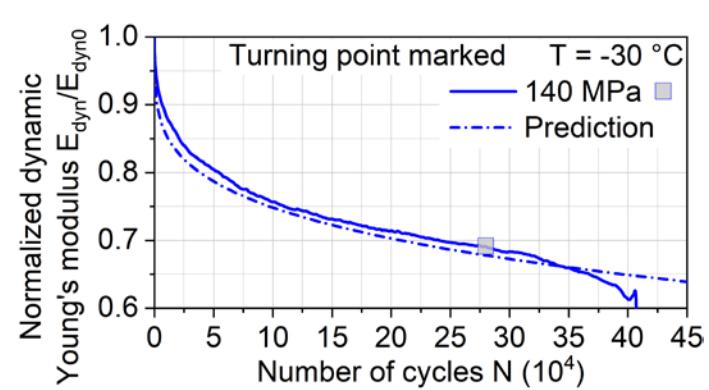


23 °C

70 °C

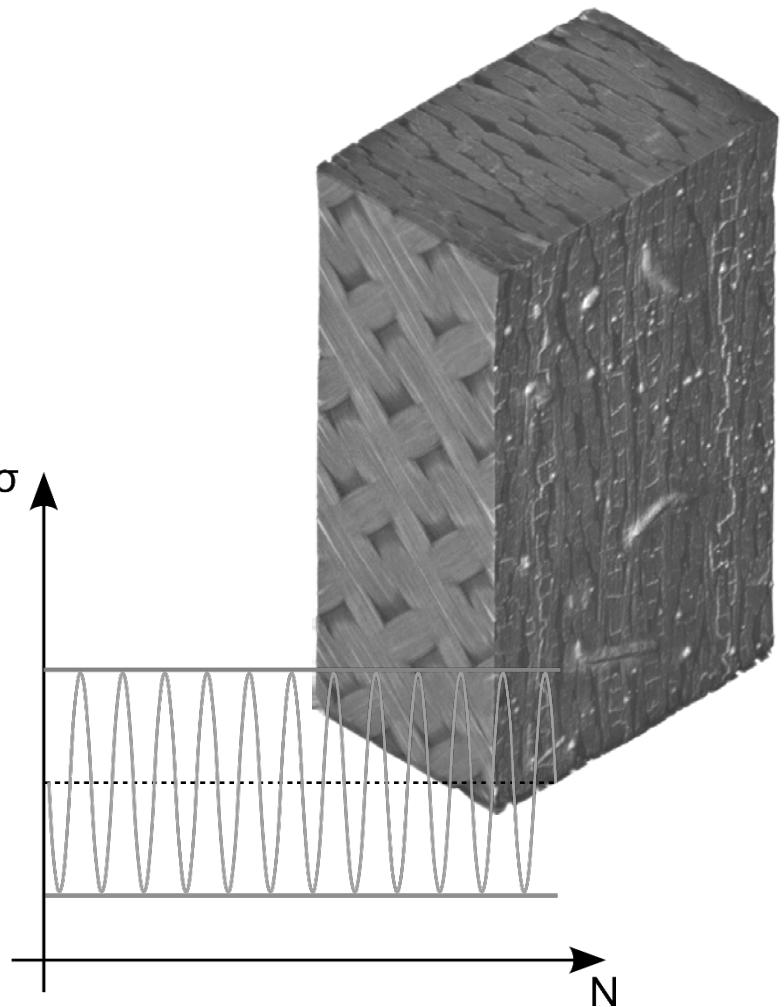


70 °C

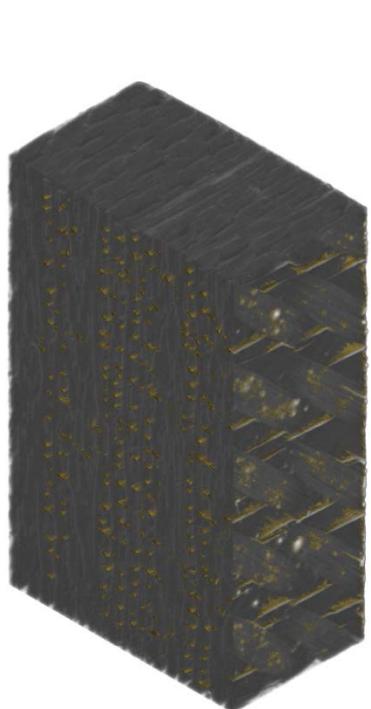


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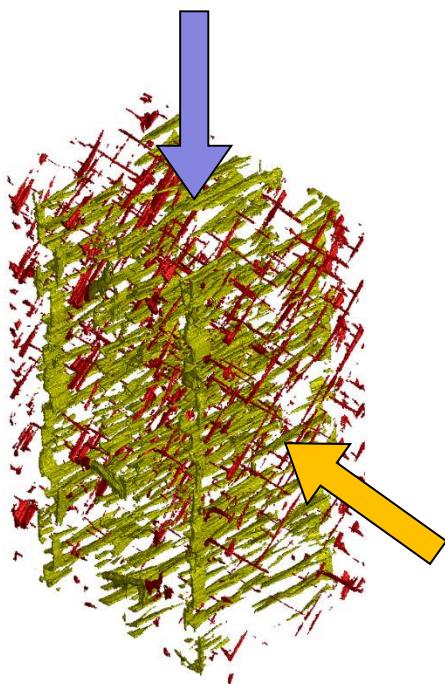
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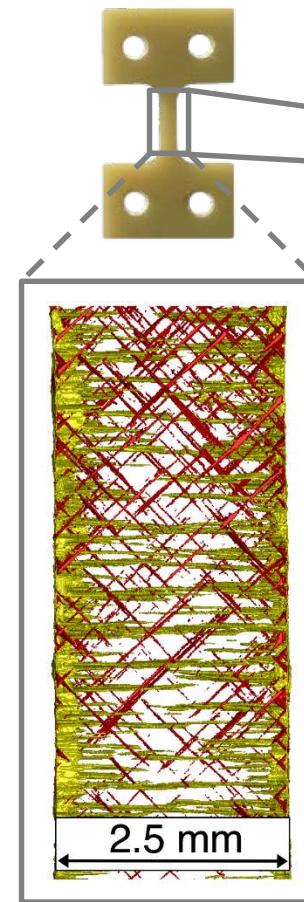
Principle for CT damage analysis



3D CT volume



Defect analysis



Front view

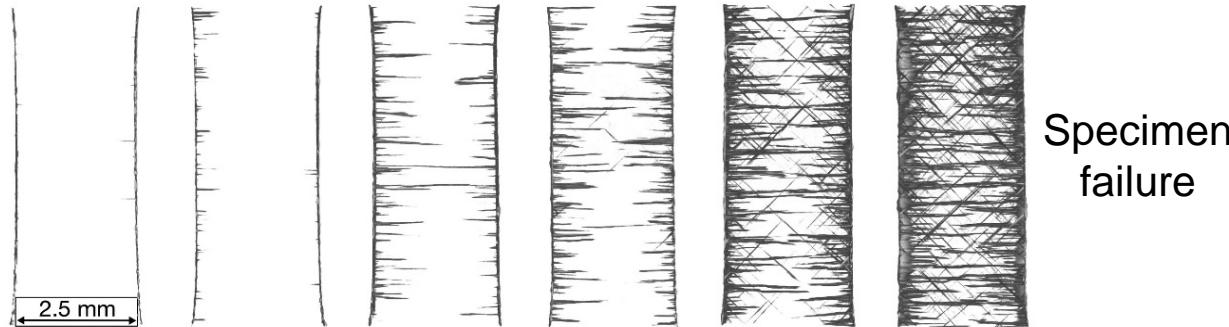


Top view



Comparison of damage development for GF-PU and -EP at 23 °C

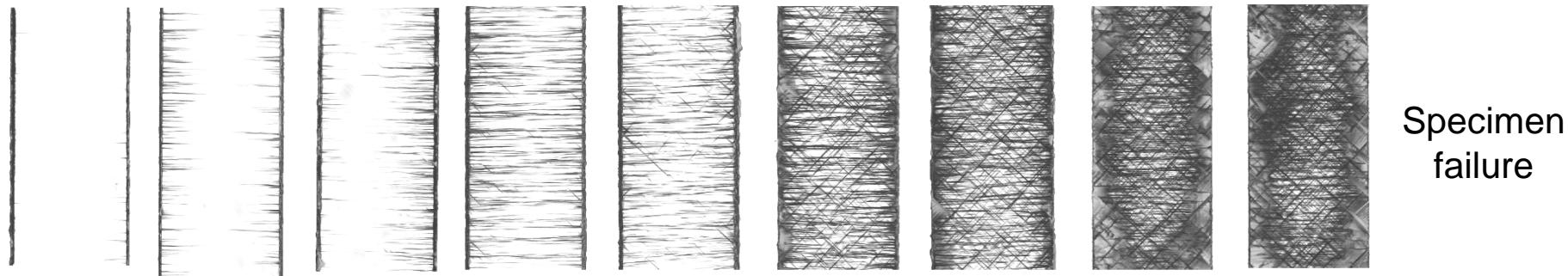
GF-PU



Specimen failure

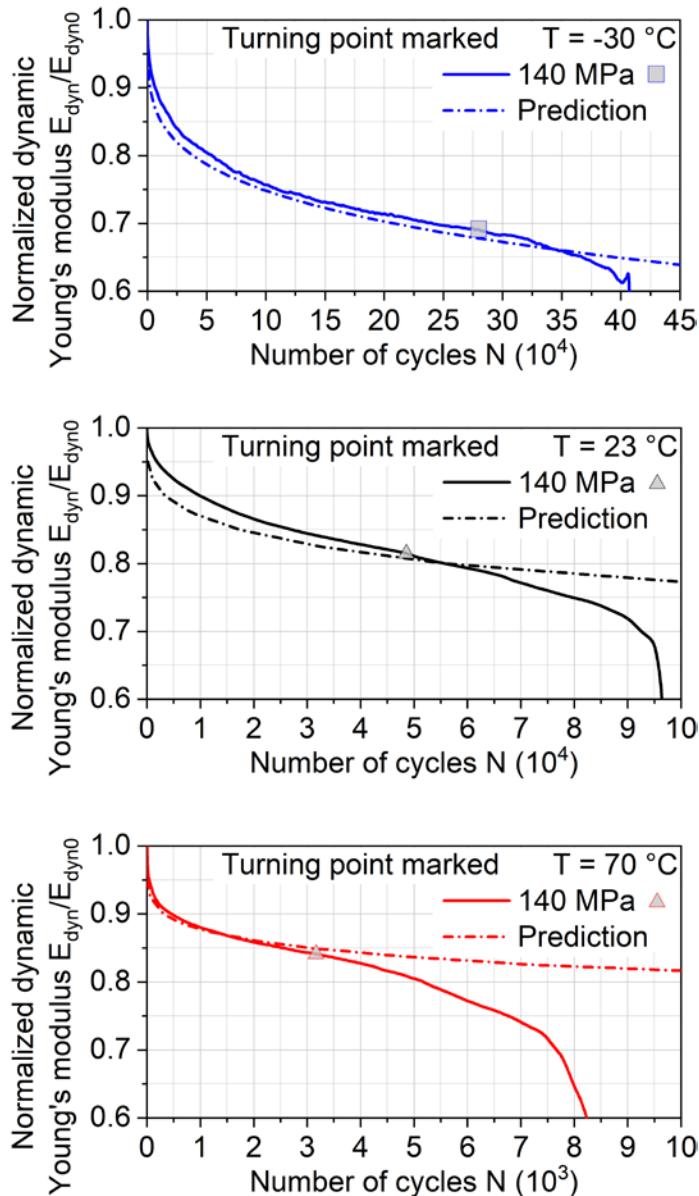
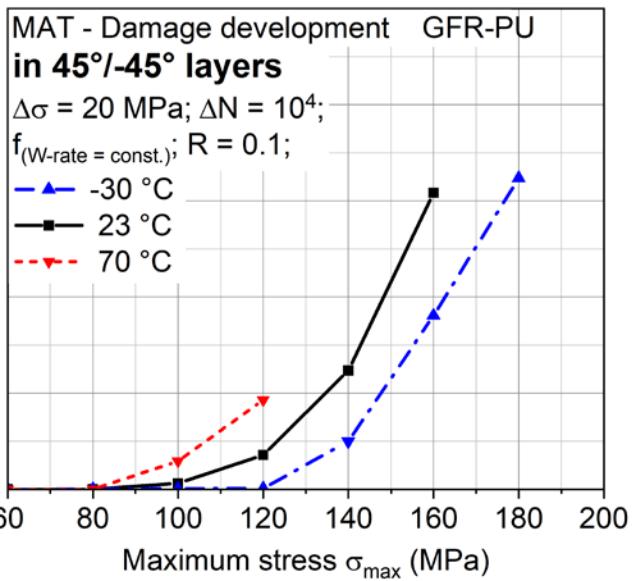
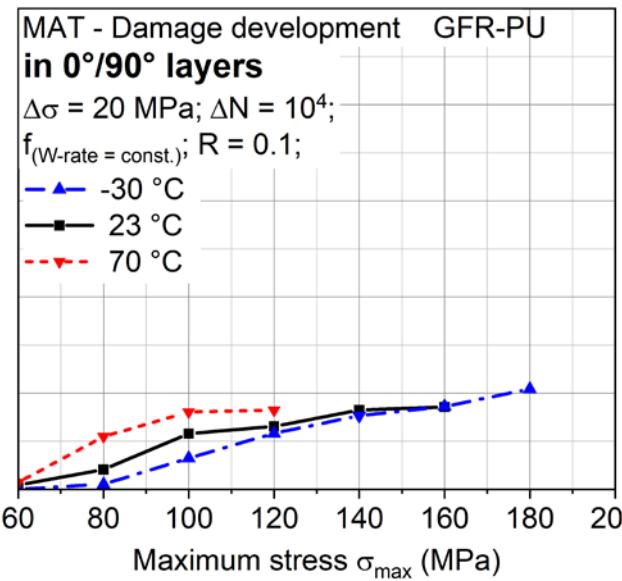
23 °C

GF-EP



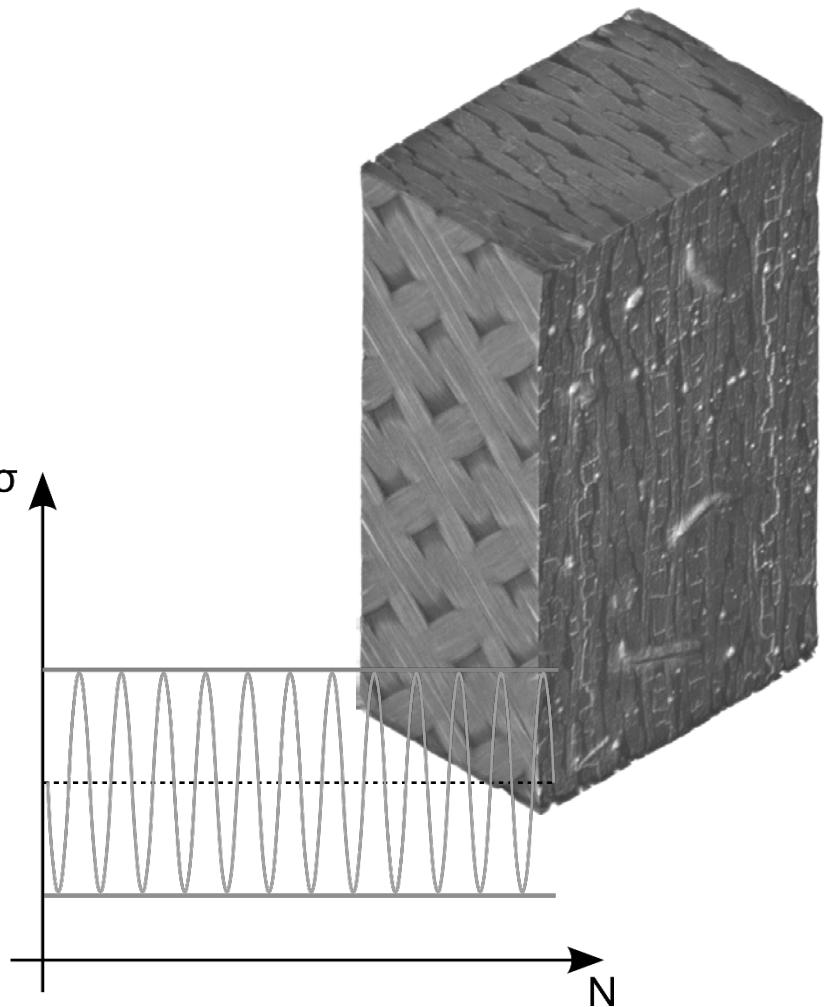
Specimen failure

Quantitative damage development for GF-PU

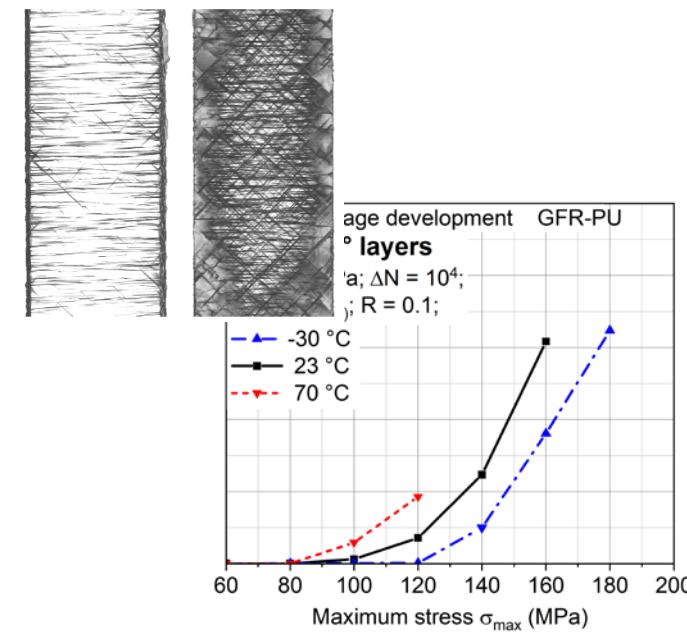
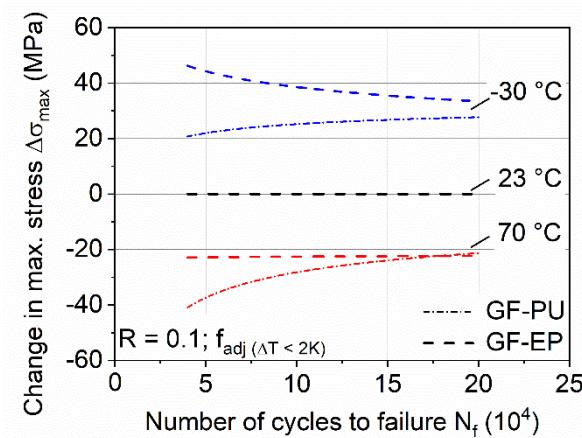
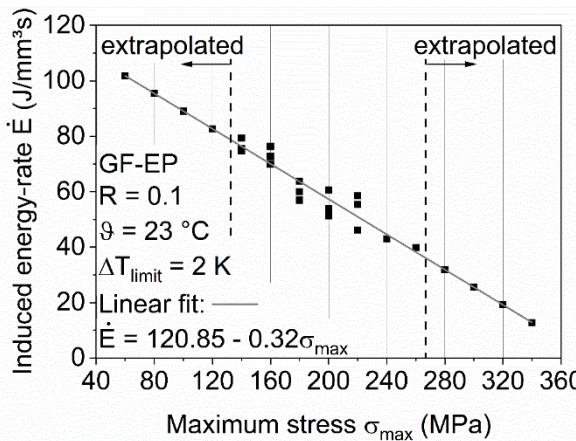


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- Energy approach for frequency selection leads to a limited increase in specimen's temperature
- Fatigue behavior
 - Epoxy exhibits significantly improved fatigue properties compared to polyurethane
 - Glass transition temperature seems to influence especially the low cycle fatigue
- Damage behavior
 - Damage development similar for each temperature
 - Damages can be separated in it's directions and layers





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QUESTIONS...?

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