North American Pultrusion Conference

Determination of real life aging on construction products made of glass fibre reinforced plastics (GFRP)

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ACMA American Composites Manufacturers Association | EPTA

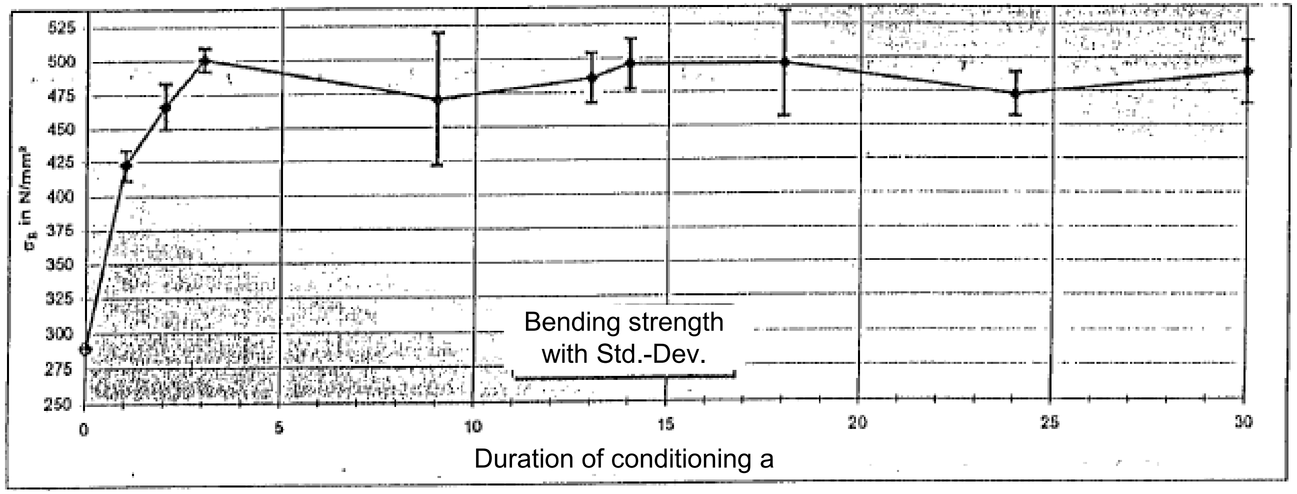
Content

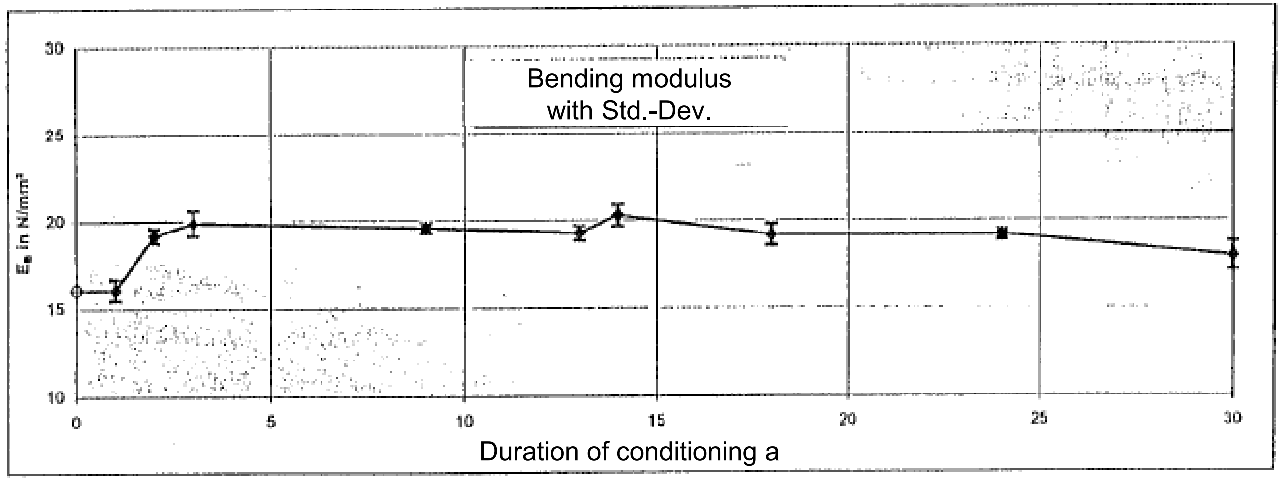
History: GFRP Antenna Carrier for a Radio Tower

Monitoring of the GFRP structure by:

- Samples exposed at antenna ("witnesses“) over a period of 24 years
- Final testing at samples cut out of GFRP antenna 30 years after installation

Television tower of Dresden, built 1969





Source: IMA Dresden, AVK Conference 1999

Factors on Aging of GFRP

Long-term behaviour

- For the construction industry GFRP-components are designed for service lives of up to 100 years.
  - During service live: changing material properties must be taken into account
    - Suitable approach from standard DIN EN 13121-3: **Factors of influence:**

- A_1: **Manufacturing** on the laminate (for advanced design: A_1 = 1.0)
- A_2: **Medium** or **environment** on the laminate
- A_3: Design **temperature** on the laminate
- A_4: **Dynamic** (cyclic) **load** on the laminate
- A_5: **Load duration** on the laminate
- A_6: Ionising **radiation**

→ Goal for design: $E_d \leq R_d$

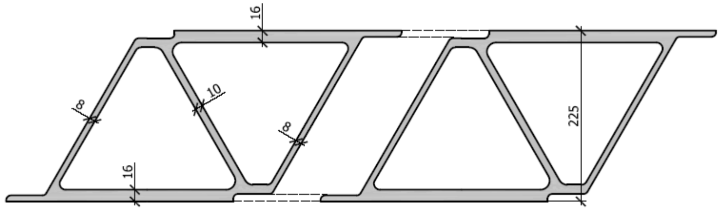
E_d … Design value of the stresses
R_d … Load-bearing resistance
E_i … Load effect
R_k … Laminate resistance
γ_F … Portion factor of variable impacts
γ_M … Portion factor for material (= 1.4)

$$E_d = A_5 \cdot E_i \cdot \gamma_{F,i} \leq R_d = \frac{R_k}{\gamma_M \cdot A_1 \cdot A_2 \cdot A_3 \cdot A_4 \cdot A_6}$$

GFRP profiles in cooling tower

Case Study 1: GFRP-Bridge

- 1st road bridge with GFRP structure in Germany
- Built in 2004 with asset profiles of manufacturer Fiberline Composites A/S
- Pre-assembly at manufacturer, final installation with on-site



GFRP-bridge: During installation; Source: Fiberline A/S

GFRP-bridge after installation;
Source: Fiberline A/S

Adhesive bonding of GFRP-bridge;
Source: Fiberline A/S

Case Study 1: GFRP-Bridge

IMA Services:

- Materials and Component testing
- Manufacturer inspection with Inspection of pre-assembly
- Inspection of insertion and adhesion
- Measurement of the bridge deformation at load of 20 t
- "Witness" samples for long-term monitoring

GFRP-bridge: After installation with Truck (weight approx. 20 t); Source: IMA

Witness samples inside the bridge; Source: IMA

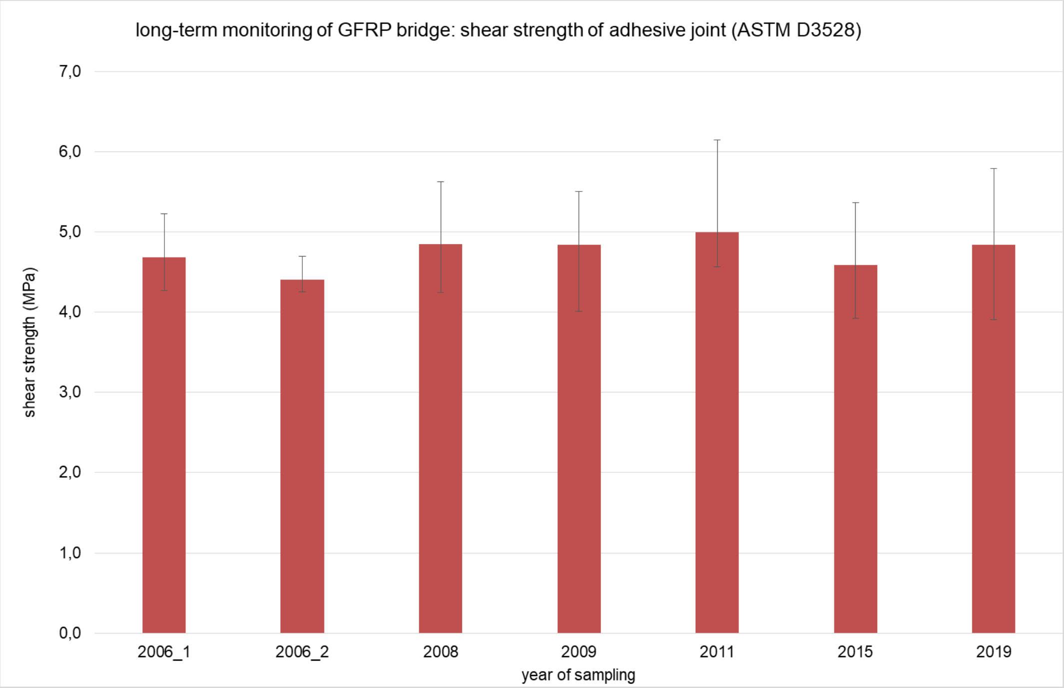
Test plan of witness samples:

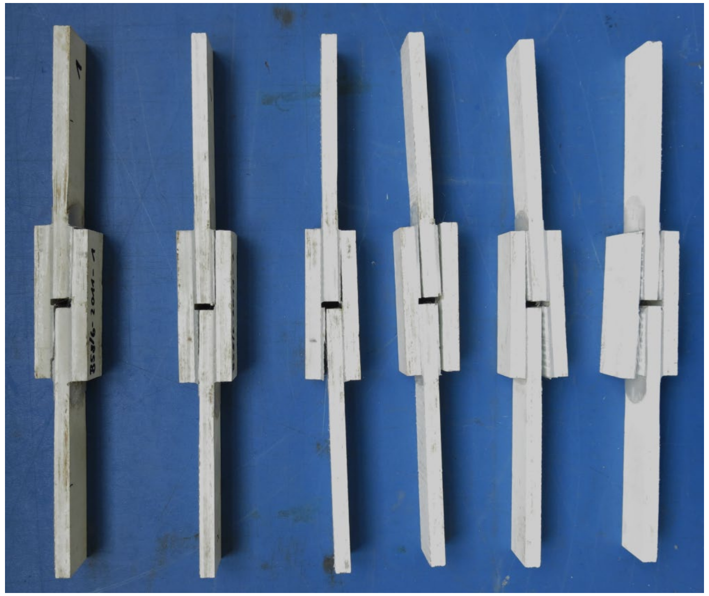
Test / year	2006	2008	2009	2011	2015	2019	2023	2028	2033	2038
DLS	x	x	x	x	x	x	x	x	x	x
Bending	x		x	x	x	x	x	x	x	x
Creep				x		x		x		x

Case Study 1: GFRP-Bridge

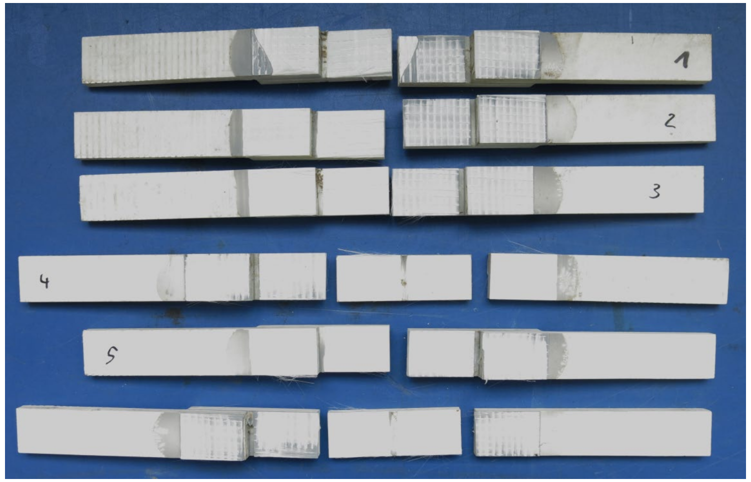
Bonding properties for practice-aged samples:

- Double lap shear test (DLS) following ASTM D 3528
- Test until shear failure of adhesive





DLS-samples before the test

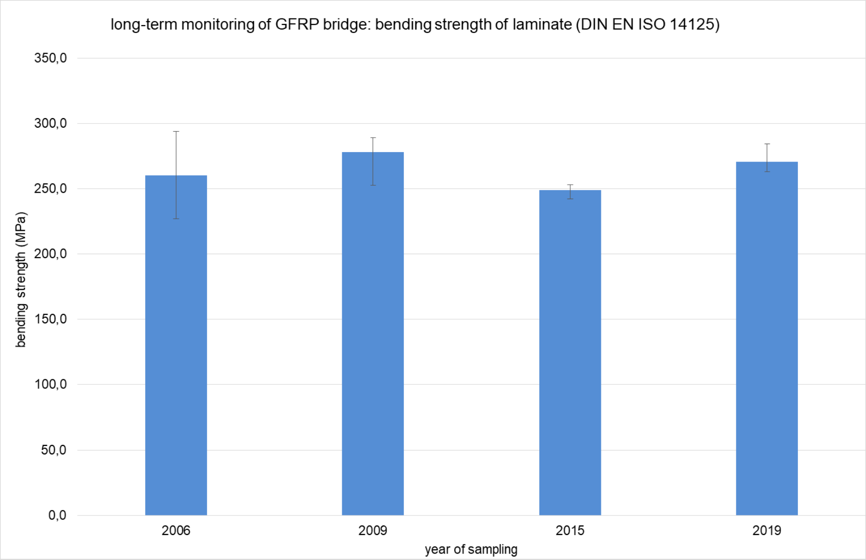


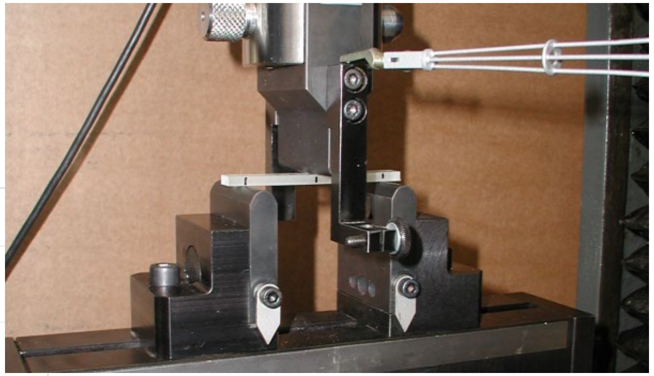
DLS-samples after the test

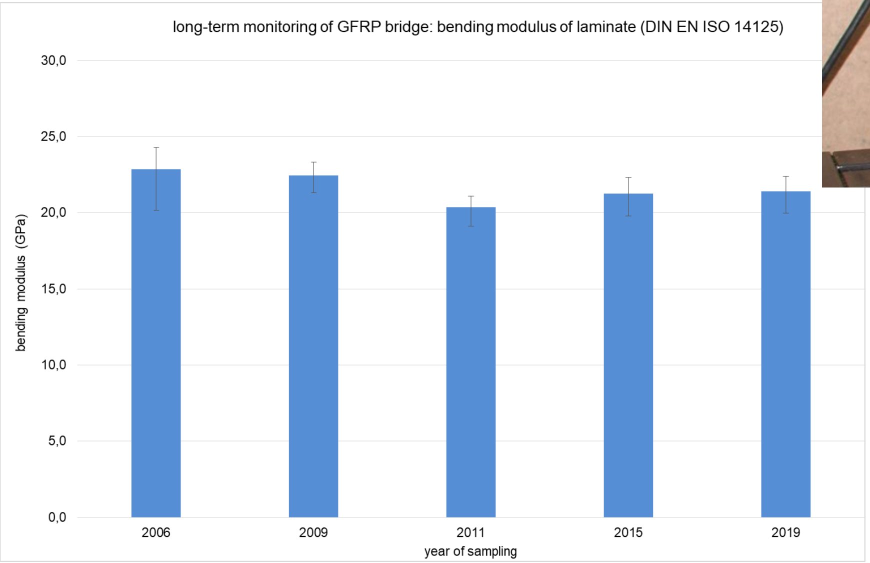
Case Study 1: GFRP-Bridge

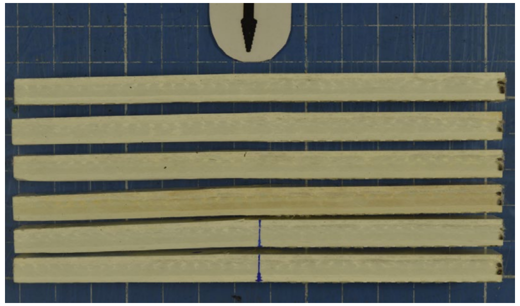
Material properties for practice-aged samples:

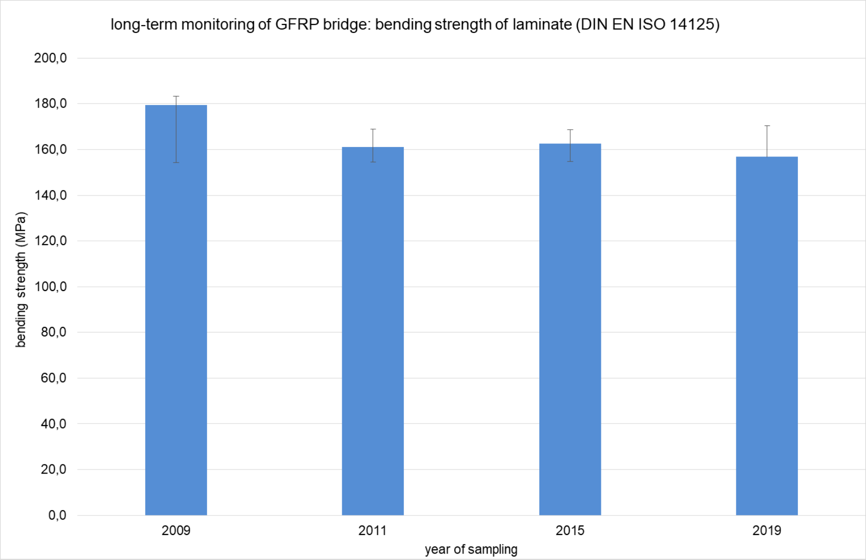
- Samples taken from tested DLS-samples
- 3-point bending test following DIN EN ISO 14125
- Test until sample failure











Case Study 1: GFRP-Bridge

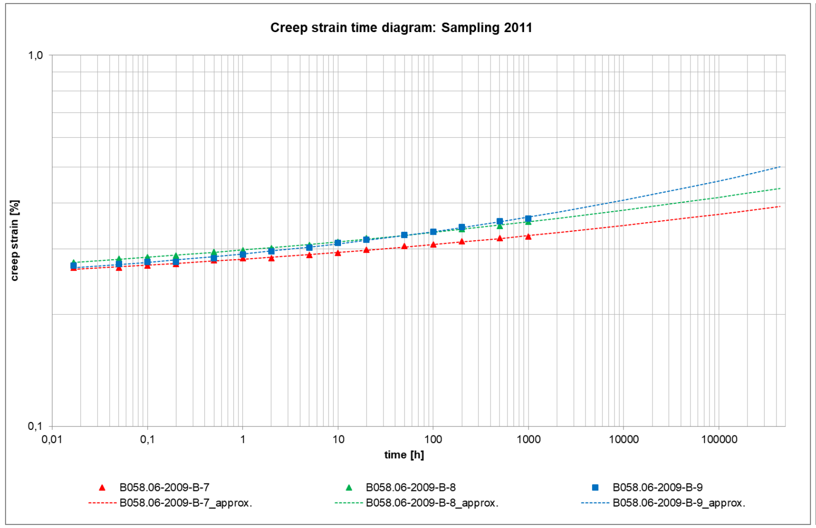
Stiffness properties for practice-aged samples:

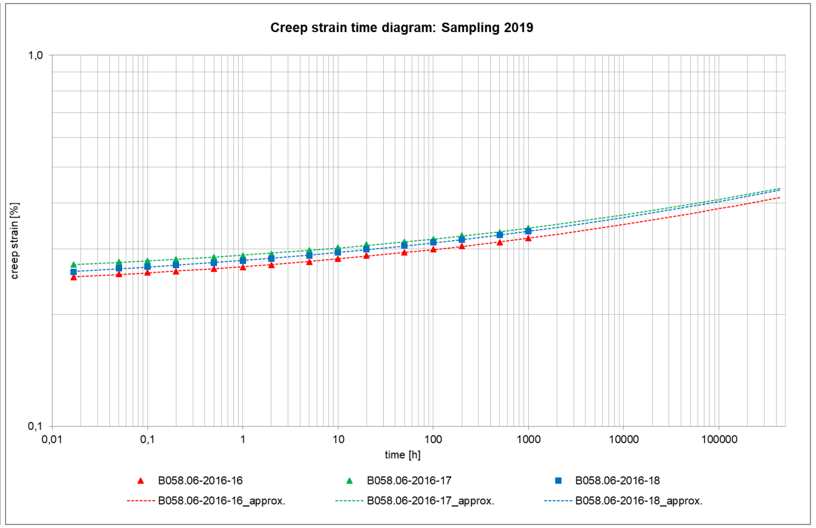
- Creep test
- 3-point bending
- Test duration: 1000 h
- Load level:
  35% of static strength
- Approximation using:
  3-parameter-exponentiation approach acc. Findley

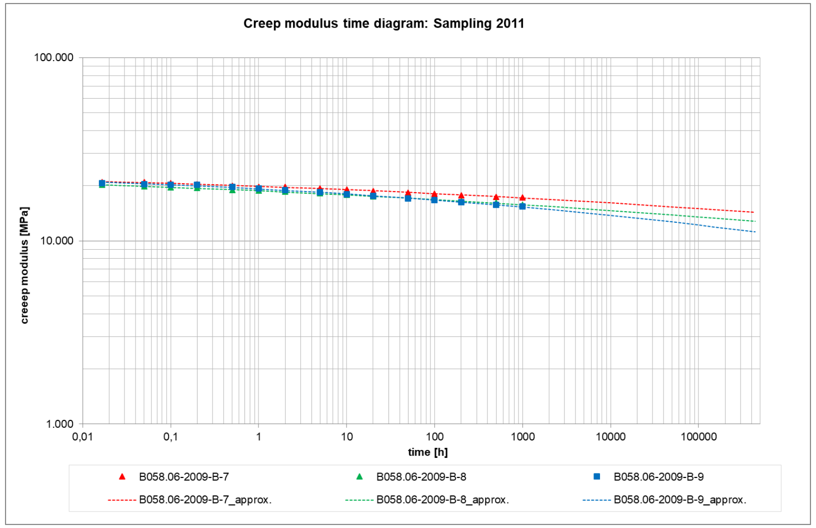
y variable for elongation (mm)

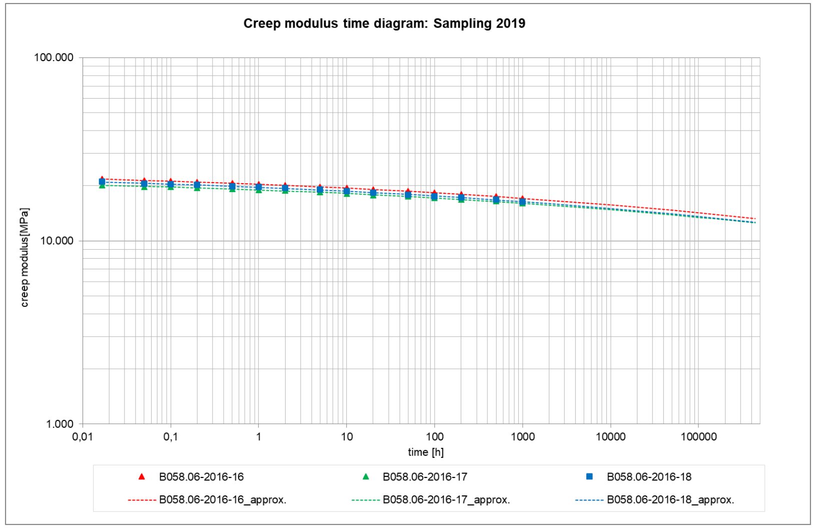
x variable for test time (h)

k_1, k_2, k_3 constants



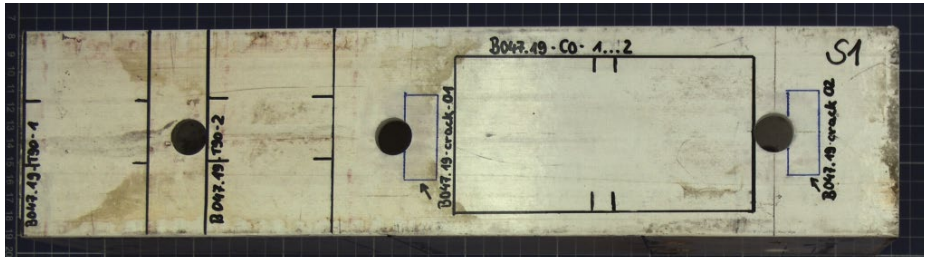




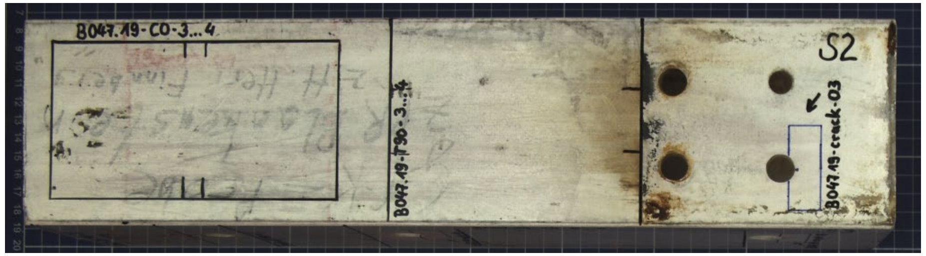


Case Study 2: GFRP-Structured Cooling Tower

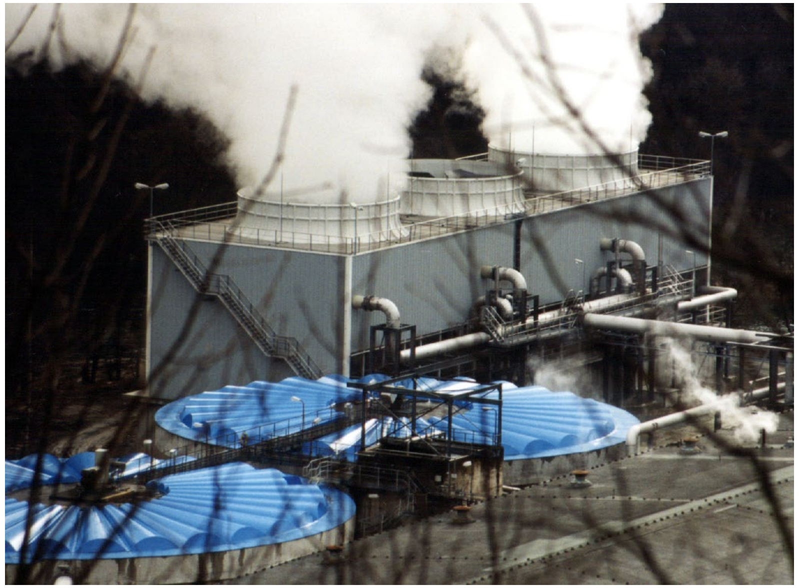
- 1st cooling tower with GFRP structure in Germany (Wet cooling tower with forced venting system)
- Built in 1999 with regular profiles of manufacturer Fiberline Composites A/S
- After approx. 20 years of service life, square-tube GFRP profile 100 x 100 x 8 mm were removed from the structure for testing



GFRP profile 100 x 100 x 8 mm with drill holes and markings for sampling



Structure of cooler tower with GFRP-profiles; Source: Fiberline A/S

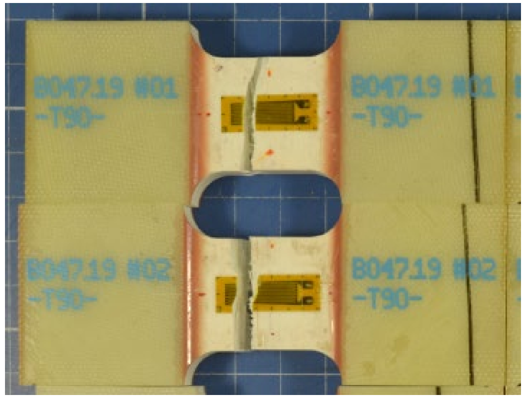


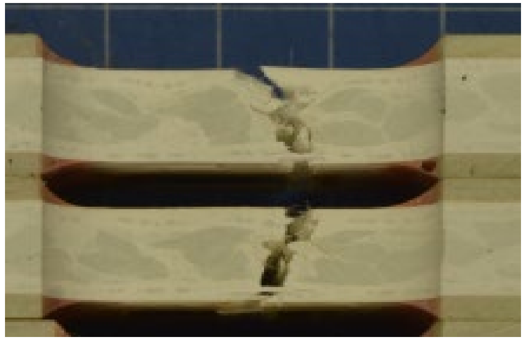
Cooling tower of pulp and paper mill; Source: Fiberline A/S

Case Study 2: GFRP-Structured Cooling Tower

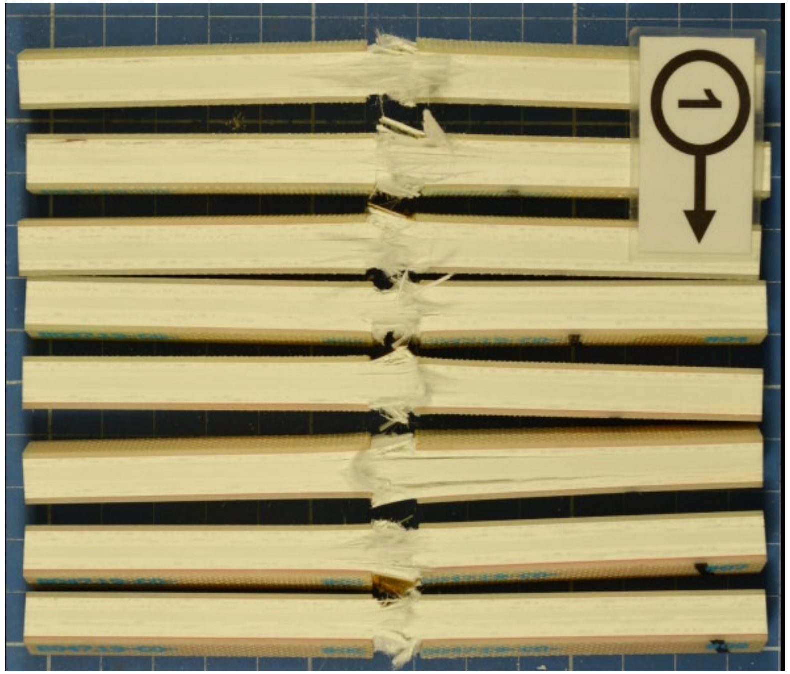
Material Testing at Standard Climate of:

- Tensile test perpendicular to profile direction following DIN EN ISO 527-4



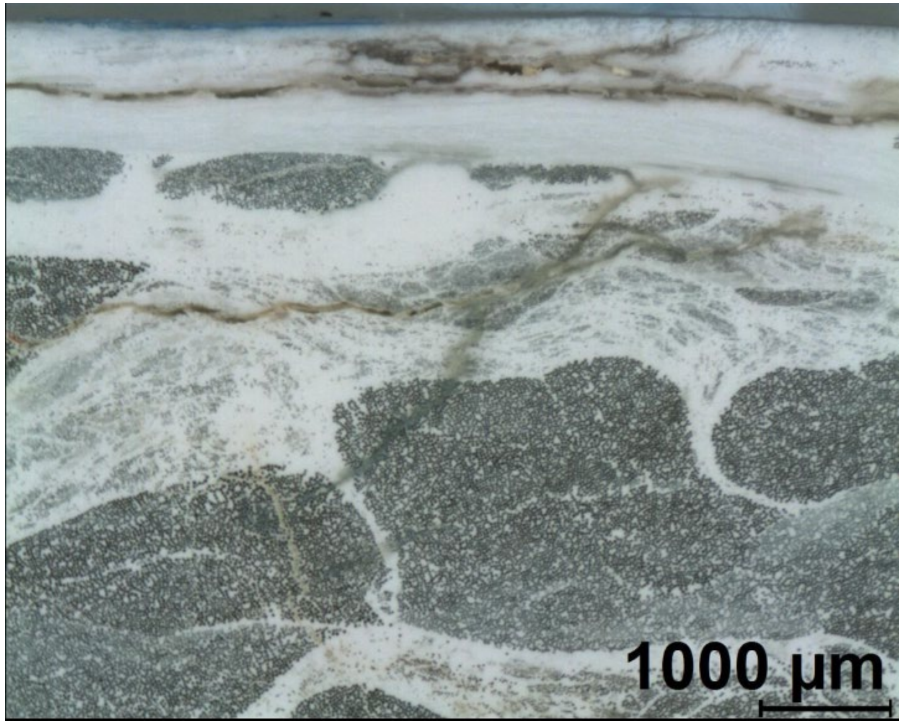


- Compression test parallel to profile direction



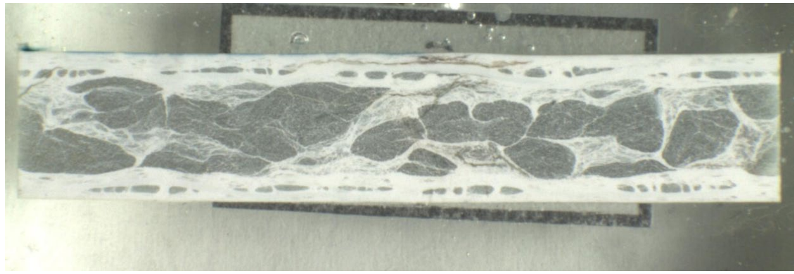
Case Study 2: GFRP-Structured Cooling Tower

Microscopy in the Area Surrounding the Drill Holes



Cutting depth approx. 1,4 mm

Cutting depth approx. 5,2 mm



- Crack depth is generally not large
- Negative influence of the cracks and delaminations on the load-bearing capacity of the profiles can be excluded
- Growth of the cracks to give a negative effect on load-bearing capacity is not expected

Case Study 2: GFRP-Structured Cooling Tower

Comparison of design values with properties after 24 years of use

- For dimensioning of structures made of GFRP creep and aging effects shall be taken into account at least via the following influencing factors:

  A_1: Duration of exposure
  A_2: Media influence
  A_3: Ambient temperature

- For determination of the total reduction factor for strength and stiffness, the following approach was used, with the DIN 18820-2 valid during the construction of the cooling tower:

  $A_F = A_{F1} \times A_2 \times A_3$ or $A_E = \times A_2 \times A_3$

- For construction profiles of company Fiberline A/S the following factors can be set for service life of 24 years:

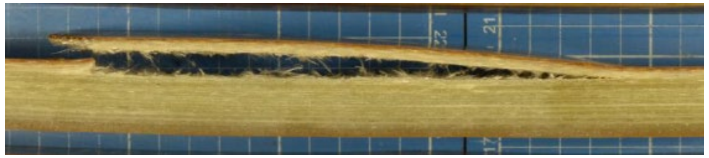
Strength parallel to profile direction:	$A^F = A^F{}_1 \times A_2 \times A_3$	= 1,3 x 1,2 x 1,1 = 1,72
Stiffness parallel to profile direction:	$A^E = \sqrt{A_1^E} \times A_2 \times A_3$	= 1,13 x 1,2 x 1,1 = 1,50
Strength perpendicular to profile direction:	$A^F = A^F{}_1 \times A_2 \times A_3$	= 1,9 x 1,2 x 1,1 = 2,50
Stiffness perpendicular to profile direction :	$A^E = \sqrt{A_1^E} \times A_2 \times A_3$	= 1,38 x 1,2 x 1,1 = 1,82

- Determined influencing factors after a service life of 24 years are within the permissible properties of the profile

Case Study 3: GFRP-Pipe at Power Plant

- Application clean gas channel (CGC) in coal power plant
- Use of GFRP since 1980
- GFRP have been used successfully applications with increased corrosive stress such as media pipes
- Issue: bubbles inside CGC
  - Root cause:
    formed in intermediate layers, when the substrate laminate is wrapped on a previously fully cured chemical protective layer
  - Mechanism:
    different coefficients of thermal expansion + thermal expansion + expansion of penetrated liquid
  - Additional effect:
    If insufficient adhesion between the layers, cavities are formed (bubbles on the surface)

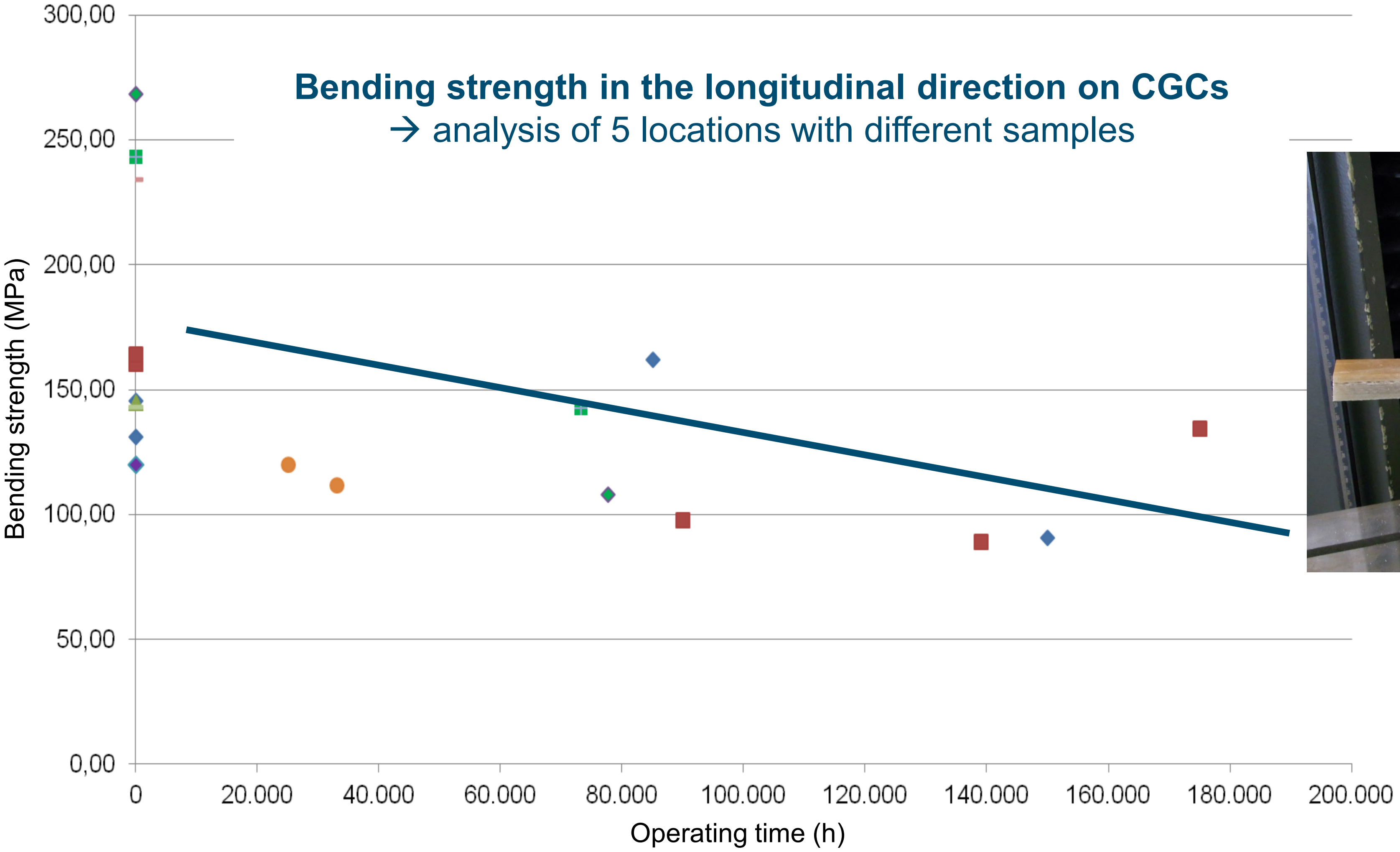
Bubbles inside clean gas channel (CGC)

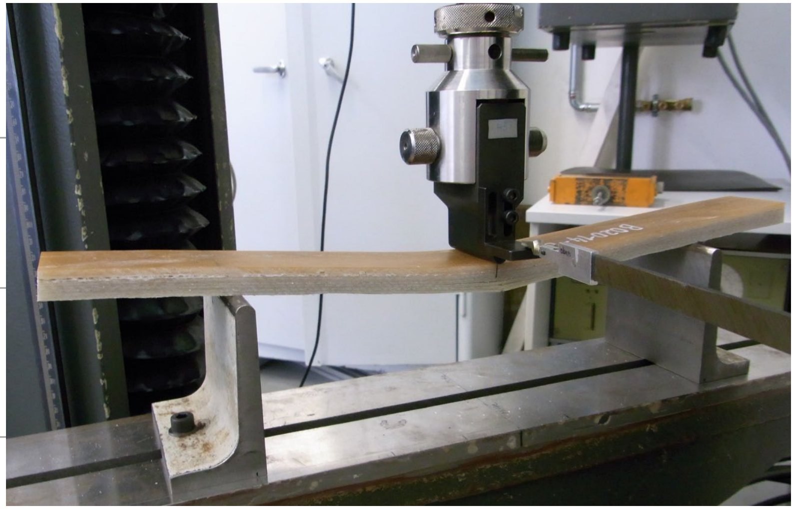


Cross section of bubble

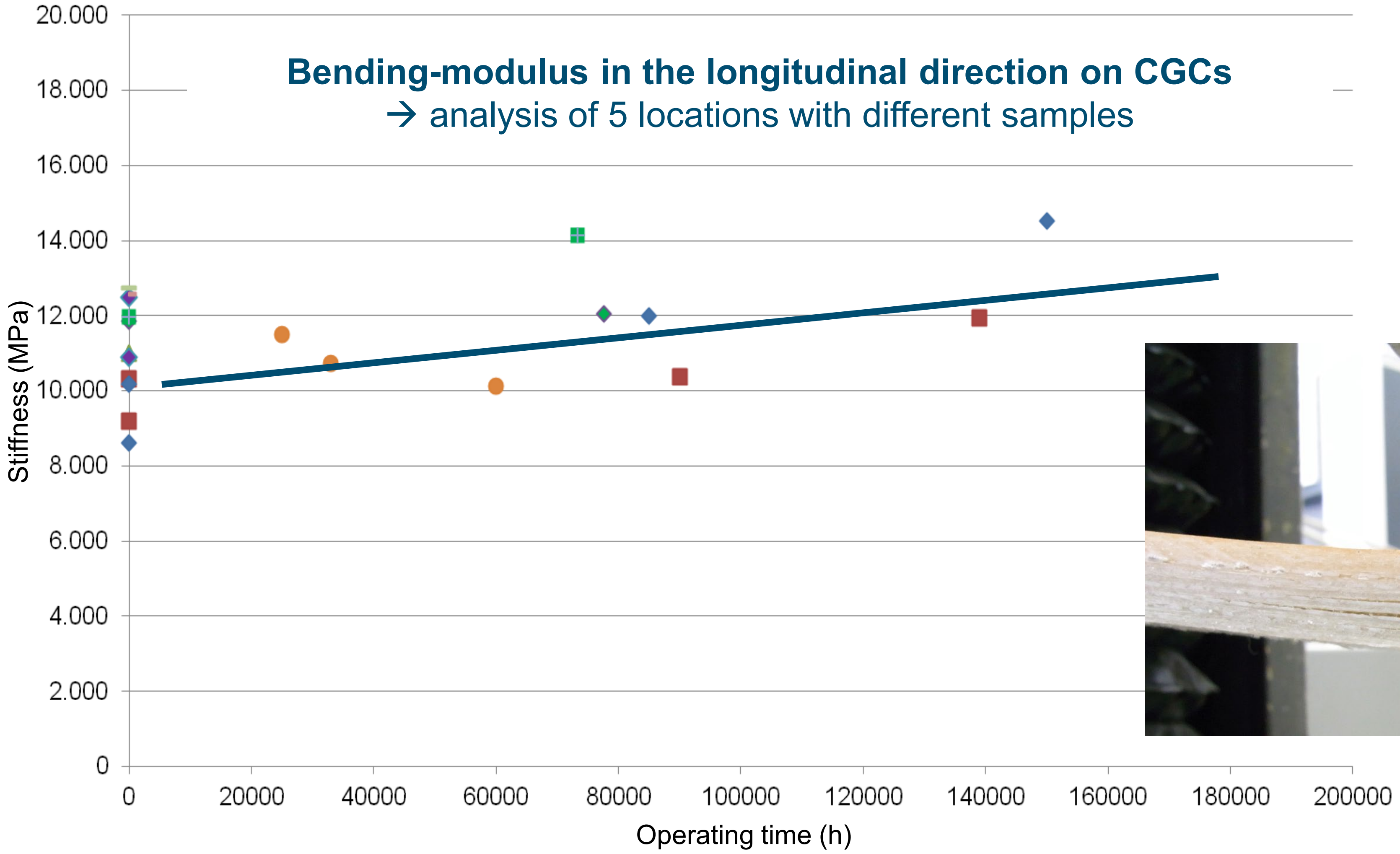
Clean gas channel (CGC) in brown coal power plant

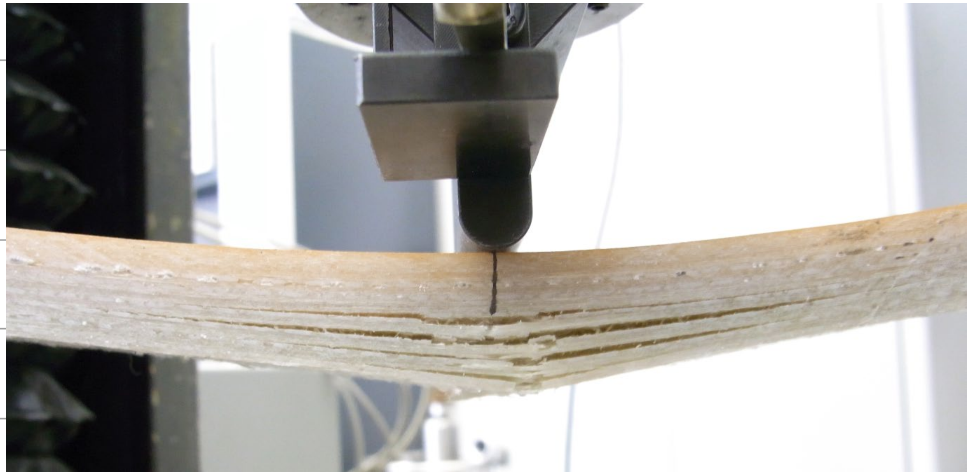
Case Study 3: GFRP-Pipe at Power Plant





Case Study 3: GFRP-Pipe at Power Plant





Case Study 3: GFRP-Pipe at Power Plant

Comparison of design values with properties after 20 years of service life

- Following characteristics were set for the laminate with given lay-up structure:
  - Bending modulus (circumferential direction): 20.000 MPa
  - Bending modulus (longitudinal direction): 11.000 MPa
  - Bending strength (circumferential direction): 420 MPa
  - Bending strength (longitudinal direction): 145 MPa
  - Creep tendency (longitudinal direction): < 8%
- Factors of influence: A1 (long-term load) = 1,4
  A2 (media) = 1,33
  A3 (temperature) = 1,35 → total reduction factor of $A_1 \times A_2 \times A_3 = 2.51$ can be derived

→ Calculation of the reduction using factors of influence, CGC after 175,000 operating hours:

circumferential direction

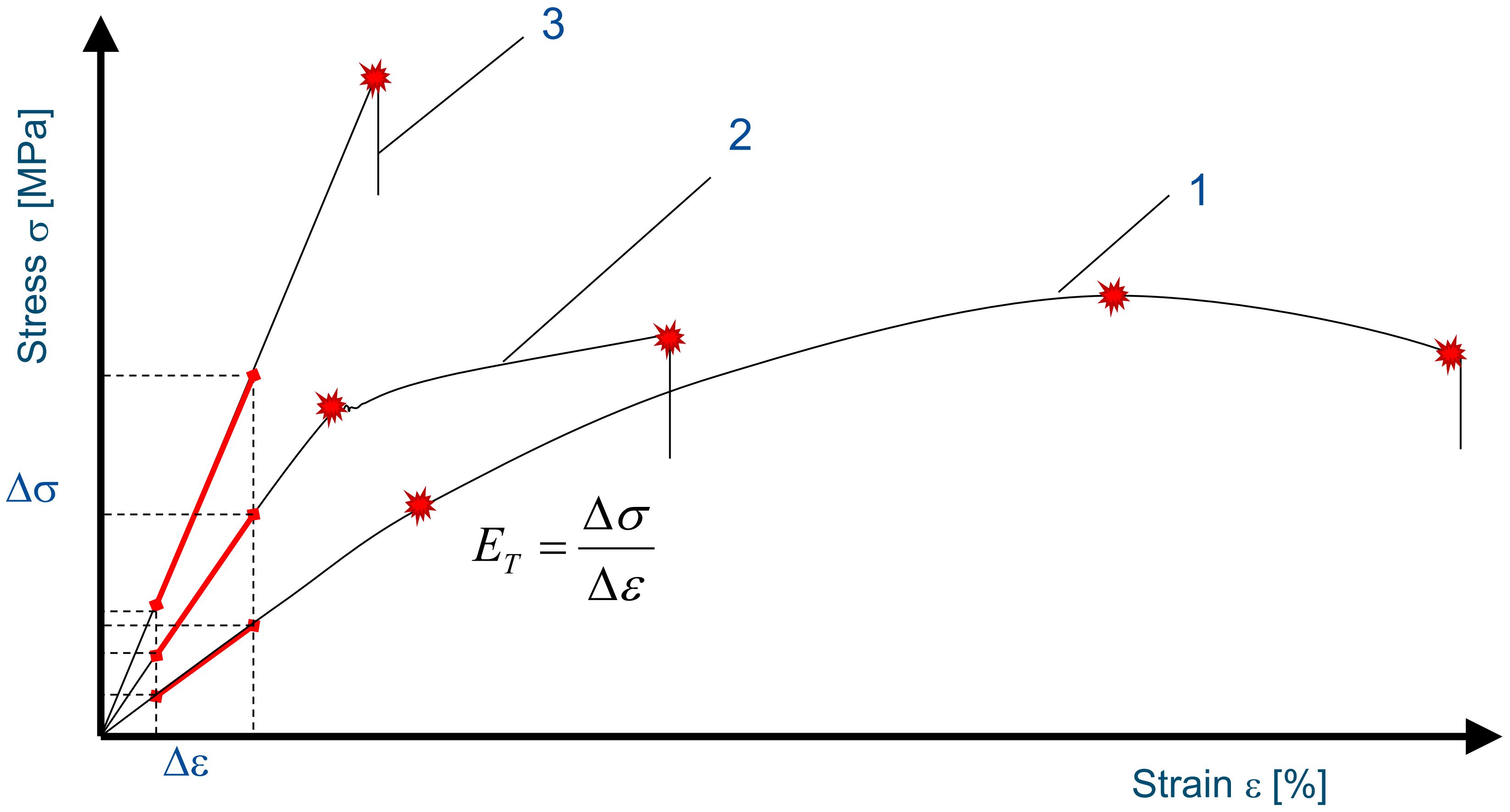
Property	After 175.000 h	Reduction $A_1 * A_2$ according to 175.000 h	Reduction A_3	Reduction $A_1 * A_2 * A_3$ according to 175.000 h	Comparison
E_F [MPa]	28.099	0,71	1,35	0,96	< 2,51
σ_F [MPa]	276,4	1,52	1,35	2,05	< 2,51

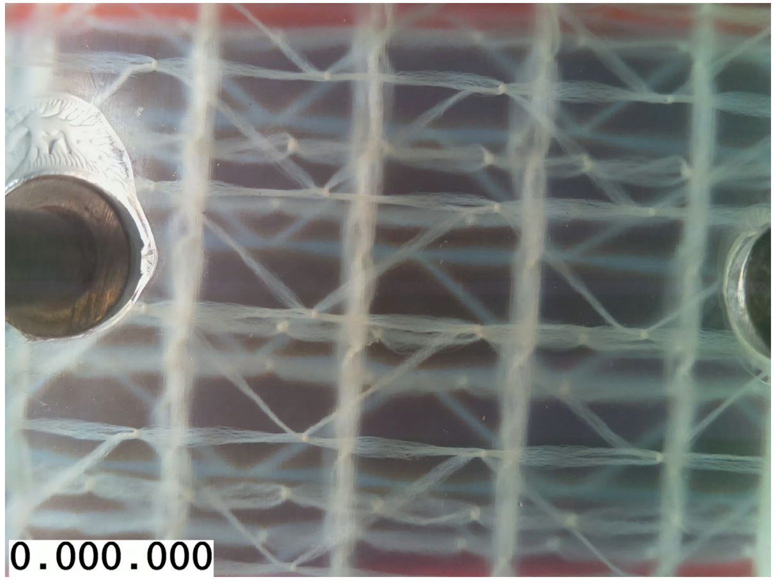
longitudinal direction

Property	After 175.000 h	Reduction $A_1 * A_2$ according to 175.000 h	Reduction A_3	Reduction $A_1 * A_2 * A_3$ according to 175.000 h	Comparison
E_F [MPa]	17.887	0,61	1,35	0,82	< 2,51
σ_F [MPa]	134,6	1,08	1,35	1,46	< 2,51

Approach for Failure Determination during Fatigue Test

General material behaviour of FRP

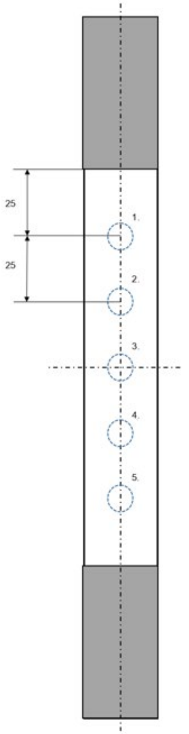




1…UD in 0°
2…Multiaxial (0°/90°)
3…BIAX

Approach for Failure Determination during Aging Test

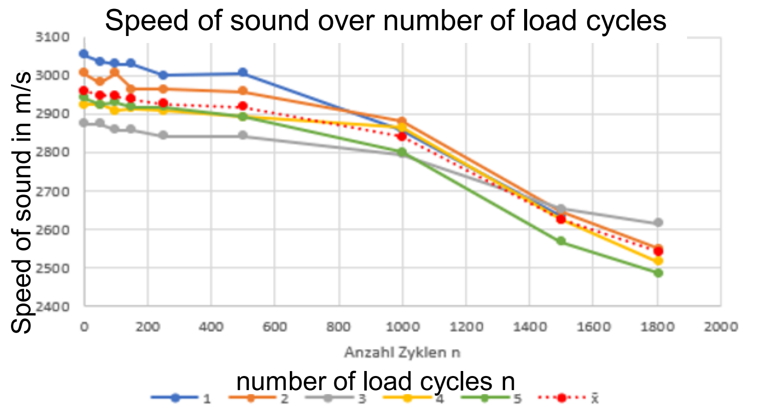
Ultrasonic testing to estimate the fatigue behavior



Schematic layout of the test points and test setup

Coupon sample with NDT after 500 load cycles

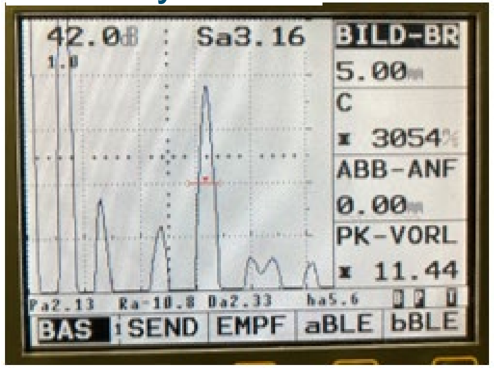
Prüfpunkt	1	2	3	4	5	x̄
Bauteildicke in mm	3,20	3,15	3,20	3,10	3,15	= 3,15
Anzahl Zyklen n	Schallgeschwindigkeit in m/s					
0	3054	3005	2874	2924	2941	**2960**
50	3036	2982	2874	2924	2924	**2948**
100	3030	3005	2858	2907	2930	**2946**
150	3030	2964	2858	2913	2918	**2937**
250	3000	2964	2842	2907	2918	**2926**
500	3005	2958	2842	2891	2891	**2917**
1000	2858	2880	2794	2863	2800	**2839**
1500	2634	2647	2652	2625	2567	**2625**
1805		2549	2615	2515	2486	**2541**
2000						
2500						
3700						
5200						



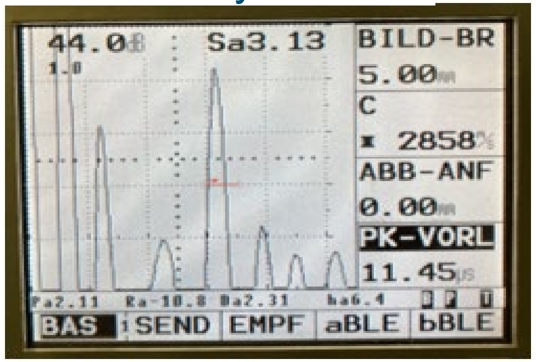
Approach for Failure Determination during Aging Test

Change of ultrasonic testing signal due to increasing number of inter-fibre failures and growing delamination in the specimen

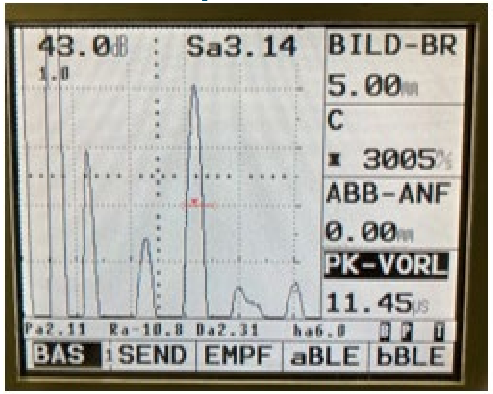
0 load cycles



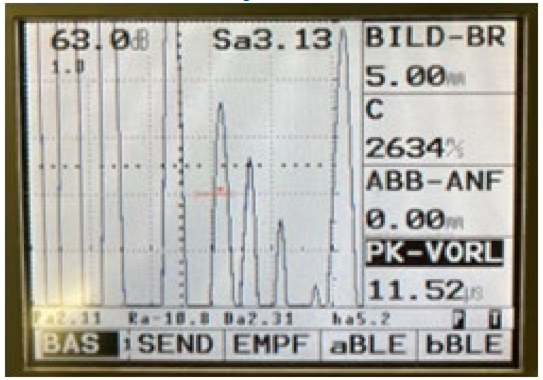
1.000 load cycles

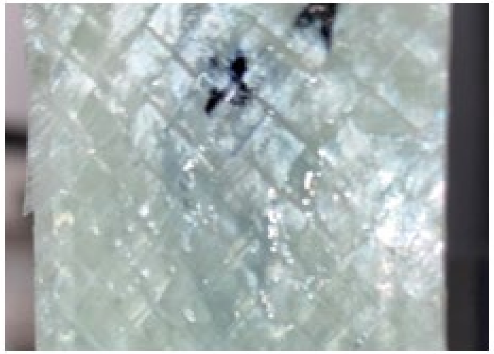


500 load cycles



1.500 load cycles





Approach for Failure Determination during Aging Test

Aim:
- Evaluation of the material condition and derivation of predictions on the remaining service life
- Increasing operational safety through recurring monitoring or permanent monitoring in critical areas

Suitable NDT methods for structural monitoring of GFRP components:
- Ultrasonics (UT)
- Guided waves (AU)
- Acoustic emission (AE)

Requirement:
- Numerous test data for different material
- Consideration of load types / load direction
- Data basis for the evaluation of NDT-images

Summary

1. With an optimised choice of reinforcement fibre, layer structure, matrix and, if necessary, fillers to meet the requirements of the application, construction projects with the highest demands can be realised over a long period of time (>25 years).
2. Applications of GRP from all industries and technologies allow us to expect service lives of 50 - 100 years.
3. The actual degradation of the material depends not only on the loads and the choice of material, but also on the manufacturing quality (degree of cross-linking) and on the assembly (residual stress).
4. I.e. the degradation factors required for the design are not purely theoretically determinable factors! They can differ greatly in practice, because they depend on the manufacturing quality.
5. The use of "witness samples" help to determine the long-term behaviour more reliably.
6. Non-destructive testing methods are suitable for structural monitoring and evaluation of the material condition.

With our materials and pultruded profiles, we are well positioned in the competition of materials.

Applus IMA

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