sgl carbon

CFRTP Rebar for Economic Straight and Bent Reinforcement

Jonas Schmitz

SGL Carbon – ACIC | Birmingham | September 5th 2019

Agenda

1. Introduction SGL Carbon
2. Composite Reinforcement
3. SGL‘s CFRTP Rebar Approach
4. Material Testing & Demonstration
5. Summary

1 Introduction SGL Carbon

Successful transformation of SGL Carbon.

Carbon and graphite for Megatrends

Lighting › **Steel, Aluminium** › **Mobility, Energy, Digitization**

1878

SIEMENS PLANIA

SIGRI

SGL CARBON
Sigri Great Lakes Carbon Group

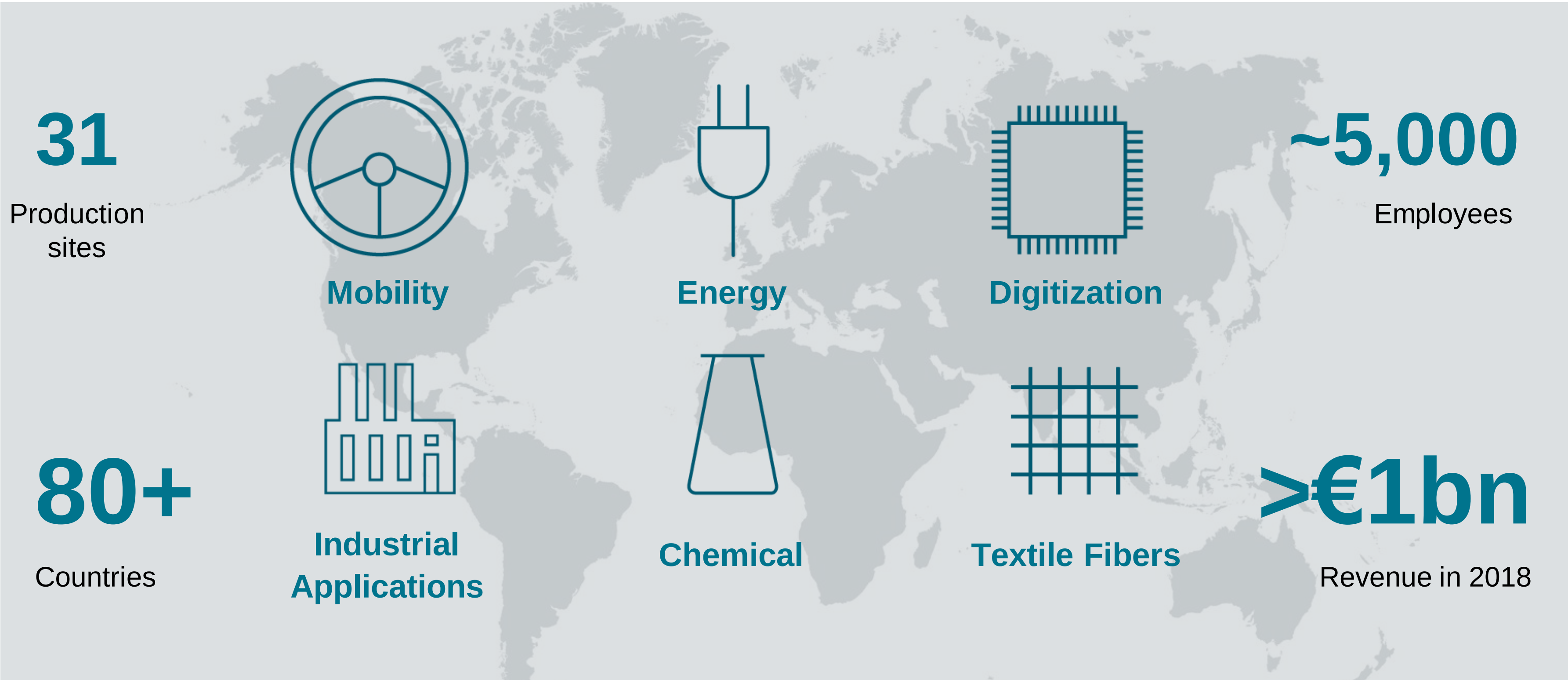
SGL CARBON GROUP

SGL GROUP
THE CARBON COMPANY

sgl carbon

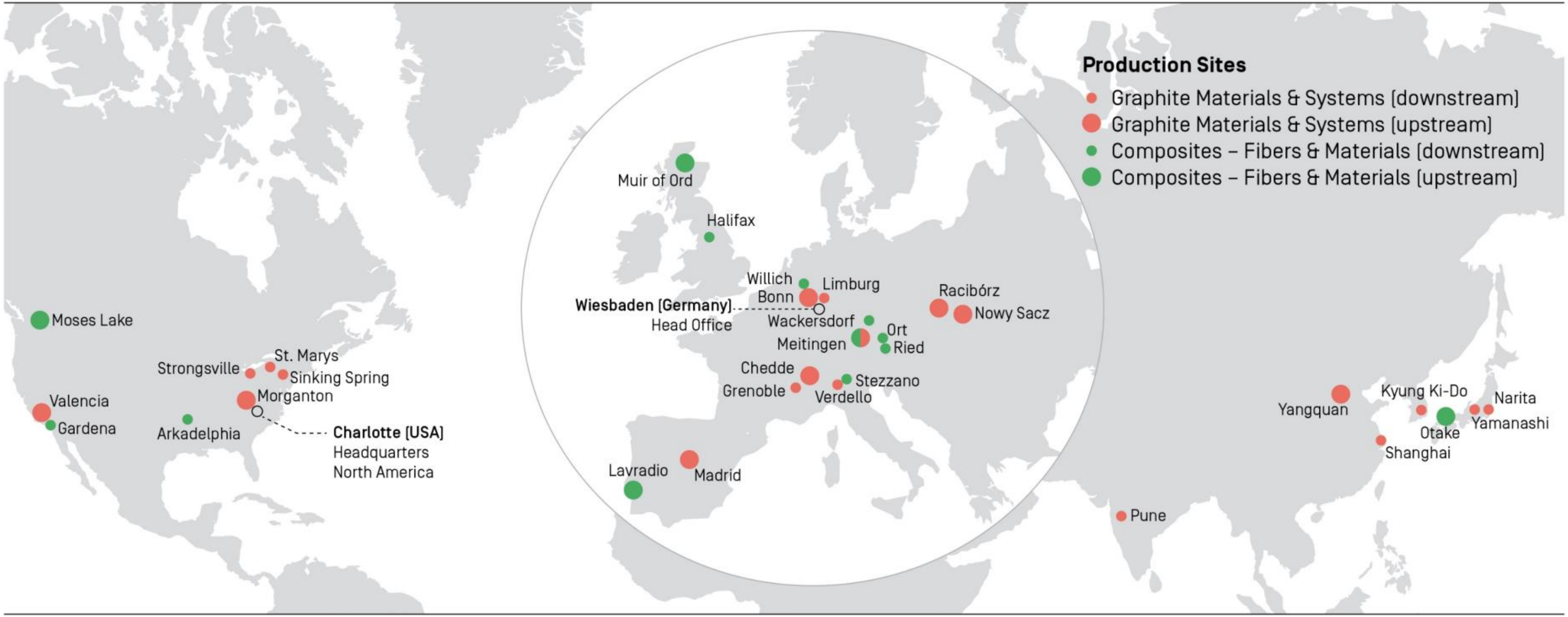
New SGL Carbon.

Specialized on carbon- and graphite-based solutions

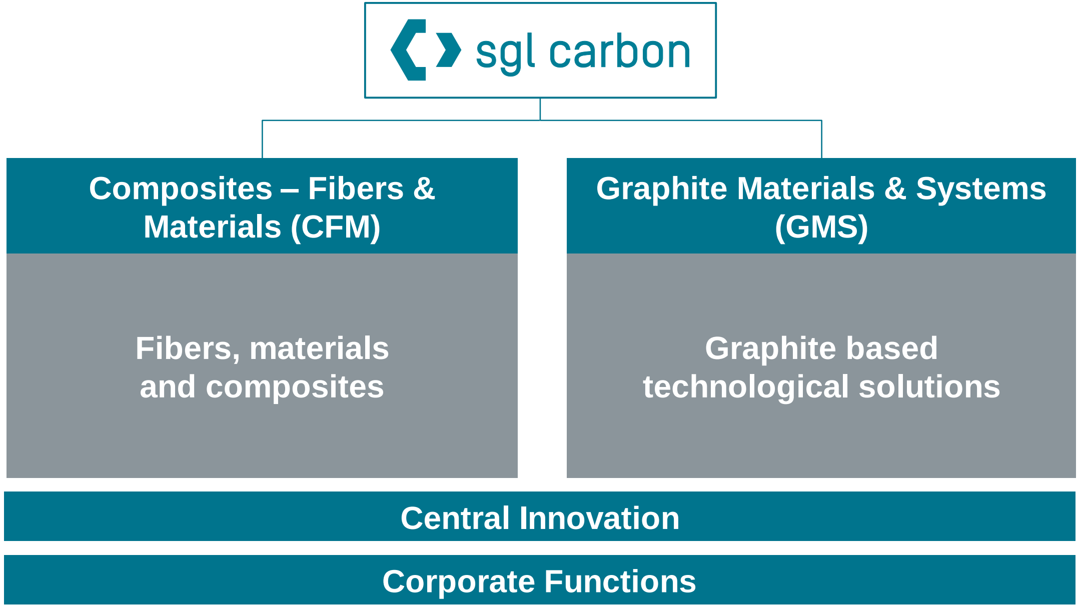


Global presence.

SGL Carbon worldwide sites



New SGL Carbon.
Focus on two innovative businesses



Focus on CFM and GMS improves the balance between markets and industries, and thus **reduces volatility in our business**

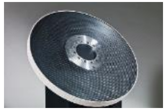
Commanding entire value chain in carbon and graphite.

Advantages in cost, quality and differentiation

Customers

CFM

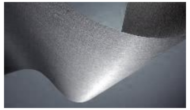


Raw materials	Intermediate stages	Semi finished products	Solutions/ components
CFM: Acrylonitrile, Polyacrylonitrile (PAN)	Acrylic fibers, oxidized fibers, carbon fibers	Preforms, prepregs, multiaxial fabrics, braidings, textile products	Composite components, carbon ceramic brake discs, leaf springs
GMS: Cokes, pitches, natural graphites	Synthetic fine grain graphite blocks, expanded natural graphite	Machining, finishing, coatings (e. g. SiC), assembly	Heaters, anode materials for lithium-ion batteries, gas diffusion layers, process equipment and solutions

GMS



Customers

Control over the entire **value chain** enables product customization to customer requirements

Customers receive **tailor made solutions** from every step of the value chain

Forward integration in finishing technologies (GMS) and CFRP-components (CFM) including application know how are essential for **differentiation**

SGL's Carbon fibers.
SIGRAFIL® continuous tow

- Production in Muir of Ord (UK) and Moses Lake (US)
- Variable mechanical properties and sizings:
  - Epoxy
  - Thermoplastic

SIGRAFIL® fiber types	C T50-4.0/240	C T50-4.4/255	C T50-4.8/280	C T24-5.0/270
Number of filaments	50k	50k	50k	24k
Fineness of yarn dry	3300 tex	3450 tex	3070 tex	1600 tex
Tensile strength	4.0 GPa	4.4 GPa	4.8 GPa	5.0 GPa
Tensile modulus	240 GPa	255 GPa	280 GPa	270 GPa
Density	1.80 g/cm³	1.80 g/cm³	1.78 g/cm³	1.79 g/cm³
Filament diameter	6.8 µm	7.0 µm	6.6 µm	6.9 µm
Elongation at break	1.7 %	1.65 %	1.65 %	1.9 %

SGL’s Dry Textiles Material Toolbox

- Tailored textiles
- Various dimensions and area weights
- Carbon and glass fiber-based

Fabrics

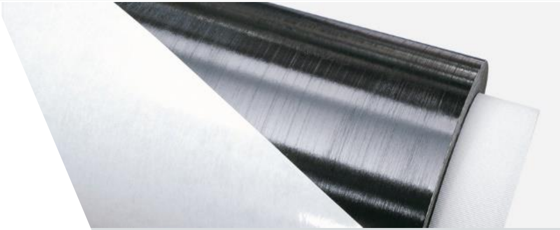
FixTows

Non-wovens

Stacks, Braidings, Preforms

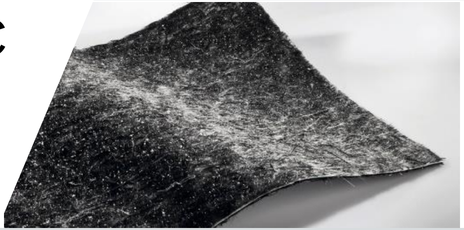
SGL's Thermoset Material Toolbox

- Curing time: 30 s/mm at T > 150°C
- Storage at room temperature: 4 weeks, Tg: 140°C
- Epoxy snap-cure resin system
- With internal release agent if required



Prepreg materials

TowPregs



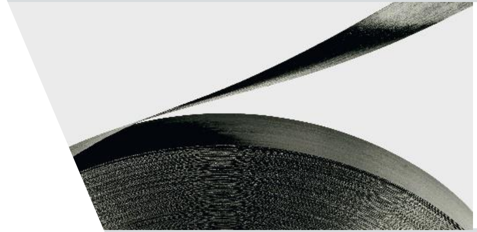
Pre-impregnated carbon fiber non-wovens

Stacks

SGL's Thermoplastic Material Toolbox

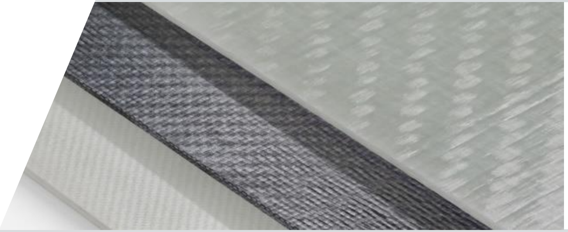
- Customized carbon fiber sizing solutions for PA and PP
- Selected semi-finished materials as a toolbox approach
- Carbon and glass fiber-based

Profiles



UD tapes

UD sheets



Customized organo sheets

SGL Central Innovation – Future Growth Areas.

From research and development to profitable business

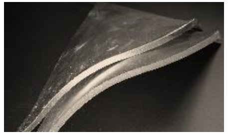
Startups:
Develop business with profitable growth

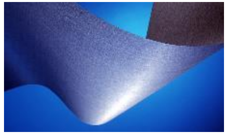
Development: Products & technology in cooperation with customers and partners

Future growth areas:
Defined by analysis of markets and Megatrends in technology

Startup GDL[1] for fuel cell

C/SiC ceramics


C/SiC[2] ceramics


GDL for fuel cell

3D printing

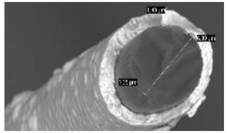
Nano Si/C for next generation lithium-ion batteries

Nano Si/C[3] for LIB


3D printing

Innovative coatings

Innovative composites

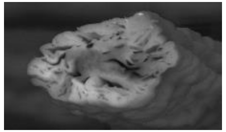

Innovative coatings


Innovative composites

Innovative carbon fibers & textiles

Scouting: Medtec, water treatment, etc.


Water treatment


Innovative C-fibers & textiles

[1]GDL: Gas diffusion layer; [2]C/SiC: Carbon/Silicon carbide; [3]Si/C: Silicon/Carbon

2 Composite Reinforcement

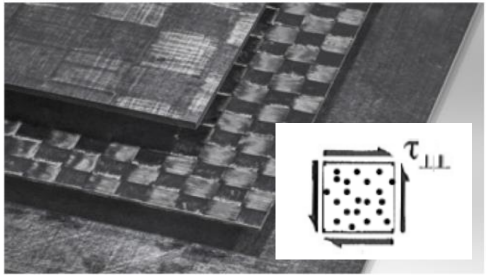
Introduction to fiber reinforcements.

Carbon fiber reinforced polymers (CFRP)

Carbon fibers

- Superior tensile properties
- Corrosion resistance
- No shear / bending stiffness

CFRP Composite



- Low weight
- Superior mechanical properties
- Good chemical resistance

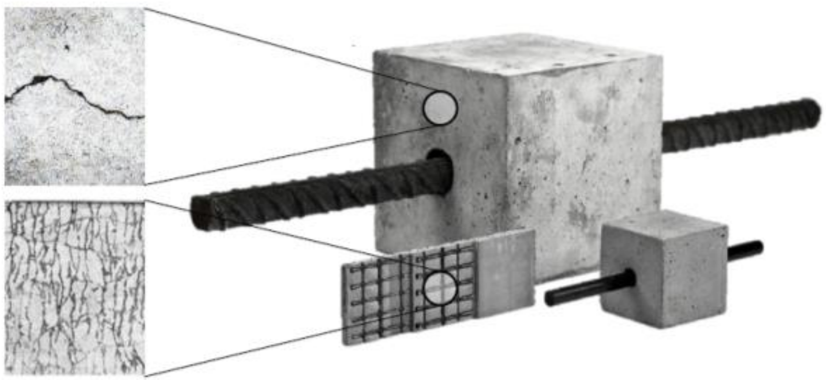
Polymers

- Low weight
- Good chemical resistance
- Low mechanical properties

Overview: carbon fiber reinforced concrete.
Fundamentals and benefits

carbon fiber reinforced concrete
=
miniaturized steel reinforced concrete

- Main Benefits
  - Higher mechanical properties -> smaller cross sections, less reinforcement mass
  - Corrosion resistance -> thinner protective concrete skin-layer, less concrete mass
- Main Requirements
  - Carbon fibers with suitable sizing to matrix
  - Possibility of economic large-scale production for construction industry



Institut für Textiltechnik, RWTH Aachen University

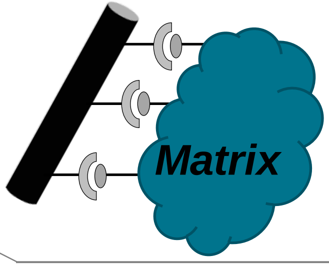
Carbon fiber sizing.
Function and requirements

Fiber handling

- processability
- filament protection (low fuzz)
- lubrication

Matrix compatibility

- interaction with matrix
  - wettability
  - adhesion
- alkaline stability (concrete)



—(sizing

Fibre sizing

(20 – 50 nm thickness)

tailoring fibers towards application / process

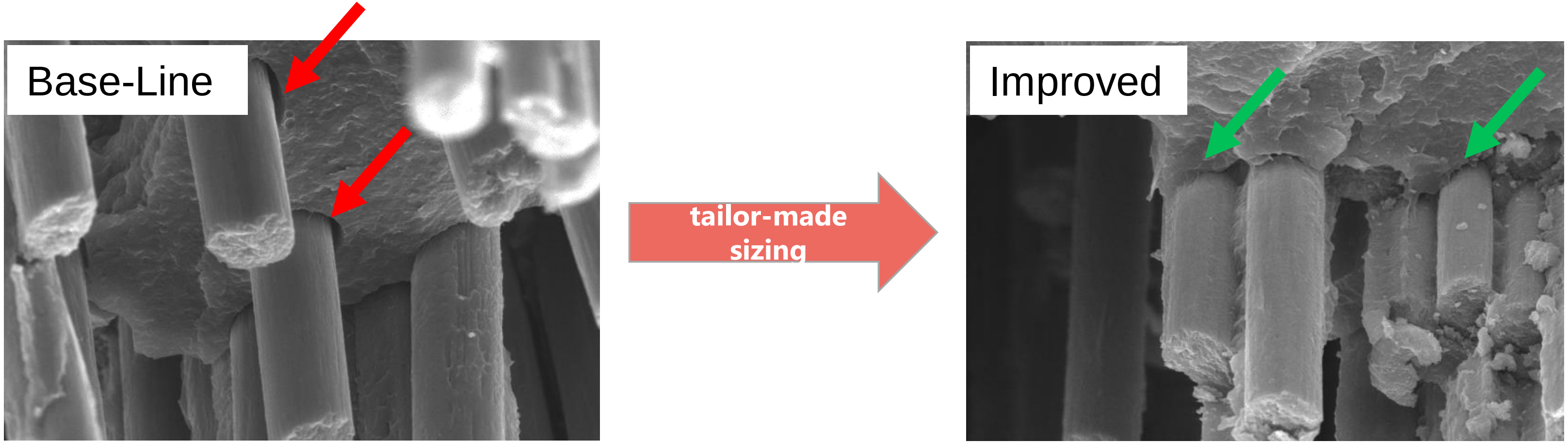
Scalability

process has to be compatible to existing SGL plants

Example: Tailor-made sizing solutions.

SGL Sizing T140 for PA6 (thermoplastic matrix)

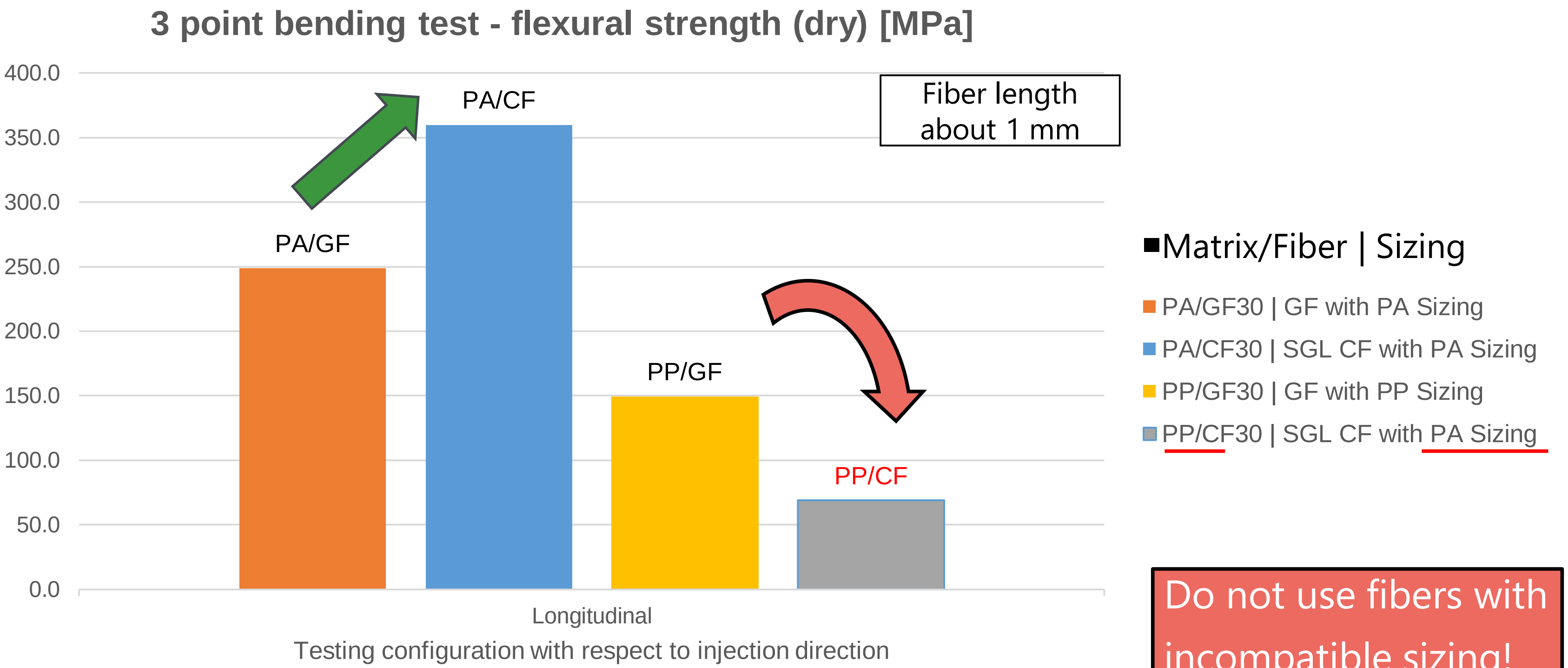
- Advanced fiber/matrix interphase by tailor-made sizing formulation
- Improved mechanical performance:
  - as received
  - hot/wet conditioned
- Textile processability similar to base-line systems



SEM cross section picture CFRP without suitable sizing

SEM cross section picture CFRP with suitable sizing

Example: Tailor-made sizing solutions.
Mechanical testing of injection molded material



Do not use fibers with incompatible sizing!

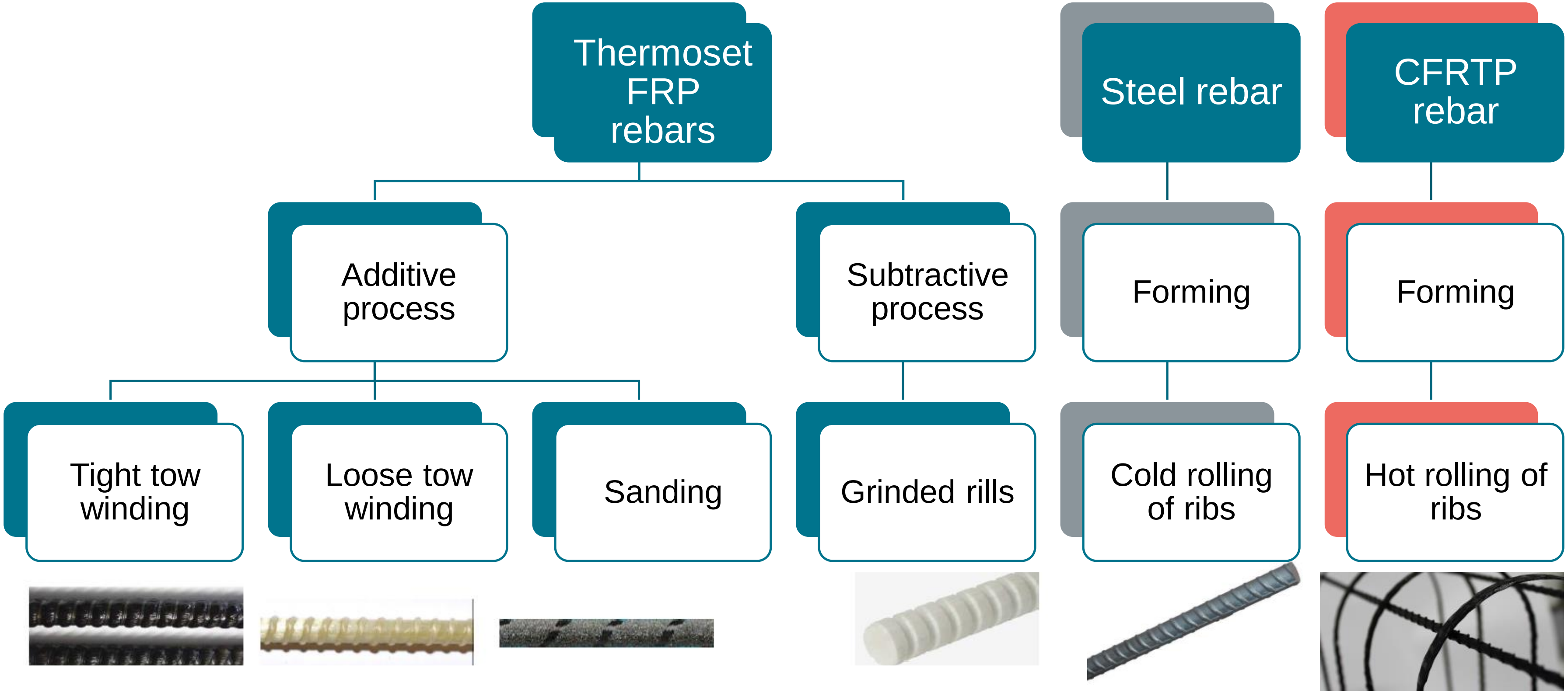
Overview: Concrete reinforcement materials.
Comparison of mechanics, durability and price

	Construction steel	Glass FRP	Carbon FRP
Tensile str. [MPa]	500	800 - 1600	1700 - 2350
Modulus [GPa]	210	45 - 60	110 - 170
Durability in concrete	low	medium – high*	high*
Price [€/kg]	0.75 (x4 for vol. comparison)	5 - 20	20 - 100
Conclusion	**Excellent price/ performance, but requires extra protection to slow corrosion**	**Good strength, but lacks modulus; glass fibers need protection vs. alkalinity**	**Excellent physical and chemical performance, but high costs**

*alkaline resistant polymer matrix assumed

3 SGL‘s CFRTP Rebar Approach

Concepts of rebar anchorage in concrete.



Pictures from C³ B1 project

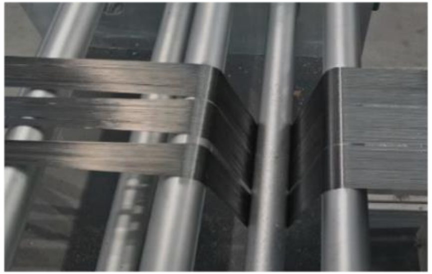
SGL's Innovative Composites for civil engineering.
Concrete reinforcement

C3 carbon concrete composite

Partners:
- TU Berlin
- Hentschke Bau
- DSI
- sbp
- TU Dresden

final demonstrator 20 m bridge part after prestressing

Pultrusion of carbon fibers → Melting of thermoplastics and impregnation of fibers → Adjust fiber fractions and shape



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General design of CFRTP rebar.

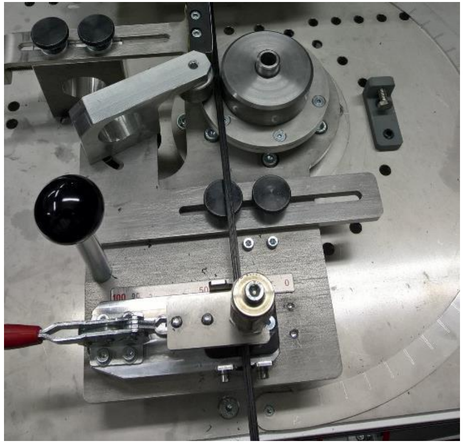
Design to most used steel reinforcement: Ø8 mm B500A

- Tensile strength 500 MPa -> force at break 25kN of steel rebar
- To match the force at break, 3 to 4 economic 50k carbon fibers are needed (SIGRAFIL® C T50 4.4/255-T140)
- Use of technical thermoplastic granulate for the matrix polymer
- 40 - 50% fiber volume fraction -> ~4,5 mm diameter

Steel and CFRTP rebar with equal force at break

Thermoforming of CFRTP rebars to Stirrups.

Fixing of rebar in forming device → Melting TP matrix in bending area → Bending needed angle and radius



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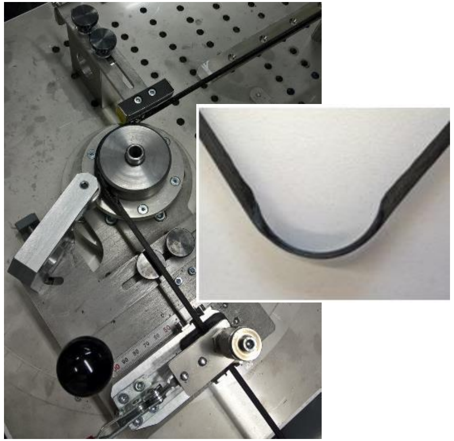
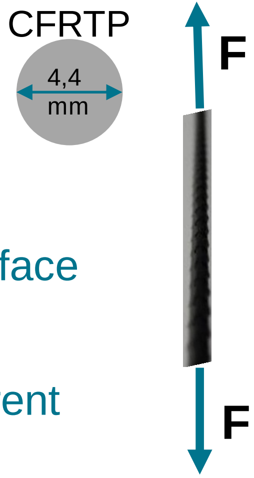


4 Material Testing & Demonstration

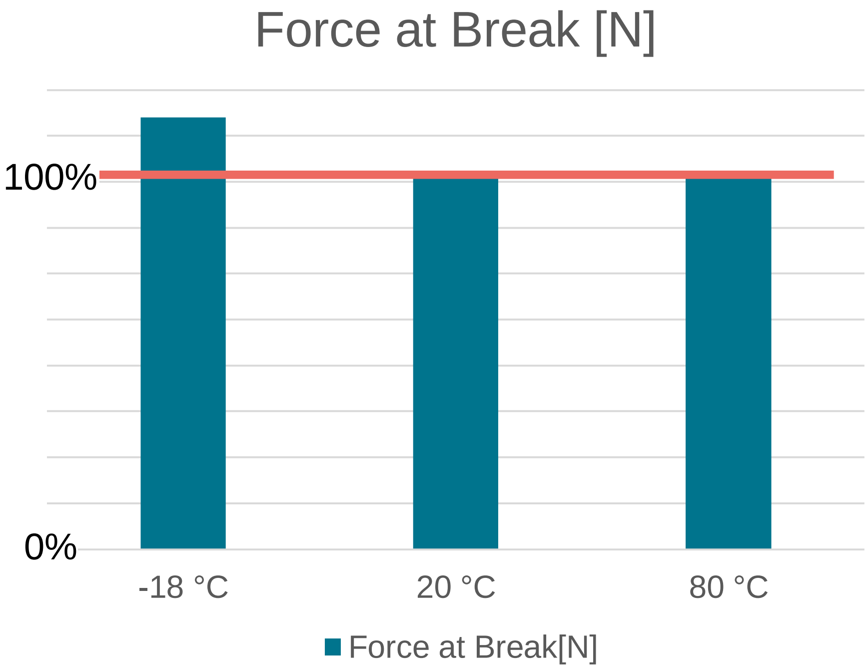
Thermomechanical stability of CFRTP rebar.

5 Specimen for each test:

- Diameter 4,4 mm
- 3x50k -> 150k CF filaments
- Thermoplastic matrix with surface profile
- Preferred fiber fraction at current state of development



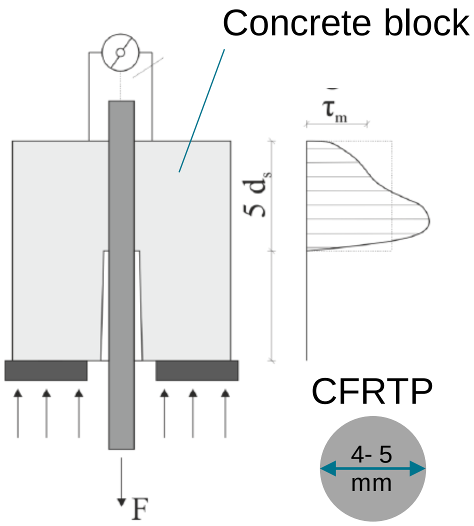
Tensile test with temperature variation



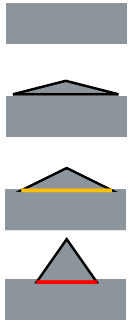
Tested at ibac of RWTH Aachen

Testing of the bonding strength.

Test setup:



Sample	Rib height [mm]	Mean of maximum bonding strength [MPa]
CFRTP rod	0	3.5
CFRTP rebar P0.4	0.4	*14.2*
CFRTP rebar P0.6	0.6	*13.5*
CFRTP rebar P0.8	0.8	*9.6*
ASTM D7957 for EP/GF rebars*		>7.6

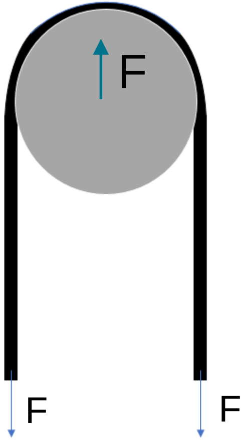


According to construction engineers a bonding strength of 15 MPa would be good.

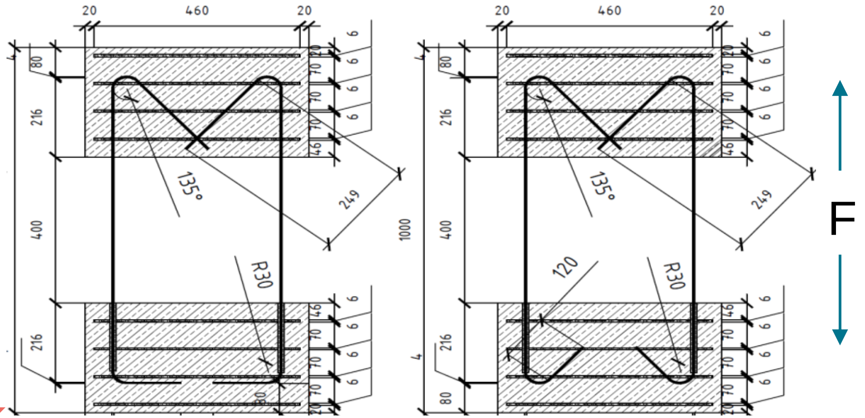
*EP: epoxy resin; tested at TU Berlin

Tensile tests on thermoformed CFRTP rebar.

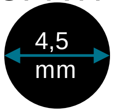
Test on 180° bent rebars



Test on stirrups in concrete



CFRTP



Bent capacity ~R_b/R_s	CFRTP rebar	Other FRP Bars
180° bent rebar	41%	33-41%
Stirrups in concrete	61-72%	46-68%

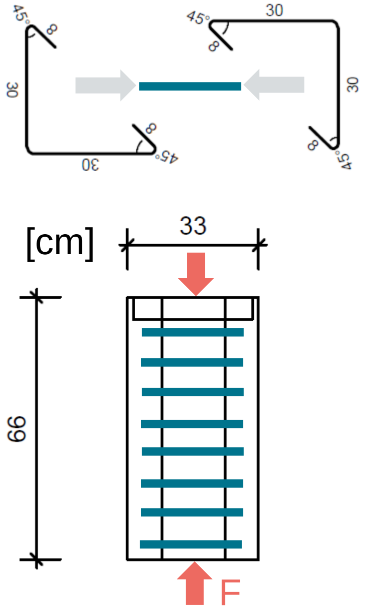
CFRTP

R_b: Tensile strength of bent bar; R_s: Tensile strength of straight bar; tested at TU Berlin

Extreme stirrup test according ETAG 013.

Ø6 mm B500A all 5 cm breaks at 3.2 MN

Ø4,35 mm CFRTP all 5 cm breaks at 3.2 MN



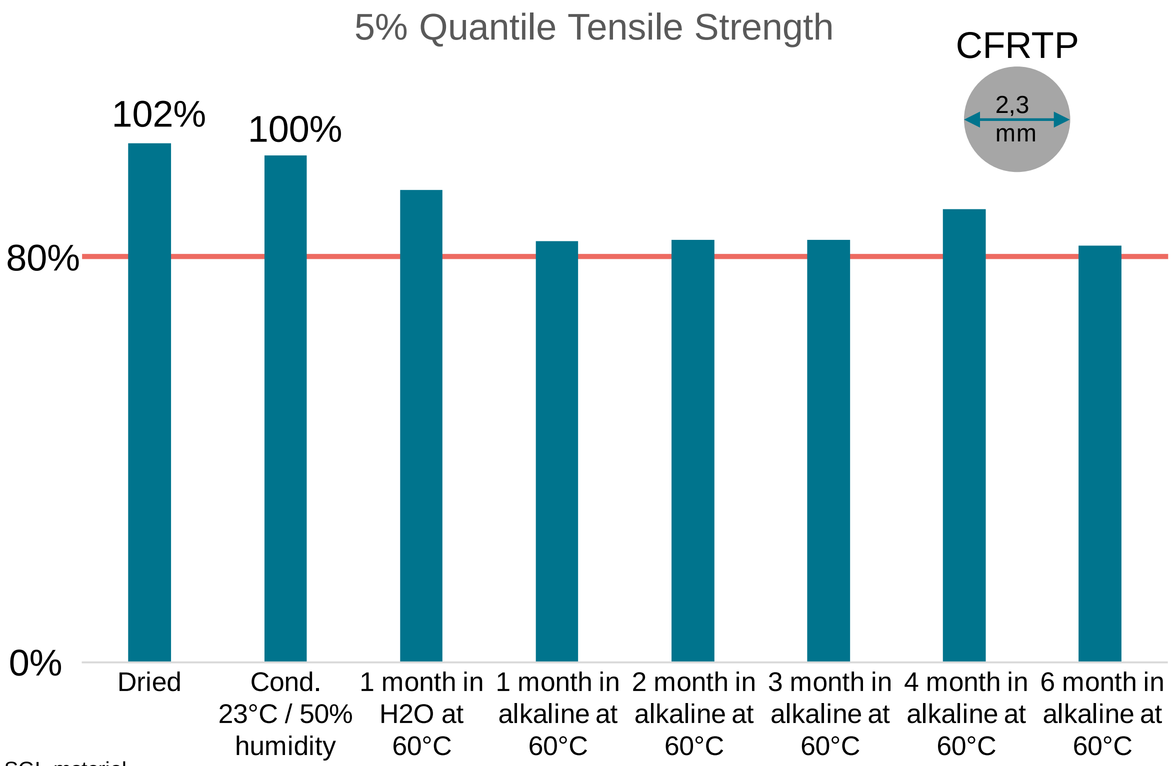
Equal performance

*tested at TU Berlin

Qualification of the material system for use in concrete.

Alkaline resistance test:

- According to ACI 440.3R Test B.6 Procedure A with up to 6 months ageing at approx. pH 12.8 and 60°C
- Then 5 tensile test on the CFRTP rods with thermoplastic matrix (3300 tex SIGRAFIL®)
- Complies with ASTM D7957 standard for GFRP reinforcement bars with epoxy matrix (80%*)



*Standard refers to difference of mean values - is also met by SGL material

Public funded project with construction industry.

C3 carbon concrete composite

Partner:

TU Berlin

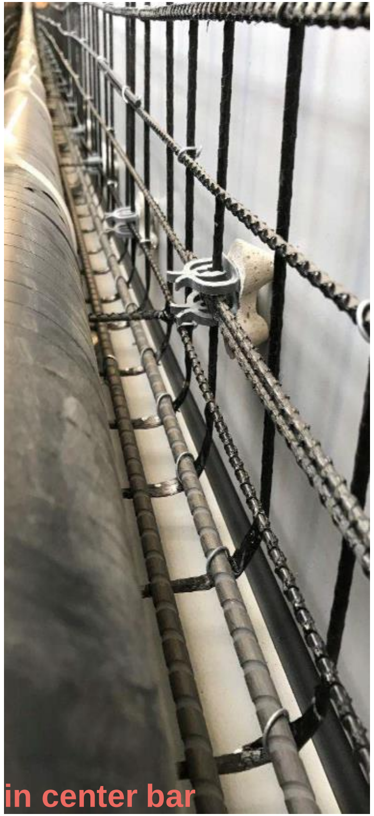
Hentschke Bau

DSI

sbp

TU Dresden

Public funded project with construction industry.

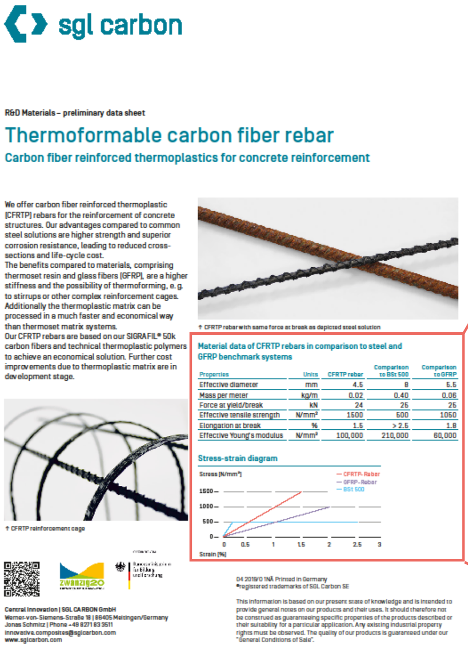


Pictures from Hentschke Bau GmbH, Bautzen

5 Summary

State of the Art and comparison.

New flyer CFRTP rebar


sgl carbon

R&D Materials – preliminary data sheet

Thermoformable carbon fiber rebar

Carbon fiber reinforced thermoplastics for concrete reinforcement

We offer carbon fiber reinforced thermoplastic (CFRTP) rebars for the reinforcement of concrete structures. Our advantages compared to common steel solutions are higher strength and superior corrosion resistance, leading to reduced cross-sections and life-cycle cost. The benefits compared to materials, comprising thermoset resin and glass fibers (GFRP), are a higher stiffness and the possibility of thermoforming, e.g. to stirrups or other complex reinforcement cages. Additionally the thermoplastic matrix can be processed in a much faster and economical way than thermoset matrix systems. Our CFRTP rebars are based on our SIGRAFIL® 50k carbon fibers and technical thermoplastic polymers to achieve an economical solution. Further cost improvements due to thermoplastic matrix are in development stage.

↑ CFRTP rebar with same force at break as depicted steel solution

↑ CFRTP reinforcement cage

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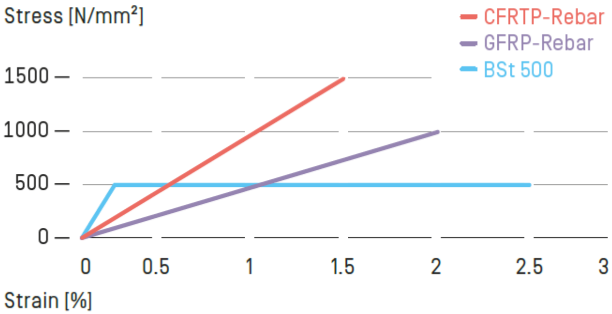
Material data of CFRTP rebars in comparison to steel and GFRP benchmark systems

Properties	Units	CFRTP rebar*	Comparison to BSt 500	Comparison to GFRP
Effective diameter	mm	4.5	8	5.5
Mass per meter	kg/m	0.02	0.40	0.06
Force at yield/break	kN	24	25	25
Effective tensile strength	N/mm²	1500	500	1050
Elongation at break	%	1.5	> 2.5	1.8
Effective Young's modulus	N/mm²	100,000	210,000	60,000

Stress-strain diagram



*Mechanical properties depend on fiber fraction, which is a key development parameter

Summary

The Carbon Fiber Reinforced Thermoplastic (CFRTP) rebar is:

- More lightweight and corrosion resistant than construction steel
- Produced by a high speed pultrusion process using molten thermoplastic polymer
- Better suited for construction than GFRP regarding stiffness
- Mechanically stable in tensile testing
  - Using common temperature variations (-18 to 80°C)
  - Resistant (up to 80% limit*) regarding warm water and harsh alkaline conditions
- Thermoformable due to thermoplastic matrix allowing
  - Hot rolling of a surface structure for concrete anchorage
  - Bending of the straight rebar to very good stirrups or other complex reinforcement structures

*ASTM D7957 standard

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Thank you!

Jonas Schmitz

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