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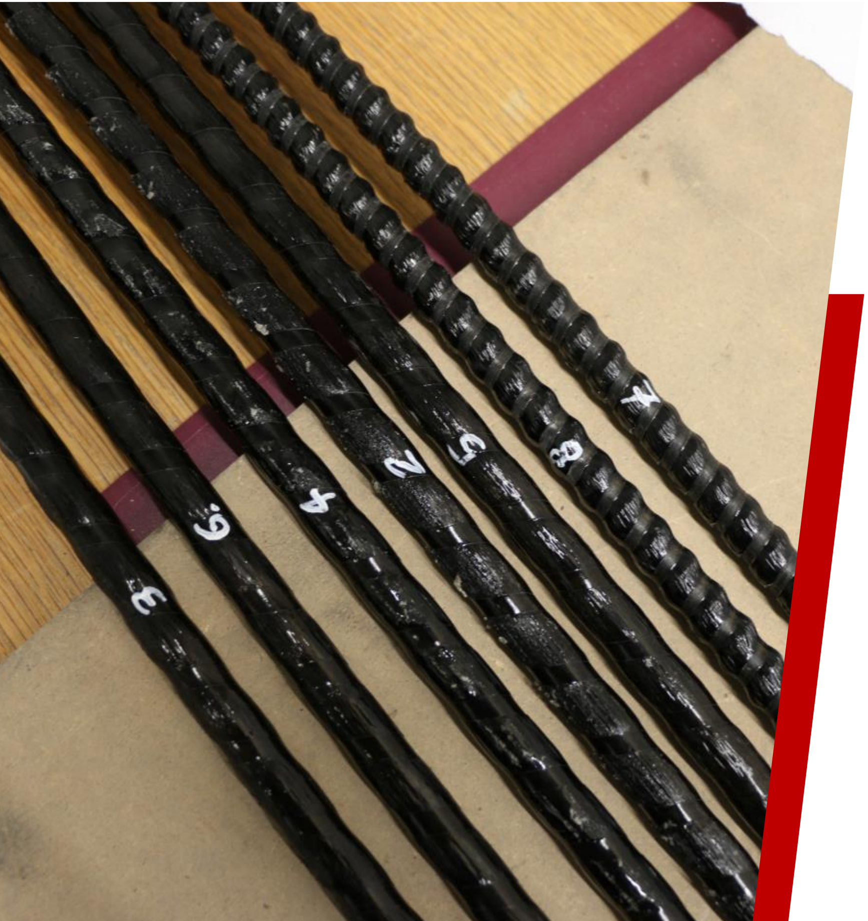


Basalt FRP reinforcing bars

BFRP, the newcomer to the FRPs

04.12.2024 Dr. Christoph Czaderski
Dr. Yasmin Lemcherreq

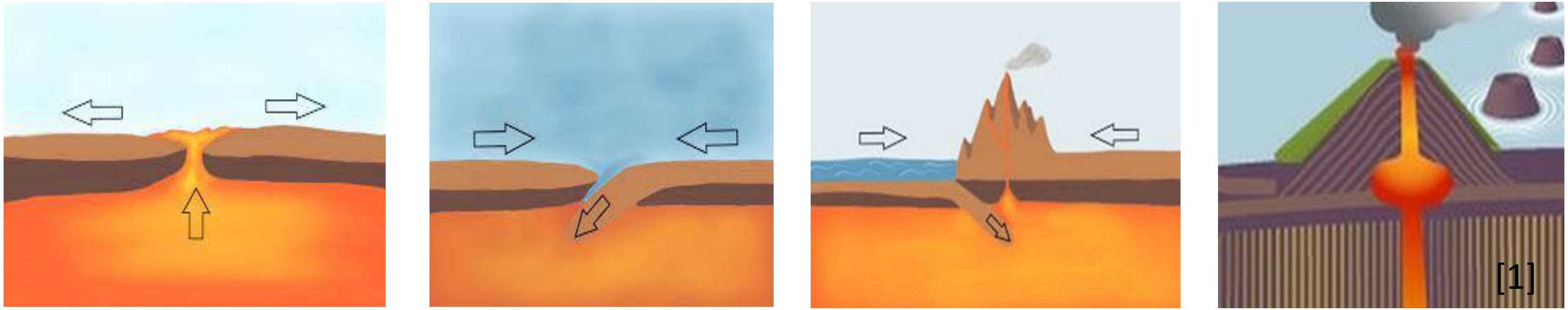
Content

- From basalt rocks to basalt fibers
- Motivation to use BFRP as reinforcement
- Innosuisse project at Empa
- Production of basalt fiber reinforcements
- Application
- Characteristics of BFRP rebars
- Previous and current research at Empa

Basalt

Definition, composition, and characteristics of basalt:

- Basalt is a fine-grained volcanic rock that forms from the rapid cooling of lava at or near the Earth’s surface.



Basalt

Definition, composition, and characteristics of basalt:

- Typically black to dark gray in color due to high content of dark colored minerals.
- Texture and structure of basalt depend on the formation conditions and cooling history
- Most abundant rock around the world, on land and under the ocean floor
- Mining: Central Europe: Germany, Austria, Ukraine, Slovenia, etc.
  Iceland, Russia, China, USA, etc.

Svartifoss, Skaftafell national park, Iceland

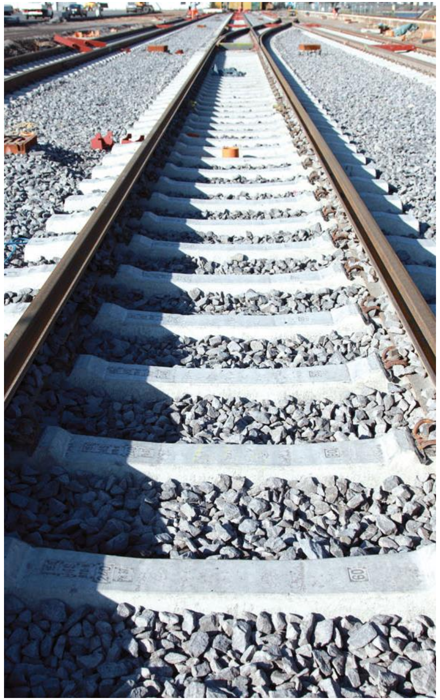
Use of basalt in construction

Characteristics of basalt

- Good workability
- High compressive strength
- Resistant to weathering
- Resistant to frost and de-icing salt

>> Well suited as a construction material

- Road and railway construction
- Pavements and tiles
- Decorative stone
- It can be processed into fibers

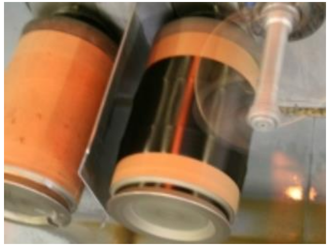


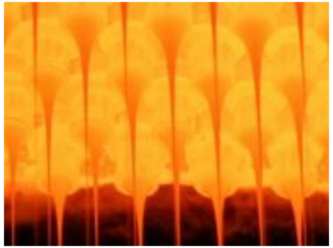
From rocks to reinforcing bars ?

[2]

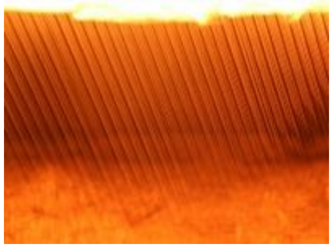
From the rock to the fiber

5-10cm basalt stones in melting furnace, 1300 to 1450°C





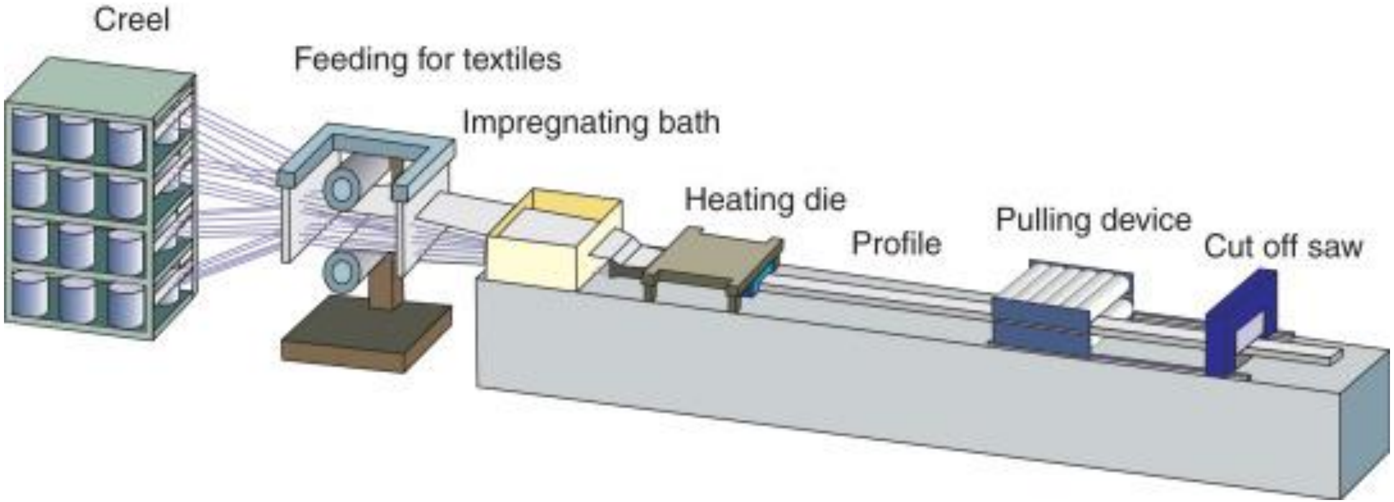
The yellow-red glowing basalt melt is pressed through nozzles.



Continuous fibers are drawn and coated with a sizing to facilitate handling and improve adhesion

[3]

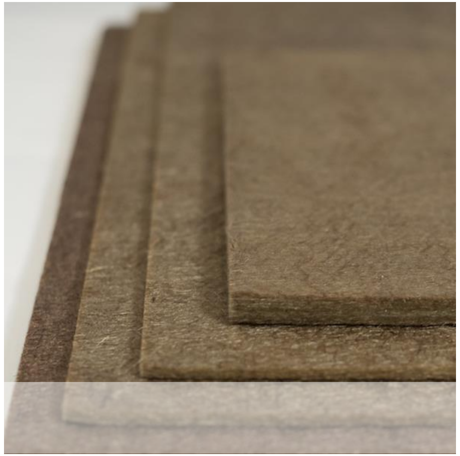
From a fibre to a reinforcing bar



Pultrusion line

Other production made of basalt fibres

Basalt roving



Veils

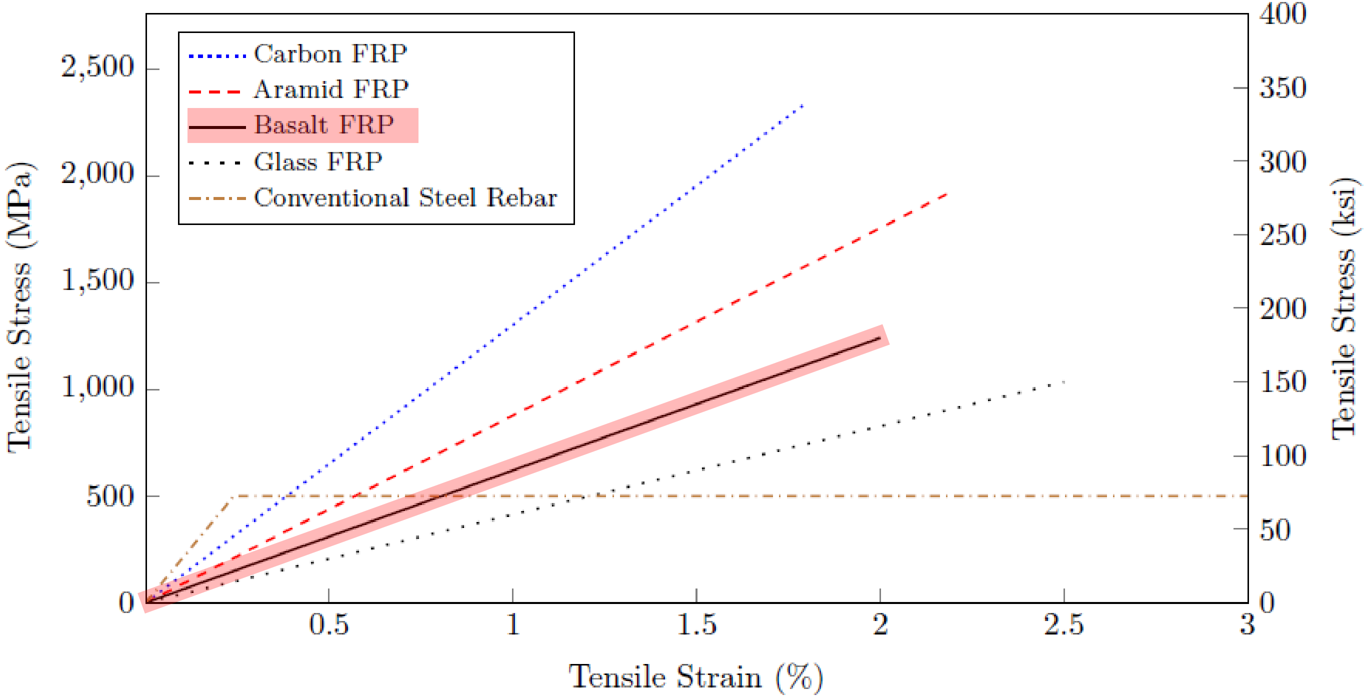
Ropes and tubes

Lamellas

→ We use basalt fibers together with epoxy adhesive to produce reinforcement rebars for concrete.

→ The epoxy adhesive protects the basalt fibers and helps to transfer the tensile stresses between the fibers.

BFRP vs. other FRPs and steel reinforcement



Motivation to use BFRP as reinforcement

- Replacement of steel reinforcement in aggressive environment (de-icing salt, sea water, etc.) to avoid corrosion such for:
  - Parapets on bridges
  - Abutments
  - Tunnels
  - Parking garage
  - Retaining walls
  - Eco-friendly concretes with lower pH-values (e.g. clinker replaced with limestone

https://commons.wikimedia.org/wiki/File:Betonkorrosion.jpg

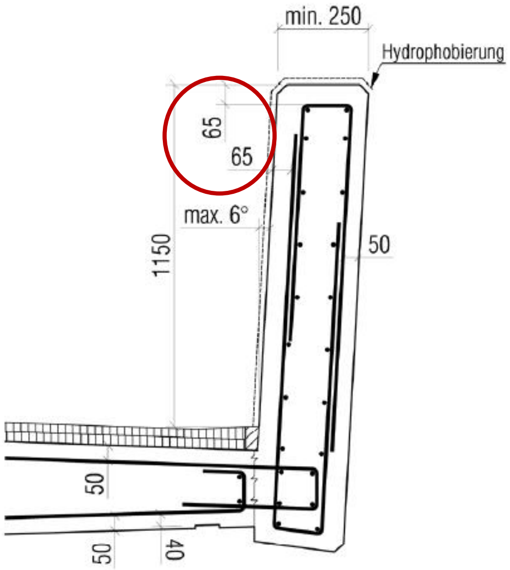


Abb. 4.5 Leitmauer mit geradem Profil, System 92, LM 1150

Motivation to use BFRP as reinforcement

- Reduction of the concrete cover.
- Basalt more cost-effective than glass and carbon fibre reinforcement, and TOP12.
- Wide occurrence of basalt around the world.
- Less susceptible to alkaline attacks than glass fibre reinforcement.

→ The aim is to increase the service life of structures without having a large concrete cover.

Research and development project

in collaboration between

Empa, Structural Engineering
Christoph Czaderski

Empa
Materials Science and Technology

Plüss AG, 6264 Pfaffnau
Heinz Kunz

PMC PLÜSS AG
Mechanics & Composites

Financially supported by Innosuisse
(Innovationsproject 100.907 IP-ENG)

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Innosuisse
Schweizerische Agentur für Innovationsförderung

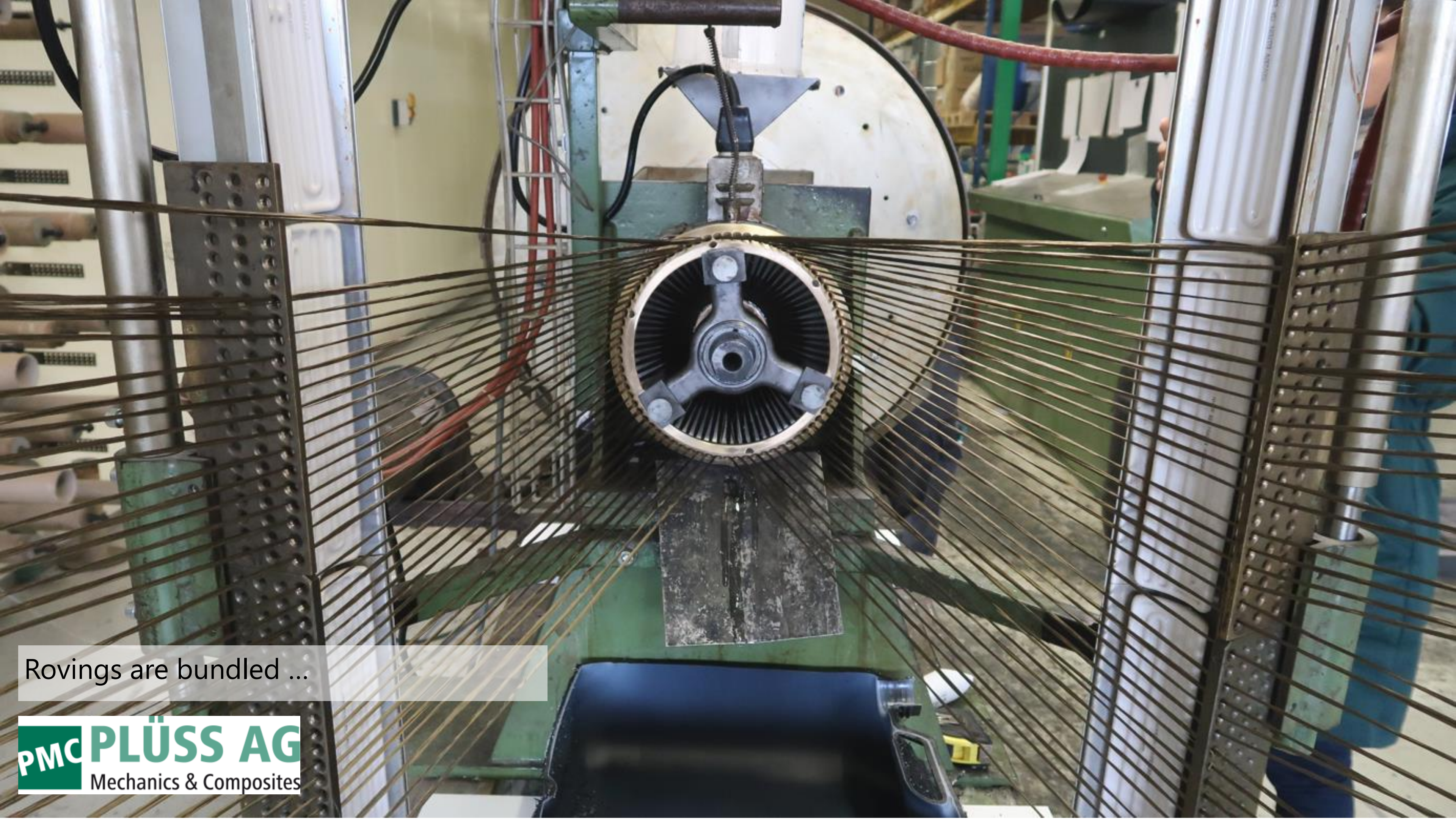
Running Innosuisse project

Goals:

- Optimize the production in terms of costs, stiffness, strength, bond behavior, etc.
- Testing the newly produced rebars (short- and long term strength, bond strength, interlaminar shear strength, etc.)
- Study the long-term durability
- Perform element tests (beams)
- Conduct a pilot project
- Propose new design guidelines (and a new SIA Merkblatt)


Rovings

PMC PLÜSS AG
Mechanics & Composites


Rovings are bundled ...
PMC PLÜSS AG
Mechanics & Composites


Filling with epoxy adhesive
… and saturated with epoxy adhesive in a valve
PMC PLÜSS AG
Mechanics & Composites


30 JAHRE
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Example of application

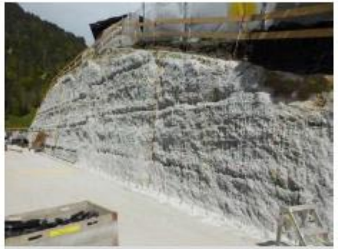
Schweizer Premiere in Grindelwald BE

Stützmauer wird mit modernster Basaltarmierung saniert

Es war eine kleine Sensation, als im Juni 2021 die Stützmauer „Rubi“ an der Kantonsstrasse nach Grindelwald saniert wurde.

Denn zum ersten Mal kamen in der Schweiz bei einem Bauvorhaben Armierungsnetze aus Basalt zum Einsatz.

Nachhaltige Sanierung
Dass die Mauer saniert werden musste, war keine Diskussion. Die Alkali-Aggregat-Reaktion im Beton (AAR) hat der Schwergewichtsstützmauer arg zugesetzt, was durch die netzartig verlaufenden Risse augenfällig wurde.



Der sanierungsbedürftige Teil der Mauer und die alten Armierungen wurden entfernt.

© www.basalt-fibertec.ch

Manual production of reinforcement mesh

© www.basalt-fibertec.ch

Transport of reinforcement mesh to construction site

© www.basalt-fibertec.ch

U-shaped stirrups for wall ends

© www.basalt-fibertec.ch

Installation of the reinforcement mesh

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Installation of the reinforcement mesh

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BFRP- reinforced retaining wall

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Long-term behaviour of basalt fibre reinforcement

- Creep rupture under high sustained loading

  → Long-term tensile strength $f_{tk,100a}$ significantly lower than the short-term tensile strength

- Strength reduction due in alkaline environment (e.g., in concrete)

- EC 1992-1-1 Appendix R

$$f_{ftk,100a} = C_t \cdot C_C \cdot C_e \cdot f_{ftk0}$$

Worst case >> $f_{ftk,100a} = 0.8 \cdot 0.35 \cdot 0.7 \cdot f_{ftk0} \approx 0.2 \cdot f_{ftk0}$

Long-term behaviour of basalt fibre reinforcement

Creep tests

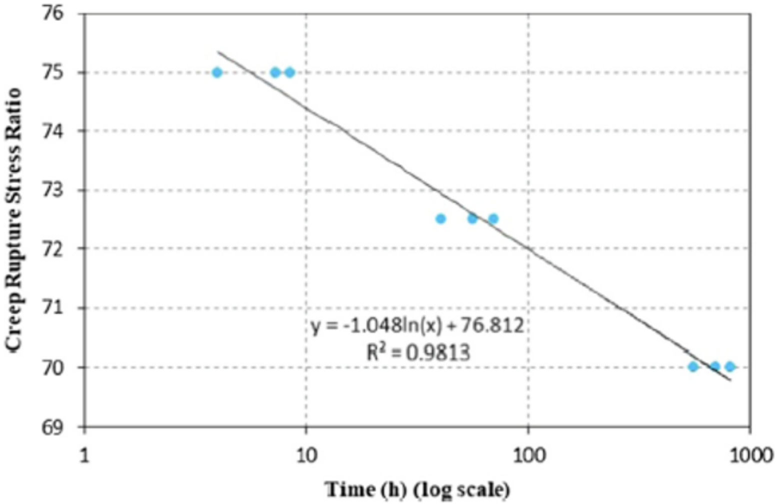


Fig. 8. The stress ratio-creep rupture time curve for 6 mm BFRP bars.

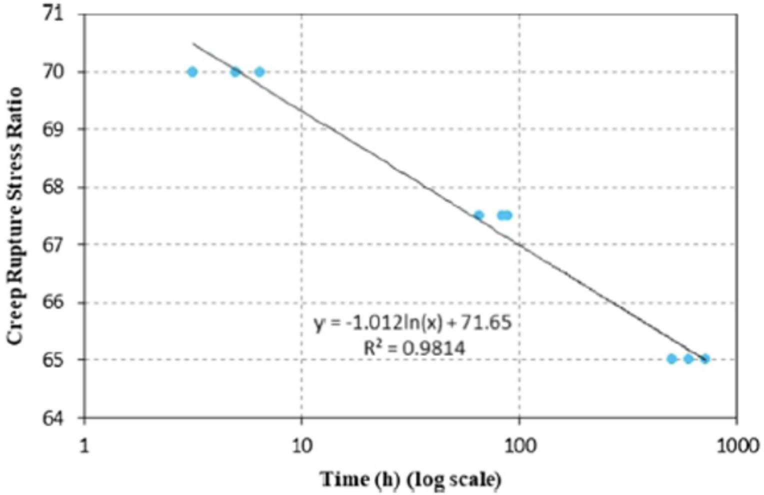
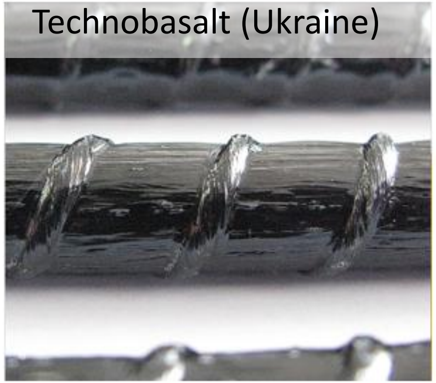


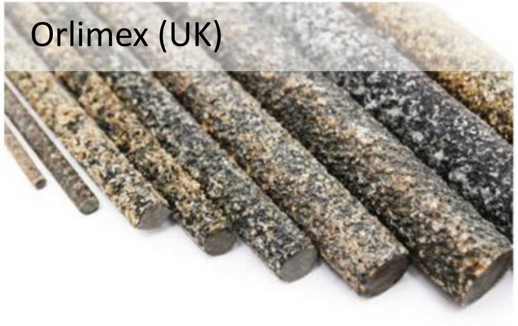
Fig. 9. The stress ratio-creep rupture time curve for 10 mm BFRP bars.

equations, the corresponding million-hour creep rupture stresses for 6 mm and 10 mm BFRP bars are limited to 62.3% and 57.7%, respectively, with linear regression coefficient "r^2" of 0.9813 and

[5]

Bond behavior of BFRP bars





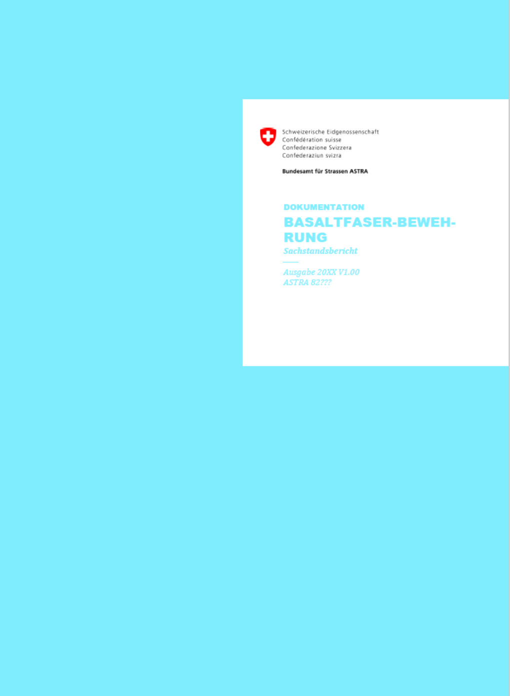
Deutsche Basalt Faser GmbH (GER)

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Bundesamt für Strassen ASTRA

- Documentation for ASTRA
  - Sachstandsbericht Basaltfaser-Bewehrung
    Astra Projekt Nummer 13510031

- Content:
  - State-of-the-art
  - Design
  - Experiments
  - Life-cycle-analysis (LCA)
  - Recommendations for use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Confederaziun svizra

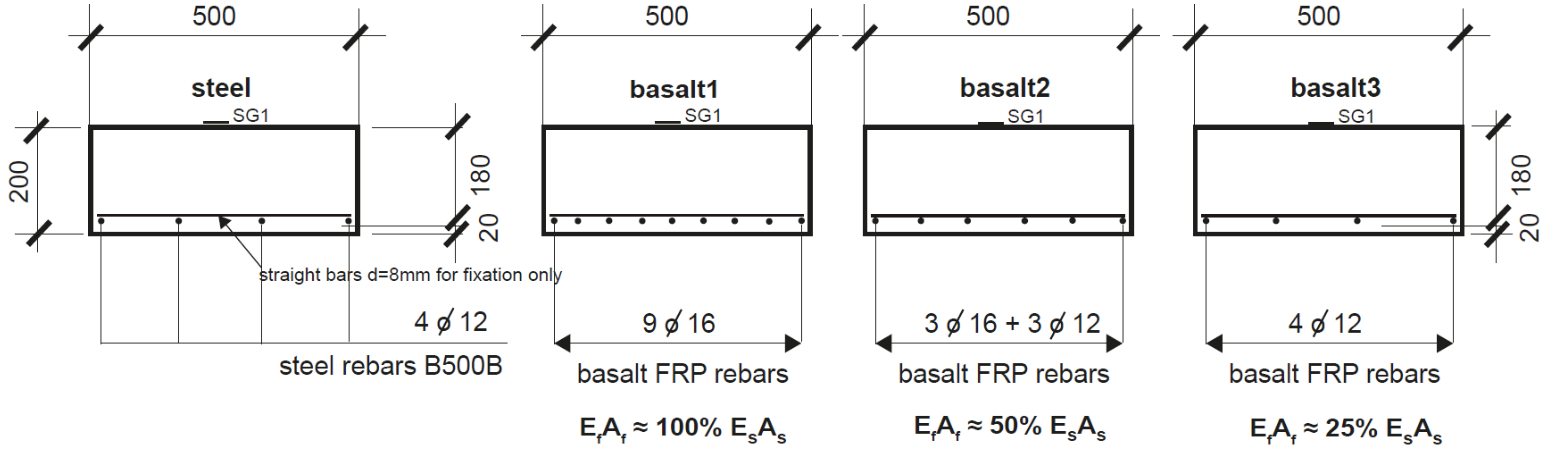
Bundesamt für Strassen ASTRA

DOKUMENTATION
BASALTFASER-BEWEH-RUNG
Sachstandsbericht

Ausgabe 20XX V1.00
ASTRA 82???

https://www.astra.admin.ch/astra/de/home/fachleute/dokumente-nationalstrassen/standards/dokumentationen.html

Bending tests



d=12 mm
E=205 GPa

EA=92.74 MN

$(E_fA_f)_1 = 87\%\ E_sA_s$

EA=80.25 MN

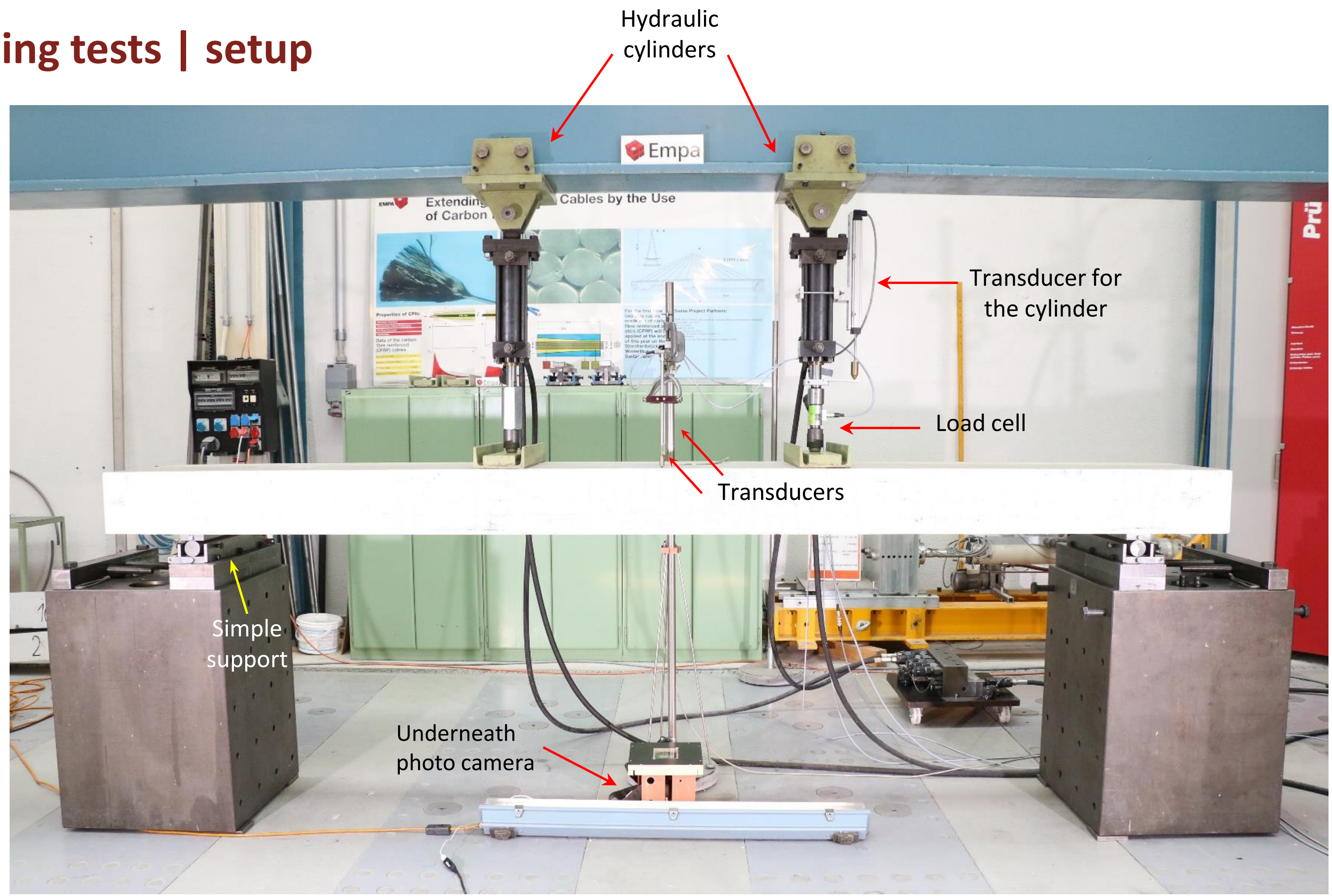
$(E_fA_f)_2 = 48\%\ E_sA_s$

EA=44.89 MN

$(E_fA_f)_3 = 26\%\ E_sA_s$

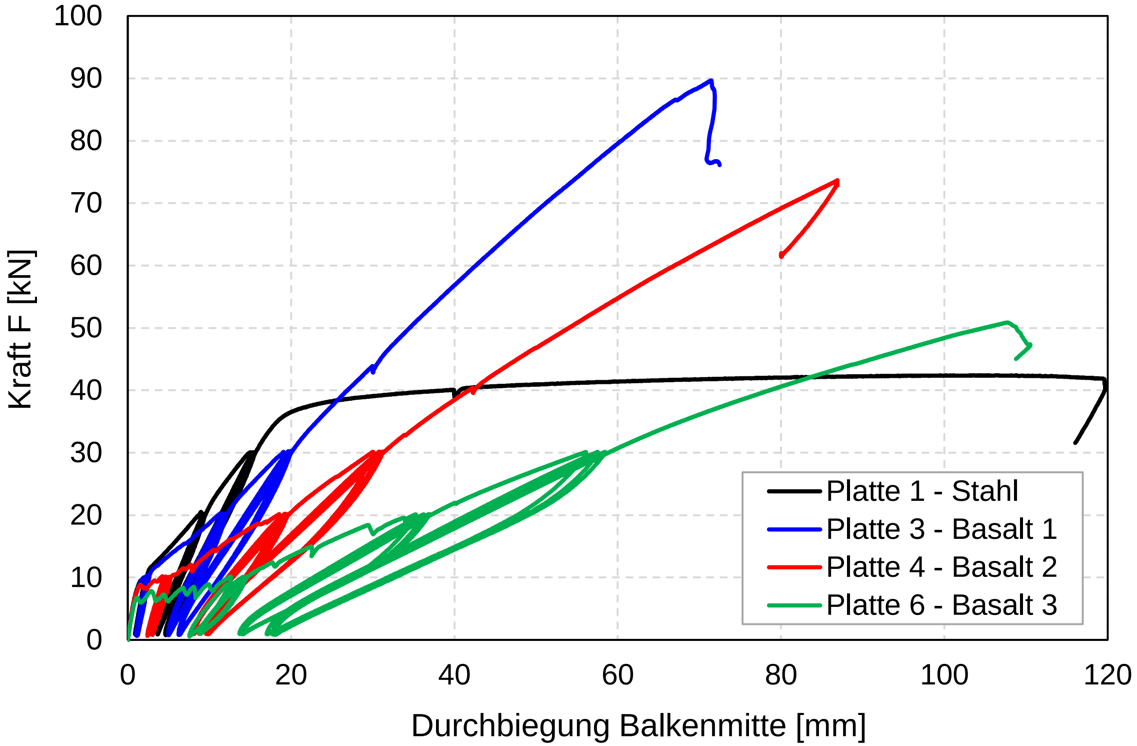
EA=24.19 MN

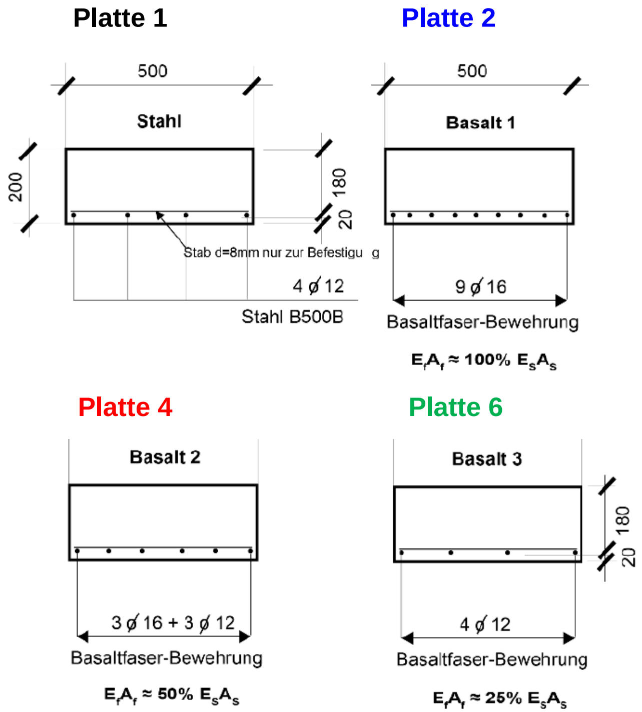
Bending tests | setup



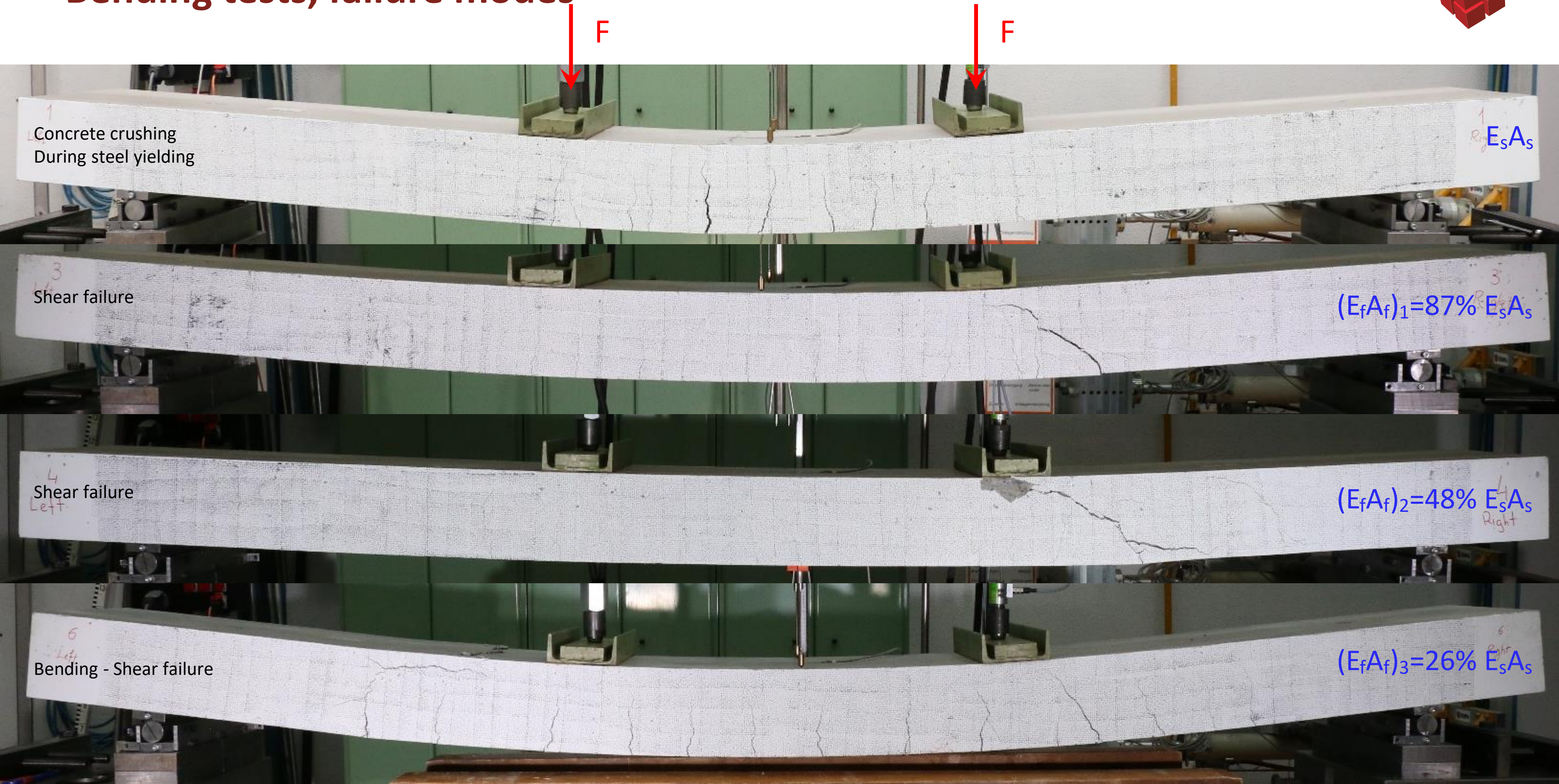
Bending tests | setup

Bending tests | Load-Deflection





Bending tests, failure modes



Bending tests | Failure modes

- Shear resistance of slabs without shear reinforcement (SIA262, 4.3.3.1)

$$v_{Rd} = k_d \tau_{cd} d_v \quad \text{with} \quad k_d = \frac{1}{1+\varepsilon_v\, d\, k_g}$$

ε_v … strain in tensile reinforcement

>> High strains in the reinforcement reduces the shear resistance

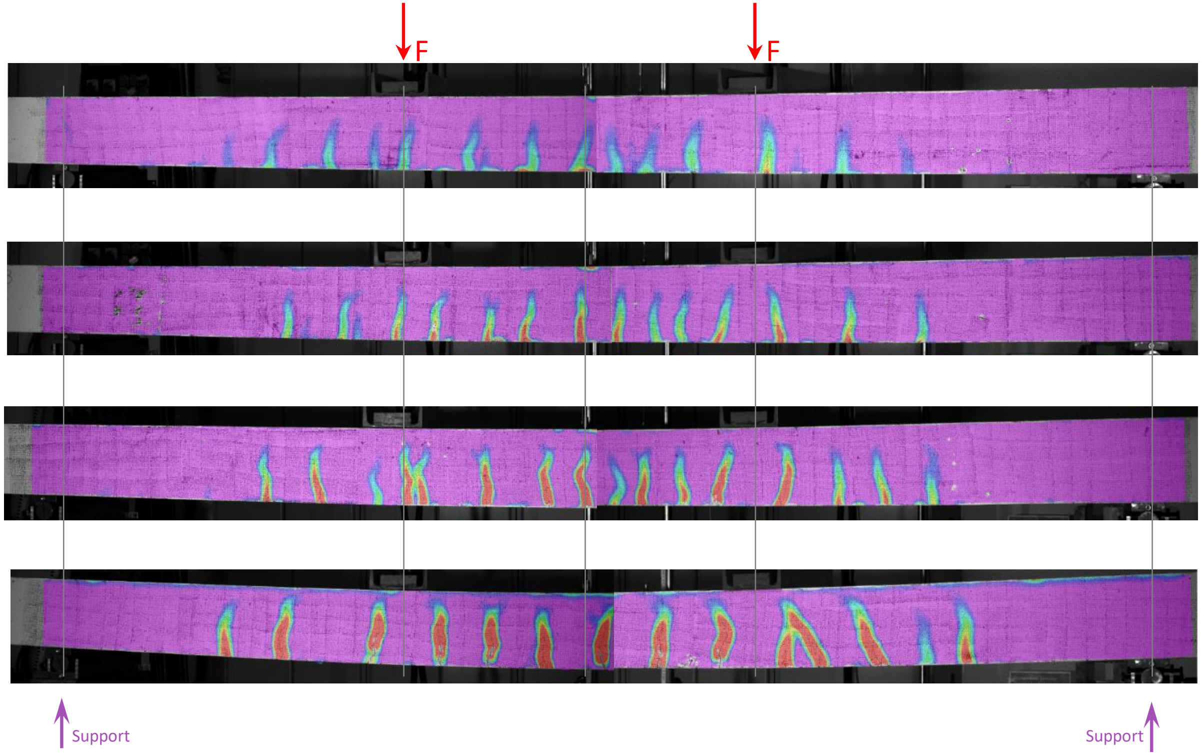
Bending tests | Crack distribution

Platte 1
16 Risse

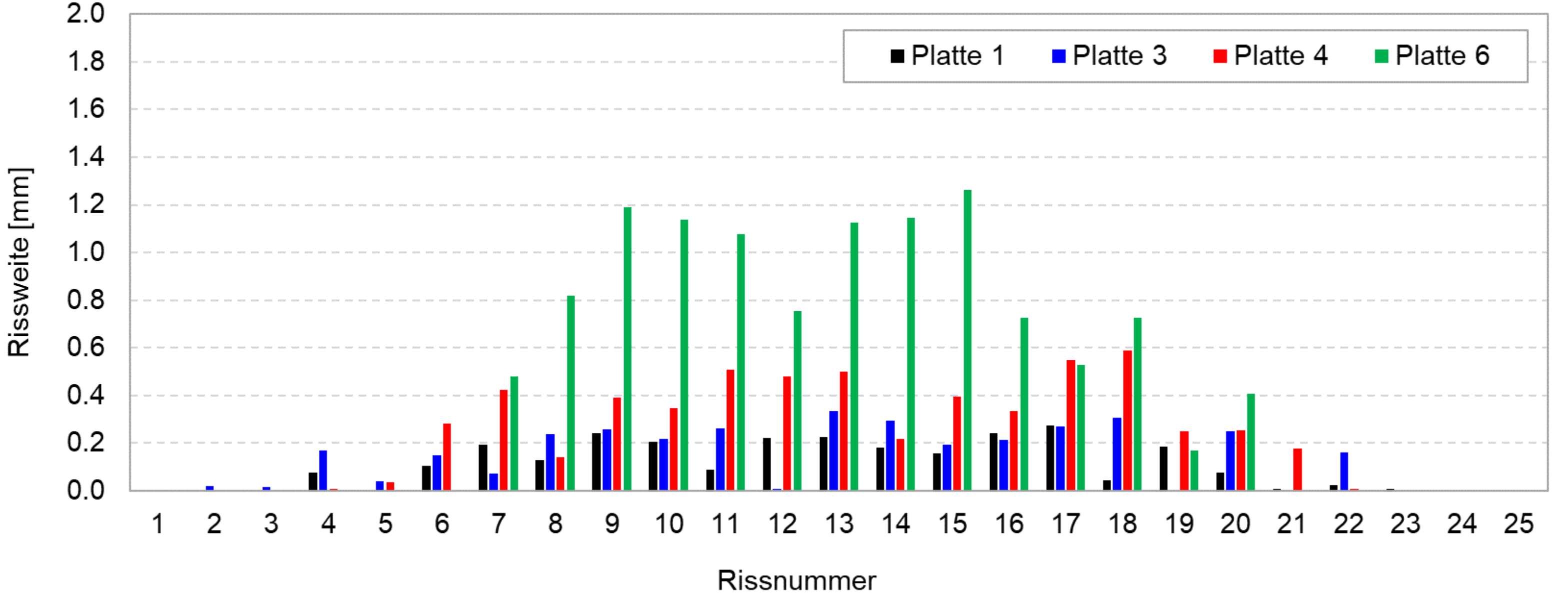
Platte 3
16 Risse

Platte 4
16 Risse

Platte 6
14 Risse



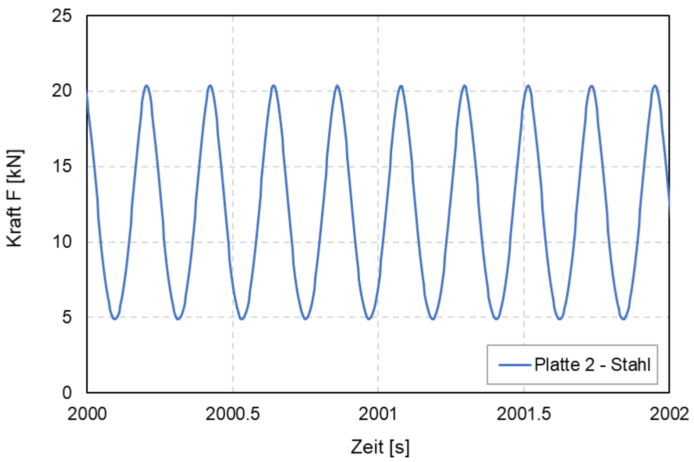
Bending tests | Crack distribution

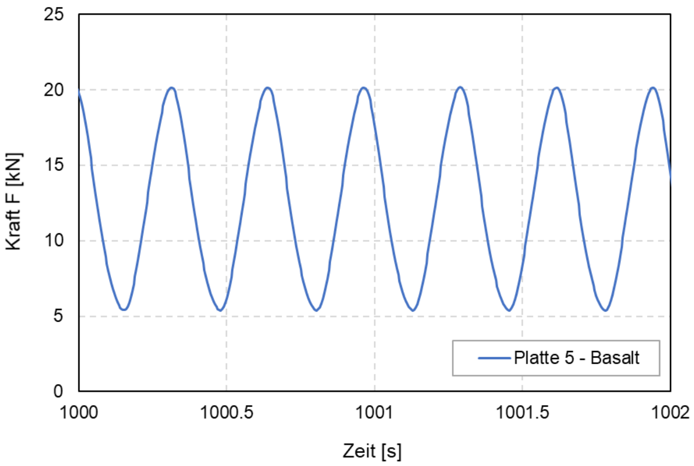


Fatigue tests

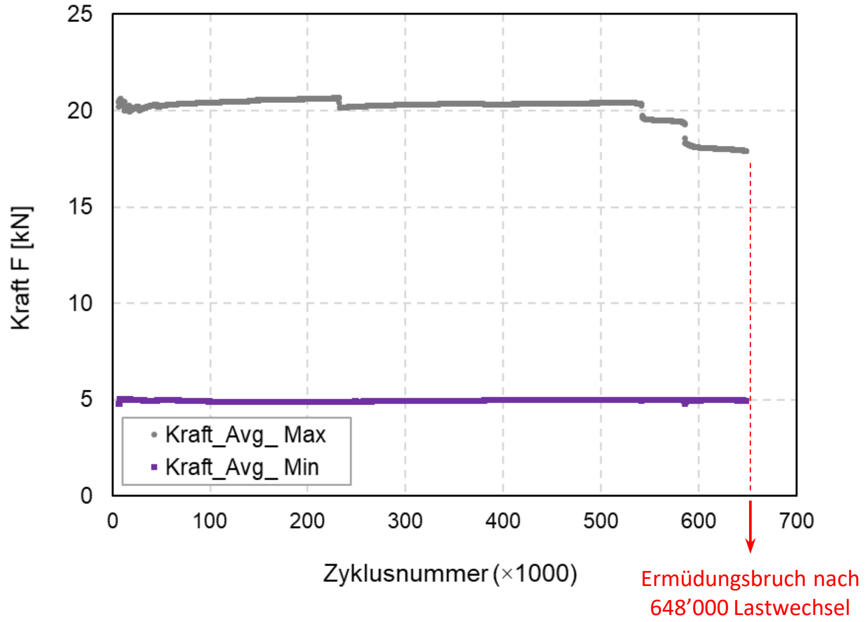
- Platte 2 – Steel reinforcement
- Fatigue loading 5-20 kN
- Loading frequency 4.6 Hz

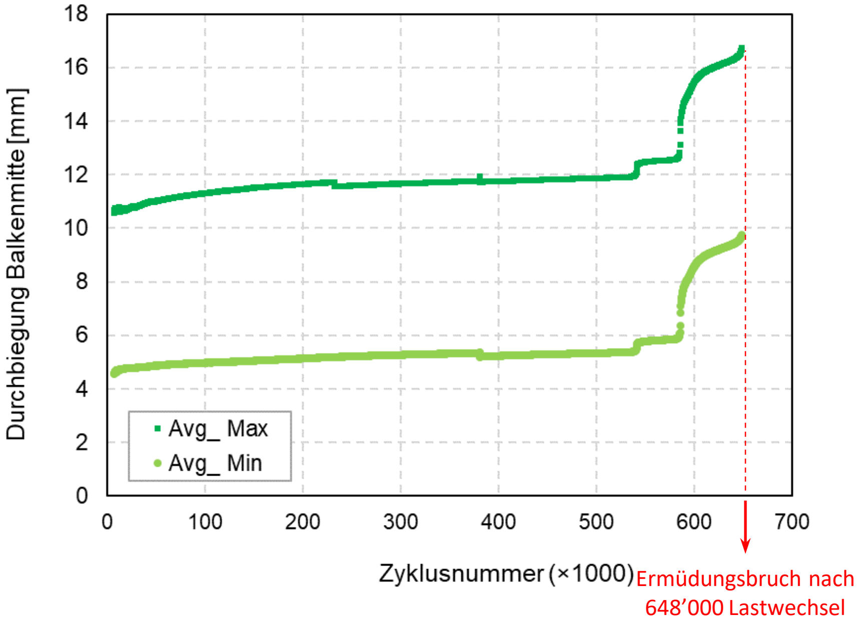
- Platte 5 – Basalt
- Fatigue loading 5-20 kN
- Frequency 3.1 Hz (first 2.1 Mio. LC)
- Frequency 4.7 Hz (subsequent 8.1 Mio. LC)



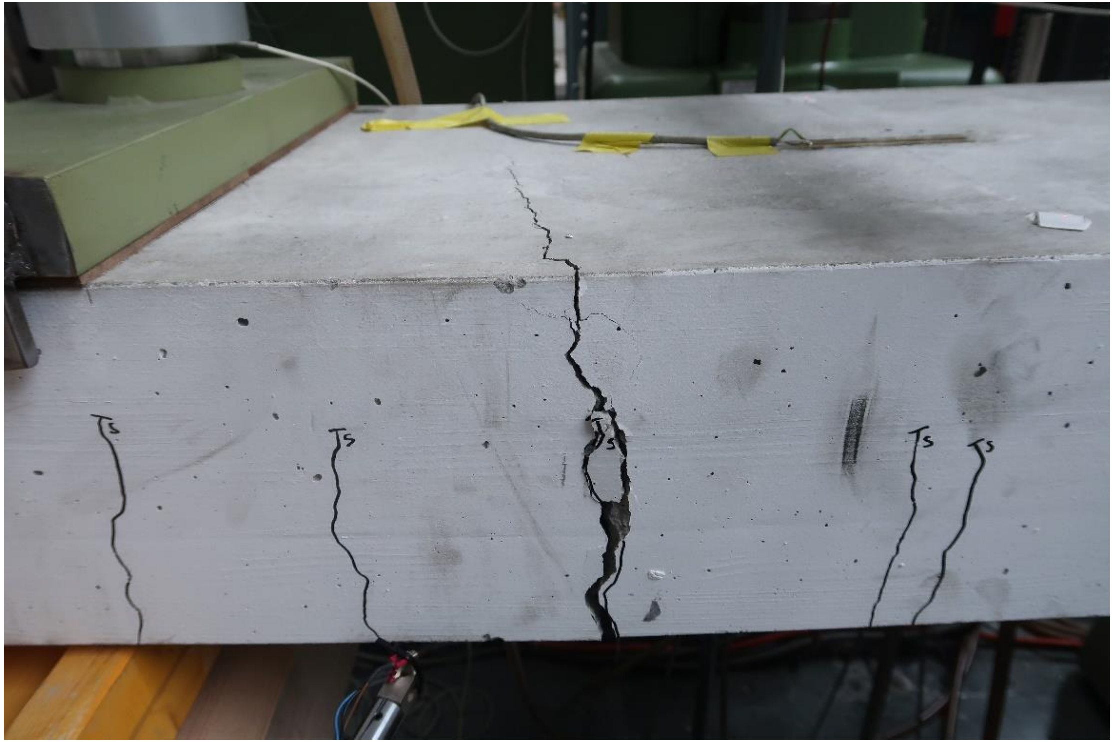


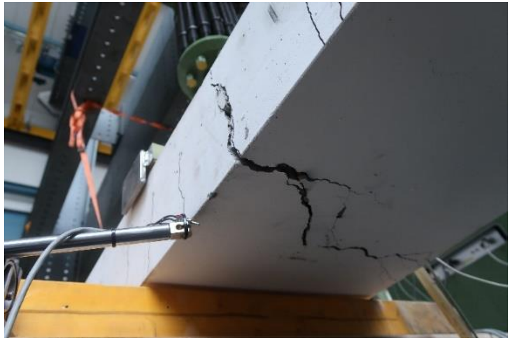
Fatigue failure of reinforcement





Fatigue failure of reinforcement





Fatigue test on

Slab 5, with basalt reinforcement

24.5.2022 / Christoph Czaderski

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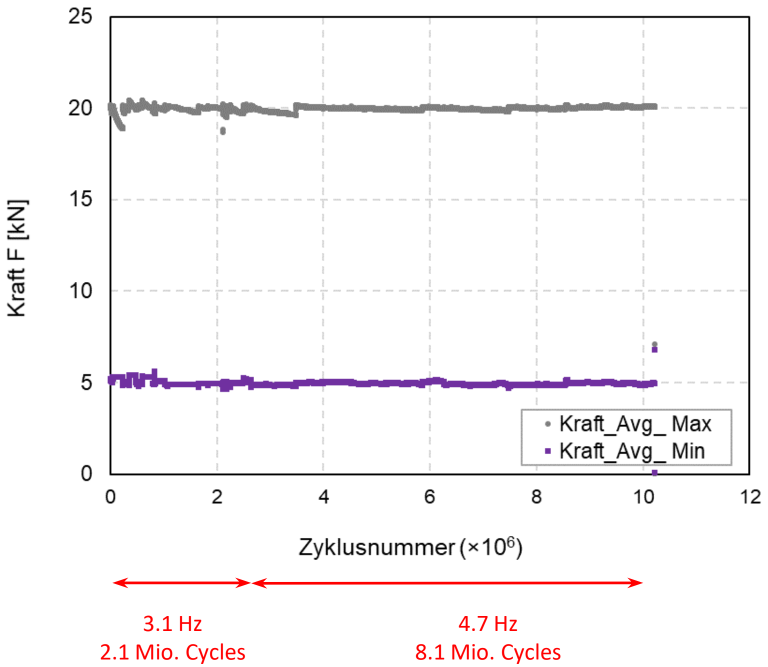
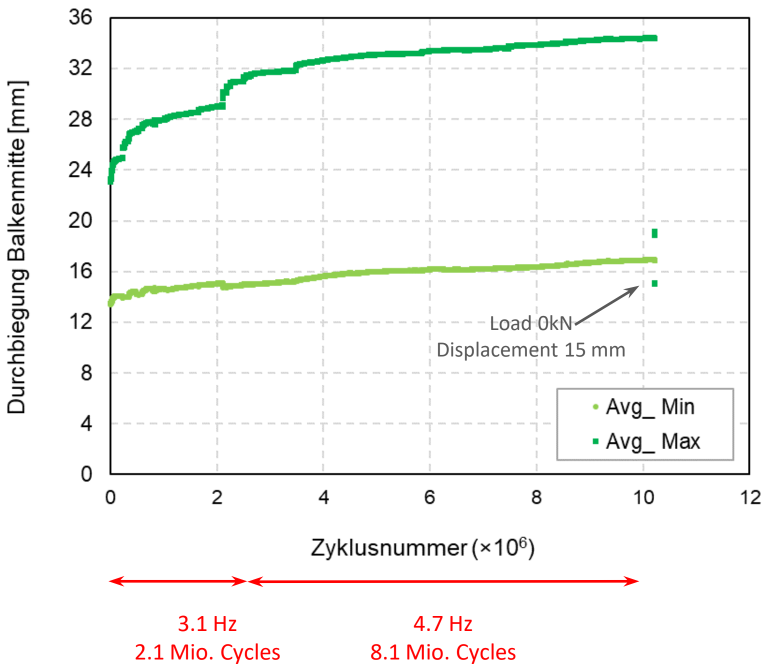
No fatigue failure – 10 Mio. cycles





Slab 5,reinforced with Basalt reinforcement

Failure test after 10 Million LC

8.8.2022 / Christoph Czaderski

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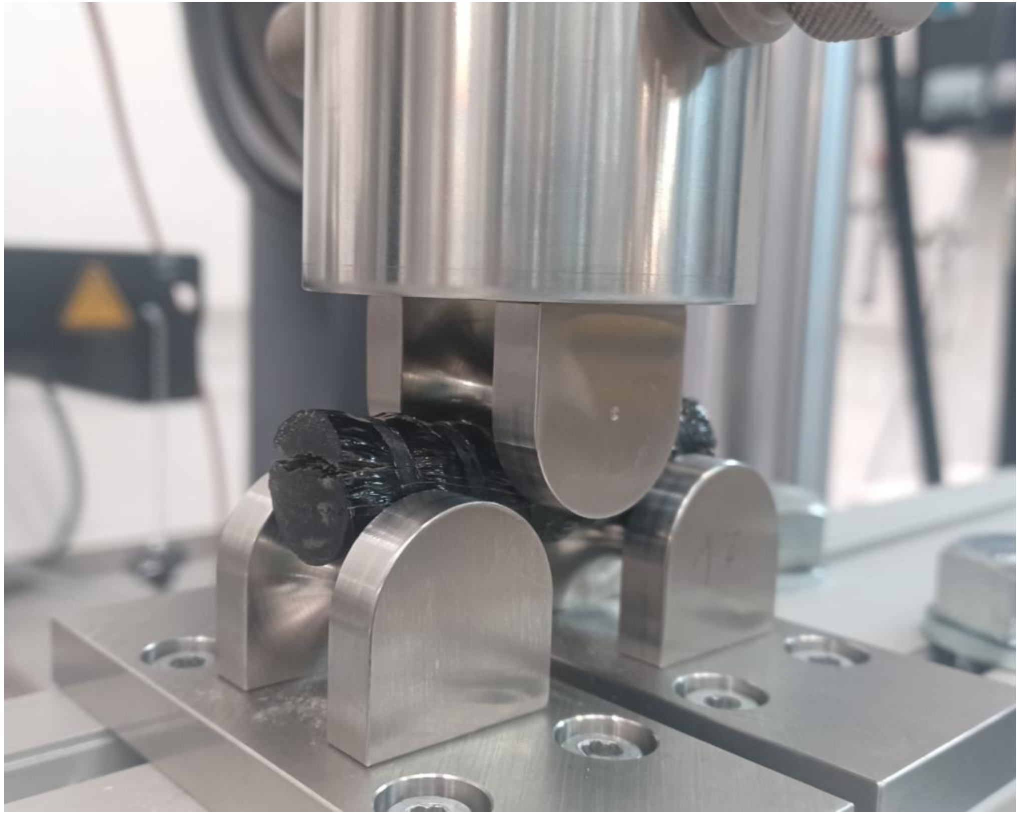
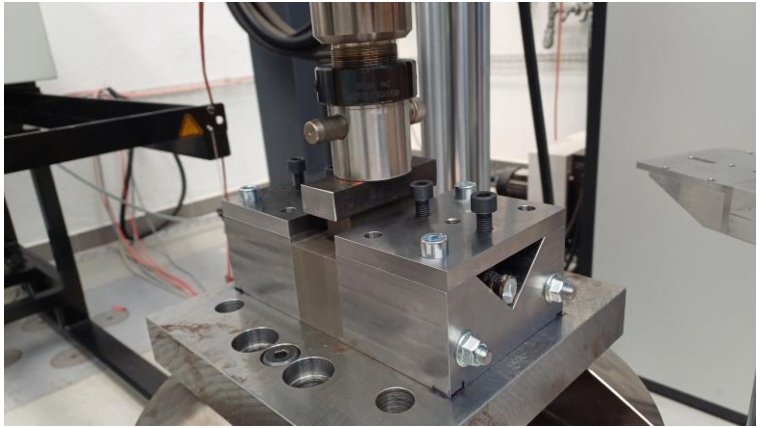
Uniaxial tensile testing


5-1

Interlaminar shear strength



Cross shear strength



Pull-out tests to investigate the bond strength of basalt reinforcement in concrete

Challenges if BFRP is used instead of conventional steel reinforcement

- Linear-elastic behavior, no yielding plateau
- Low elastic modulus (¼ of steel)
- Creep rupture under high sustained load
  → Long-term tensile strength $f_{ftk,100a}$ is clearly lower than the short term tensile strength
- Strength reduction in alkali environment in concrete
- Further points to be considered:
  - Shaping (e.g. stirrups) is finalized after the production
  - Bond behavior (short and long-term) depends on the surface of the bars
  - Minimal bending radius, cover, bar spacing, etc. needs to be defined in a SIA guideline

Preliminary recommendations for the design of basalt fiber concrete reinforcements

Ultimate limit state

- Bending: Failure mode concrete crushing or tensile failure FRP with long-term tensile strength $f_{ftk,100a}$

Serviceability limit state

- Deformations < according to SIA260/261
- Crack width < 0.5mm

Fatigue

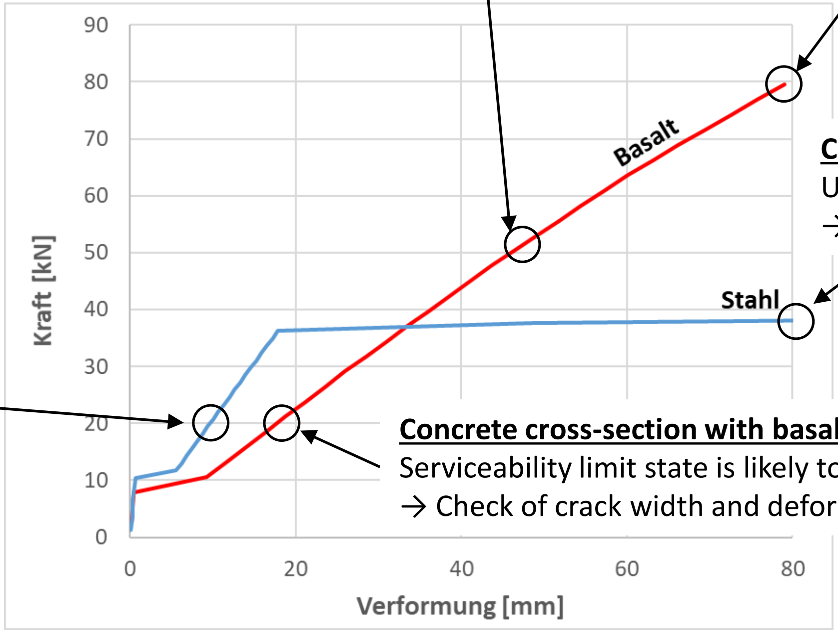
- If the tensile stresses are below 50% $f_{ftk,100a}$ then, it should be ok

Preliminary design concept for bending

Concrete cross-section with steel reinforcement:
Serviceability limit state → Check of crack width and deformations (ev. tensile stresses)

Concrete cross-section with basalt fiber reinforcement:
Ultimate limit state with $f_{ftk,100a}$

Concrete cross-section with basalt fiber reinforcement:
Tensile failure of basalt fiber reinforcement or concrete crushing



Concrete cross-section with steel reinforcement:
Ultimate limit state is likely to be decisive
→ Concrete crushing during steel yielding

Concrete cross-section with basalt fiber reinforcement:
Serviceability limit state is likely to be decisive
→ Check of crack width and deformations (ev. tensile stresses)

Summary

BFRP as internal reinforcement	• Good alternative to stainless steel reinforcing bars in harsh environments • Cost-efficient
Design with BFRP	• Design with long-term tensile strength • SLS decisive for design • Sudden failure • Not prone to fatigue
Ongoing research	• Study the long-term behaviour durability • Improve bond behaviour

References

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[6] Ahmed, S. A. S., Fahmy, M. F. M., and Wu, Z., “Experimental Study and Numerical Modeling of Cyclic Bond–Slip Behavior of Basalt FRP Bars in Concrete,” J. Compos. Constr., vol. 22, no. 6, p. 4018050,2018.