CAPACITIVE SENSING OF THE FATIGUE BEHAVIOR IN COMPOSITES BY USING CARBON FIBER LAYERS

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Introduction

With the growing digitalization of products and processes, the condition monitoring of structures is gaining momentum, too. Composites are ideal for the integration of sensors due to their layered structure. However, any integration of a sensor can be a defect, and may have a negative effect on the mechanical properties [1]. To reduce these negative effects, new approaches are identified where the material properties of single carbon fibers can be used as integrated sensing function [2, 3]. A different approach is investigated in this work by using the electric and dielectric properties of the whole basic laminate of a hybrid fiber composite. This enables the monitoring of the fatigue behavior without the need of an additional sensor integration or application.

Material & Methods

Sensor principle

- Hybrid composite (epoxy with glass fiber and carbon fiber fabrics).
- Produced as a plate in resin transfer molding process (RTM).
- Plates consisted of five layers of glass fiber (GF) fabric and a layer of carbon fibers (CF) at the top and the bottom of the laminate setup, Figure 1 (ii).
- By contacting copper electrodes conductive to the carbon fibers, the structure became a capacitive sensing element. Damage due to fatigue leads to a change in capacity.

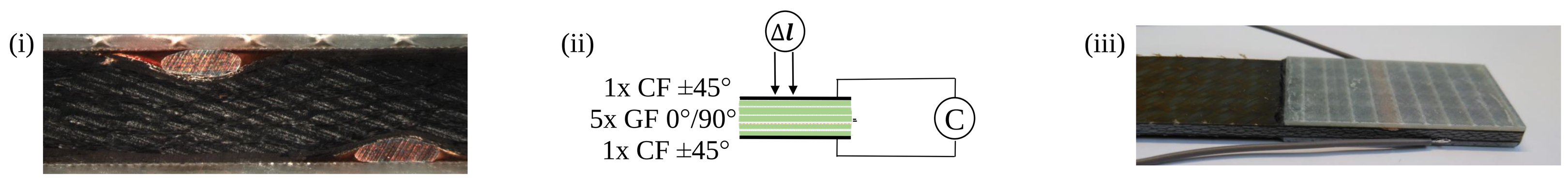

Figure 1: Electrical contacting (i) and (iii), laminate setup (ii)

Fatigue tests

- Dynamic tensile tests on a servohydraulic testing machine HC25kN, Zwick & Roell.
- Cut samples based on DIN EN ISO 527 (250 mm x 25 mm x 3 mm).
- Test parameters: ambient temperature, load ratio R = 0.1, frequency f = 5 Hz, load levels varied from 10 kN to 25 kN (31 % to 78 % of the ultimate tensile strength).

Measurement and data processing

- The capacitive signal was captured using an Analog Devices AD7746 capacitance-to-digital converter with a microcontroller connected to a computer.
- The measured values were stored in sections and evaluated continuously using frequency analysis (power spectral density PSD) as well as further methods afterwards.

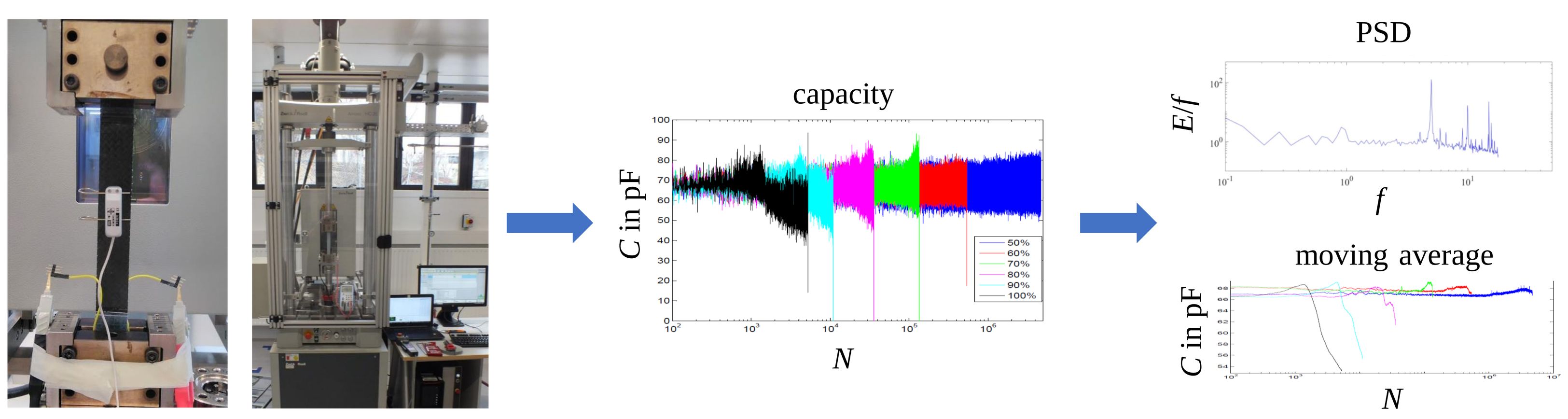

Figure 2: Test setup and steps of data processing

Determination of damage state

- Reference method: measuring of strain ε with a Clip-On extensometer and calculation of the damage parameter D by:

$$D = 1 - (\varepsilon_0/\varepsilon) \qquad \text{with} \qquad \varepsilon = \Delta l / l_0$$

  where ε_0 is the strain at the first cycle, Δl the change in length and l_0 the initial length.
- Second method: optical analysis of the edge surface with a Leica optical microscope at ultraviolet light with the fluorescent agent KD-Check FWP-1. Grey scale analysis was used to quantify the damage, Figure 3.

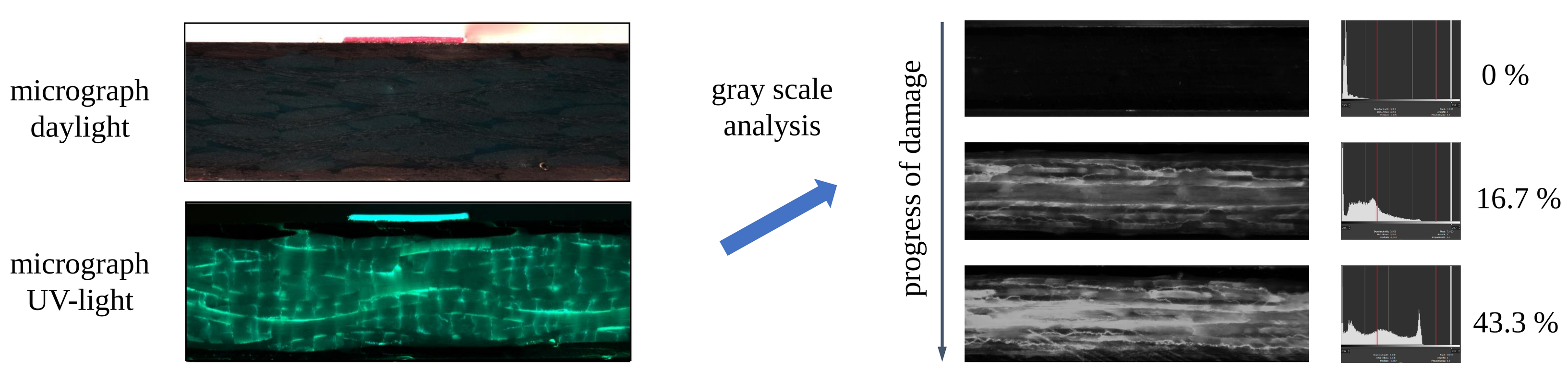

Figure 3: Grey scale analysis of the edge surface for damage evaluation

Results

- A basic correlation between sensor signal and damage evolution has been observed. The capacitance amplitude increased with increasing damage, Figure 4.
- At load levels up to 70 % of 25 kN, a linear function could be approximated between the damage evolution and the capacitive PSD amplitude at excitation frequency (5 Hz).
- Load levels above 70 % showed a geometric influence on the capacitance signal, due to a stronger deformation of the specimen at higher forces.

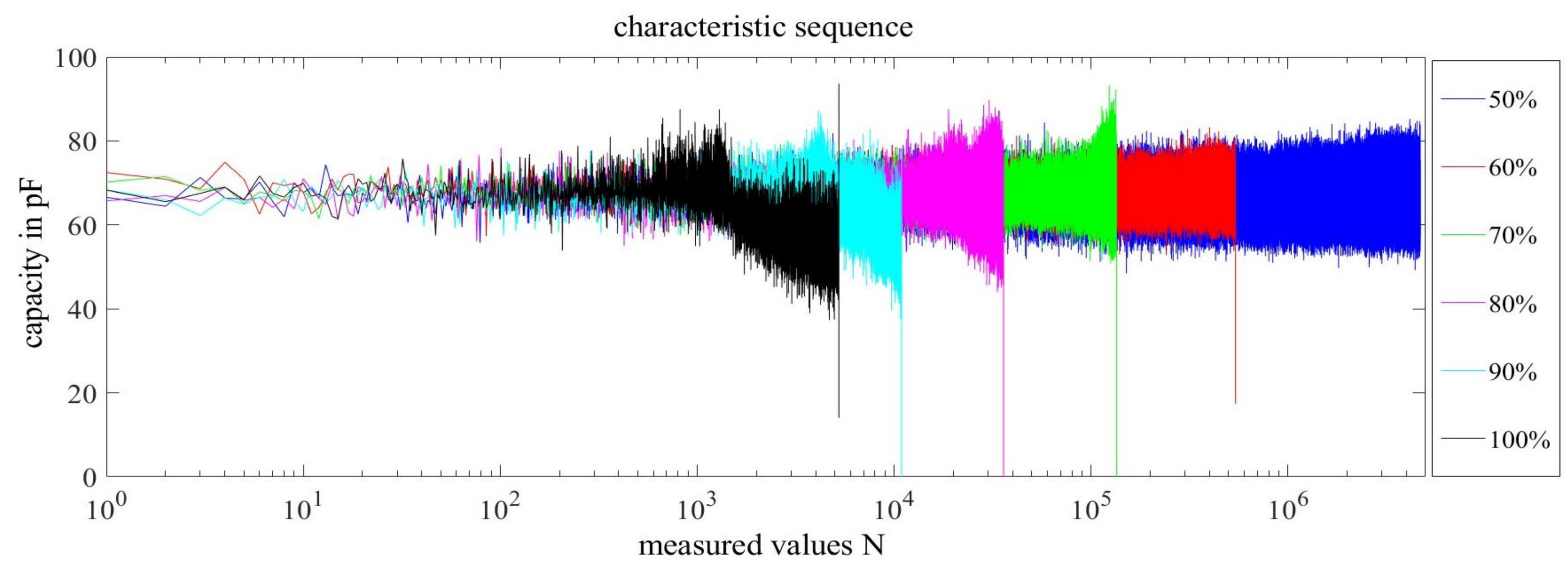

Figure 4: Development of the capacitance signal during cyclic fatigue

- **Figure 5 (i)** shows the microscopic images of the grey scale analysis of a specimen at four different numbers of load cycles N.
- The fluorescent agent also infiltrated the cracks inside the sample. Through this, and the optical transmission of the glass fiber reinforced areas, we also could observe the progress of the internal damage of the samples.
- **Figure 5 (ii)** illustrates the damage parameter D determined with the different methods.
- The reference methods (strain extensometer and microscopic analysis) showed a high correlation in the full range of the damage parameter.
- The capacitive approximation function also correlates in most of the evaluated sections. At N = 2500 cycles the geometric influence leads to a deviation of 10 %.

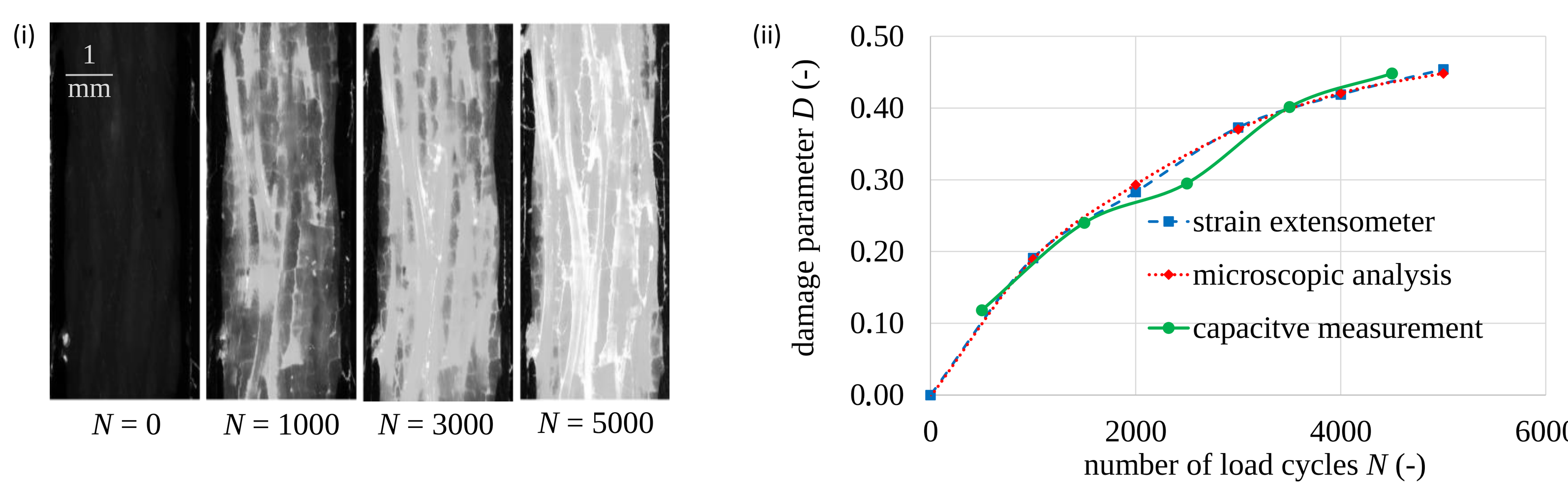

Figure 5: Damage evolution at a load level of 80 % ultimate tensile strength
(i) UV-micrographs for grey scale analysis, (ii) determined damage parameter

Conclusion

- By combining glass fibers and carbon fibers in a smart design, the electric and dielectric properties of the base materials could be used to monitor the damage state.
- The optical analysis of the edge surface, using fluorescent agents in combination with UV light, allowed the determination of the damage state and the simultaneous detection of the occurring damage modes.
- The observed capacity curves could be explained by the fatigue-induced crack propagation up to load levels of 70 %. At higher dynamic loads a tension-related geometrical impact was identified which will be part of a following investigation.

References

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