Structural Health Monitoring of Fiber Reinforced Plastics
Strukturüberwachung von Faserkunststoffverbunden

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Sensorsysteme 2014, Lichtenwalde
Outline

1. Initial Situation & Motivation
2. Goals & Approach
3. Results
   I. Functional model 1 - Textile membrane for biogas storage facilities
   II. Functional model 2 - FRP wind turbine blade
4. Conclusions & Outlook
1. Initial Situation & Motivation

- Substitution of classic construction materials by increasing usage of FRP’s in multiple application areas
- Early prediction of safety critical structural degradations in textile reinforcement structure of FRP’s becomes essential
- Reliability requires structural health-monitoring techniques (in-situ sensor systems)

Investigation 09/2013: \( \sum = 1020 \times 10^6 \text{ kg} \)

SMC, BMC
Open Mould
RTM
Continuous Processing (pulltrusion, sheets)
Winding, Casting
Hybrid-Prepreg: GMT, LFT, SFT
Others

Investigation 08/2009: \( \sum = 815 \times 10^6 \text{ kg} \)
2. Goals & Approach

- Long-term stable structure-monitoring and damage detection for FRP’s
- Textile-technological realization of tailored & structure-compatible sensor networks
- Cost- and time effective usage of textile-technological fabric generating techniques
- Integration of piezo-resistive materials during textile fabric’s production (multiaxial weaving and warp knitting)
2. Goals & Approach

- **Strain measurement principle**

Piezo-resistive effect of CF by mechanical straining; geometry change causes change in resistance

![Diagram](image)

\[
\Delta R = \frac{F}{R_0} \cdot A_0 \cdot E_{II} \cdot k = \frac{\Delta l}{l} \cdot k
\]

\[
\Delta R = \frac{U_1 - U_0}{I_0}
\]

exPAN CF-Roving
Toho Tenax®-J
HTA40
1k 67 tex 15S
2. Goals & Approach

Factors of influence on the sensory characteristics:

- carbon filament yarn (CFY)
  - elasticity
    → Toho Tenax® HTA40 1k 67tex
    \( E_{II} = 238 \text{ GPa} \)
  - resistivity
  - coupling agents or rather filament sizing

- Filament-matrix interface
  - filament-matrix adhesion
  - interaction with functional groups of matrix and/or filament
  - infiltration ability of the matrix (polymer/pressure/temperature)

- Sensor embedding (crimp)
  - textile technique related crimp in the reinforcement structure of the FRTP

Performance of CF based strain sensors in FRTP

## Overview Functional models

<table>
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<tr>
<th>Membrane for biogas storage facilities</th>
<th>FRP wind turbine blade</th>
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<td><img src="Zorg_Biogas_%C2%A9_2014" alt="Membrane" /></td>
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<td><img src="image1" alt="Woven fabric" /></td>
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### Functional model 1 (FUM1)

- Membrane for biogas storage facilities
- FRP wind turbine blade

### Functional model 2 (FUM2)

- Multiaxial weaving with ORW® technology & warp yarn shogging device
3. Results (FUM1)

3.1 Specification of textile reinforced membranes for biogas storage facilities

- Basic structure: single-layer woven fabric
- Dimensioning of sensor structure: 2D layouts with reachable basic resistances \( R_0 = (100...1000) \Omega \)
- Usage of CF as warp & weft yarns and for additional warp yarn shogging
- CF trassing in 0° direction to serial interface on membrane’s geometrical periphery
3. Results (FUM1)

3.2 Sensor integration by weaving with ORW® technology

- Multiple warp yarn shogging device
- Lateral move = ± 150 mm
- Working width = 1,035 mm
- Basic fabric: 1.400 x PES 1.100 dtex, plain weave
- Warp/weft density: 10/9 cm⁻¹
- Sensor material: CF 1k; 67 tex

Detail A: linear drive unit with needle bar and Open Reed Weave (ORW®)

Detail B: needle bar with CFY in open shed position
3. Results (FUM1)

3.3 Manufacturing of membranes with integrated CF sensors

- Woven fabric 200x200 mm²,
- Meandering CF sensors with $R_0 \approx 700 \, \Omega$
- Hand lamination with 2C silicone rubber
- 2-layer laminat $[-90^\circ_{CF}, 0^\circ, 90^\circ]_2$ with 2 meanders in $0^\circ/90^\circ$ direction
3. Results (FUM1)

3.4 Sensor behaviour during cyclical in-plane shear stressing

- Stress-depending sensor signal of CF strain sensor (WHEATSTONE bridge) integrated in GF reinforced VMQ membrane

Membrane’s relaxation measured with load cell

Membrane’s transient strain measured with integrated CF sensors
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**Functional model 1 (FUM1)**

**Functional model 2 (FUM2)**
3. Results (FUM2)

3.5 Specification of textile reinforced small wind turbine blade

- Design and composite construction of small wind turbine blade
- Half shell segments with tension and compression flanges (no main beam)
- Accumulated strain measurement along integrated CF sensor's length
3. Results (FUM2)

3.6 Adaption multiaxial warp knitting technique for 2D sensor integration

- Patended warp yarn shogging device for multiaxial warp knitting machines
- GF Triax NCF [0°, +45°, -45°] for blade’s tensile flanges with integrated CF sensors
- GF Biax NCF [+45°, -45°] for blade’s half shells
- Sensor material: CF course-oriented linkage of sensor & NCF
3. Results (FUM2)

3.7 Final assembly of small wind turbine blade

Blade with integrated CF sensor system for spatially resolved strain measurement

Detail: CF sensor aligning FRP wind turbine blade

Detail: Electrical contacting within blade’s root

Pre-cut & Drapery (II)

VAP Infiltration & Curing (III)

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3. Results (FUM2)

3.8 Rotor resistance change under constant loading

![Graph showing rotor resistance change under constant loading.](image)
4. Conclusion & Outlook

- Realization of 2 functional FRP models: wind turbine blade and membrane with integrated CF sensors for SHM
- Good correlation between mechanical stress and measured change in resistance
- Outlook: Measurements under biaxial and dynamic loading scenarios
5. Appropriation of funds

The IGF project 17529BR/1 of the Forschungsvereinigung Forschungskuratorium Textil e. V is funded through the AiF within the program for supporting the „Industriellen Gemeinschaftsforschung (IGF)“ from funds of the Federal Ministry of Economics and Energy (BMWi) by a resolution of the German Bundestag.

The ITM would like to thank all the mentioned institutions for providing funds.
6. Acknowledgment

We would like to thank all members of the committee accompanying the project IGF17529BR/1 for their technical support and the provision of test materials.

Last but not least, many thanks to all of our colleagues and students (Mr. cand. Ing. Ralf Müller) for their support within the context of our research in this application area.
MULTIFUNCTIONAL FIBER-REINFORCED PLASTICS WITH INTEGRATED TEXTILE-BASED SENSOR AND ACTUATOR NETWORKS

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Thank you very much for your attention