STRUCTURAL BEHAVIOUR OF CONCRETE MEMBERS WITH EMBEDDED FIBRE REINFORCED POLYMER (FRP) BARS

PhD topic overview

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Bauhaus Summer School, 30th August 2023, Weimar

Concrete infrastructure

Corrosion

- Deicing salts
- Aggressive environments

↓

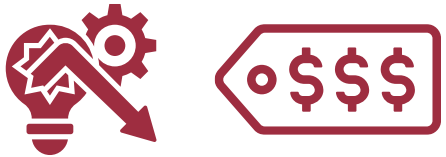
- Reduced lifespan
- High maintanance needs

?

Csömöri bridge (in 2020)

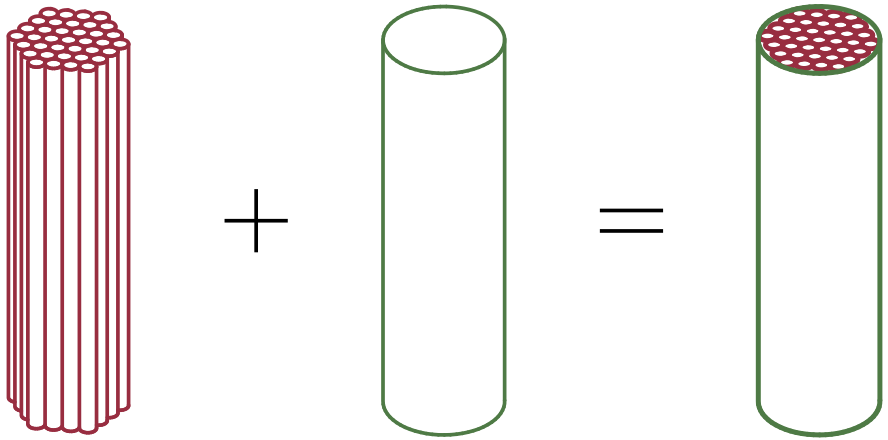
SOLUTIONS

- Increase concrete cover
- Stainless steel
- Galvanised steel
- Cathodic protection
- Epoxy coatings
- Concrete coatings



Non-metallic reinforcement:
FRP bars

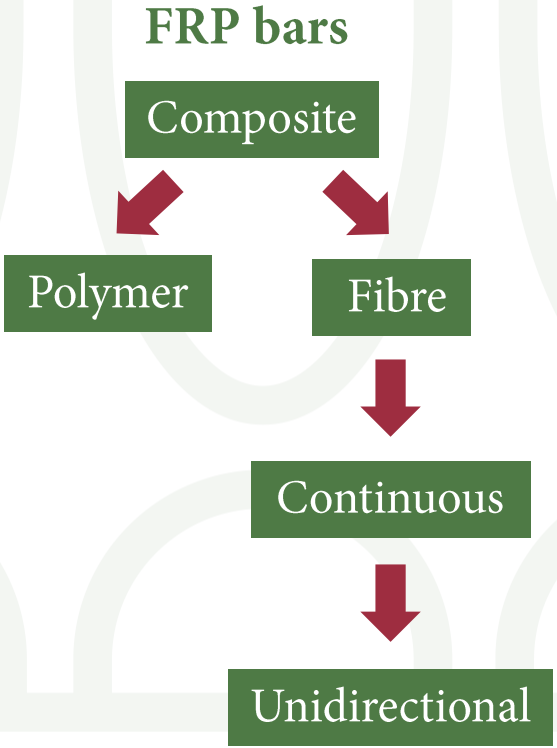
What are FRP bars?



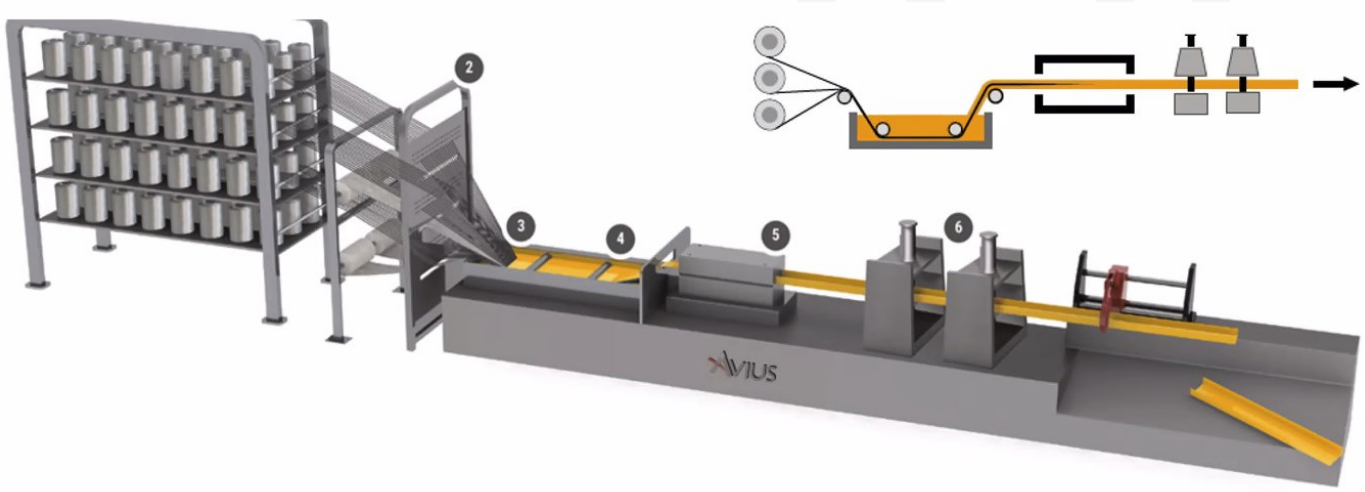
Fibres
- Glass
- Carbon
- Aramid
- Basalt

Matrix
- Epoxy
- Polyester
- Vinyl ester

Composite
- GFRP
- CFRP
- AFRP
- BFRP

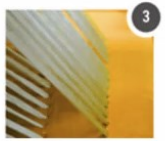


Manufacturing: Pultrusion

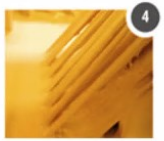


Rovings

Strand Mat



Guide

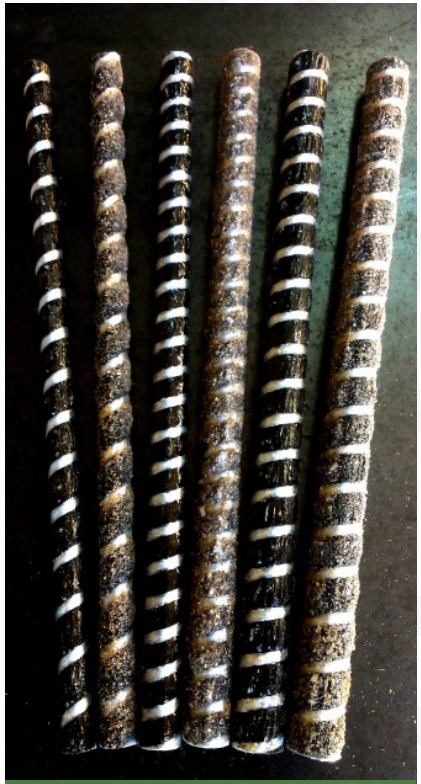


Resin bath

Curing die

Cut-off saw

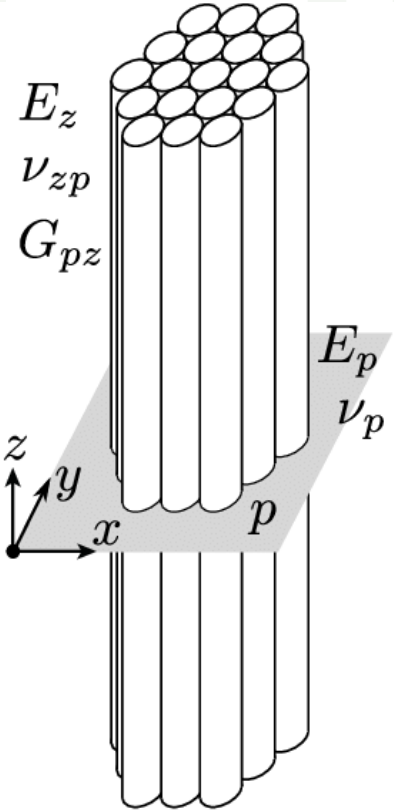
FINISHED PRODUCT



Composite behaviour

- Matrix:
  - *Isotropic*
  - *Linear elastic, ductile*
  - *Protection, load transfer, geometry*
- Fibres:
  - *Material dependent*
    - Isotropic – glass, basalt
    - Anisotropic, orthotropic
    - Transversely isotropic: aramid, carbon
  - *Linear elastic, brittle*
  - *Load-carrying*

Transversely isotropic FRP bar



Transversely isotropic

PHYSICAL PROPERTIES

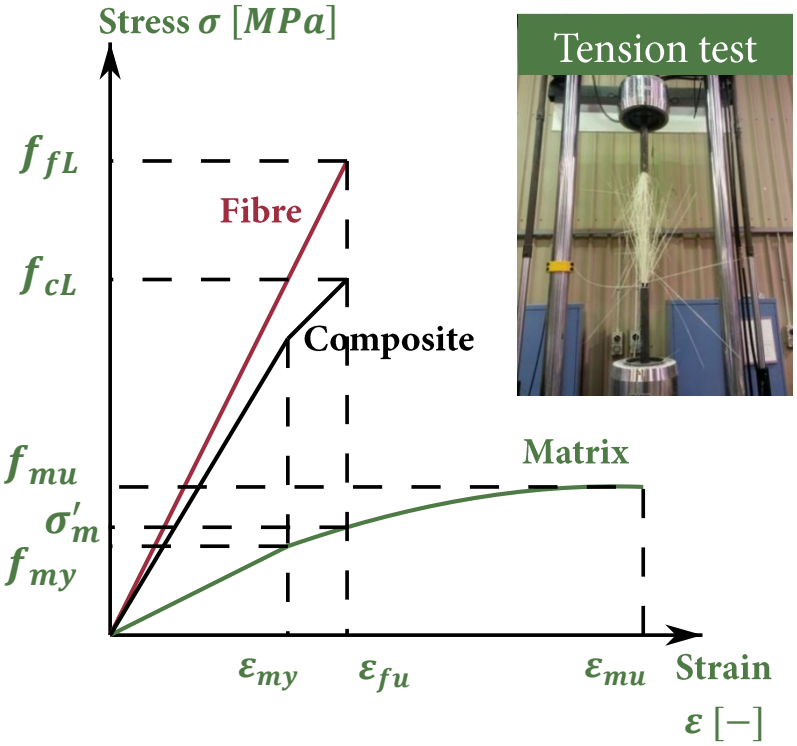
- Fibre volume fraction: $V_f = 0.5 - 0.75$
- With pultrusion: $V_f^{max} = 0.8$
- Carbon, aramid: negative CTE

$$V_f + V_m = 1$$

$$\rho_c = \rho_f V_f + \rho_m V_m$$

	GFRP	CFRP	AFRP	BFRP	Steel
Density [kg/m^3]	1730-2180	1430-1670	1300-1450	1990-2500	7850
Diameter [mm]	3-40	3-40	3-40	3-40	6-40
Length [m]	-	-	-	-	12
CTE longitudinal [10^{-6}/°C]	6-10	-9-0	-2-(-6)	~8	11
CTE transverse [10^{-6}/°C]	21-23	74-104	60-80	18-27	11
Glass transiton temperature [°C]	70-175	70-175	70-175	70-175	(~300)

MECHANICAL BEHAVIOUR



Tension

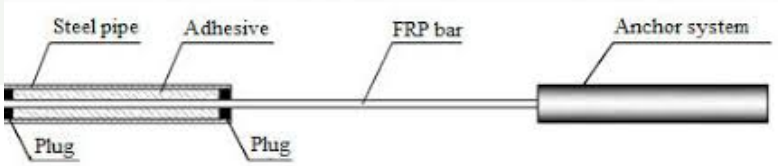
Isostrain situation: $\varepsilon_c = \varepsilon_m = \varepsilon_f$

Load bearing: $F_c = F_m + F_f$

Elastic modulus: $E_{cL} = E_m(1 - V_f) + E_{fL}V_f$

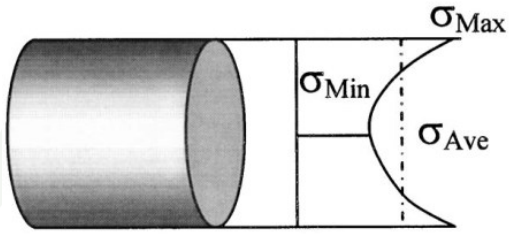
Tensile strength: $f_{cL} = \sigma'_m(1 - V_f) + f_{fL}V_f$

$$\sigma'_m = f_{fL}\,\frac{E_m}{E_{fL}}$$



MECHANICAL PROPERTIES

- ~ Properties of constituents + quality of bond
- ~ Volume fractions + distribution
- ~ Diameter
- ~ Quality control – voids
- ~ Load direction



Shear-lag effect

	GFRP	CFRP	AFRP	BFRP	Steel
Longitudinal tensile strength [MPa]	450-1600	600-3500	1000-2500	1000-1700	450-700
Longitudinal Young's modulus [GPa]	35-60	100-580	40-125	40-70	200
Transverse Young's modulus [GPa]	2.1-4.1	2.1-4.1	2.1-4.1	2.1-4.1	200
Ultimate tensile strain [%]	1.2-3.7	0.5-1.7	1.9-4.4	2.0-2.7	5-10
(Major) Poisson ratio [-]	~0.28	~0.34	~0.27	~0.20	~0.30

Long-term effects

Long-term strength

- Fibres → excellent
- Matrix → viscoelastic

→ Debonding, resin microcracking ! Tension in the matrix is low

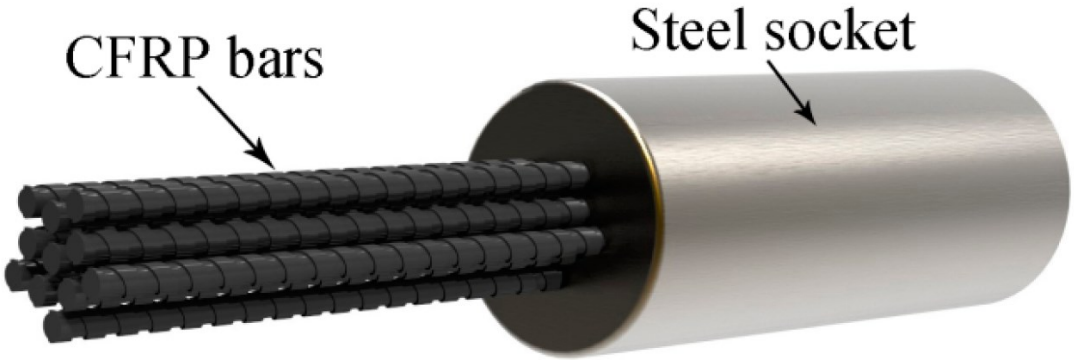
→ Implies: FRP bars long term strength is lower

Relaxation

~ Matrix, fibre

~ Environment

- Aramid is susceptible
- Generally small



Summary of Material Properties

Advantages

- Corrosion resistance
- High strength
- Light weight
- Easy cuttability
- Electromagnetic neutrality
- Heat insulation (~0.04 W/mK)
- Tolerates low temperatures

Disadvantages

- Low transverse strength
- Low modulus of elasticity
- Brittle failure
- Compression behaviour
- Thermoset resin – deforming
- CTE, T_g - fire resistance
- Diameter – shear-lag

Applications I. – Traffic infrastructure

+ barrier and retaining walls, tunnels etc.

Applications II. – Liquid structures

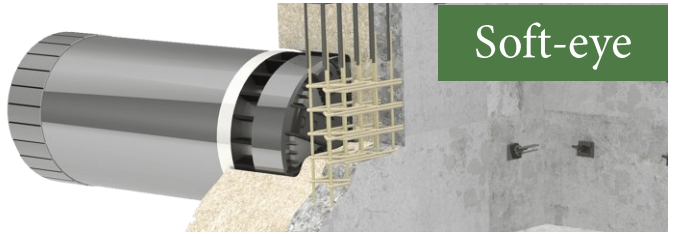
Pools

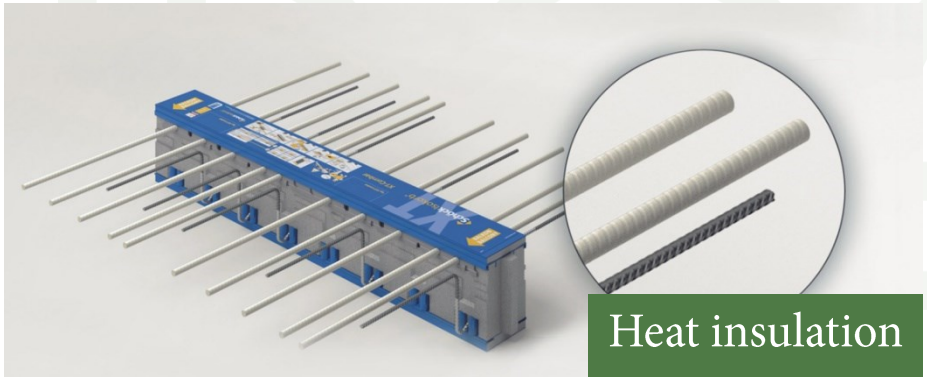
Submerged in sea

Sea walls

+ wastewater treatment plants, containers, etc.

Applications III. – Special applications





GUIDES AND STANDARDS

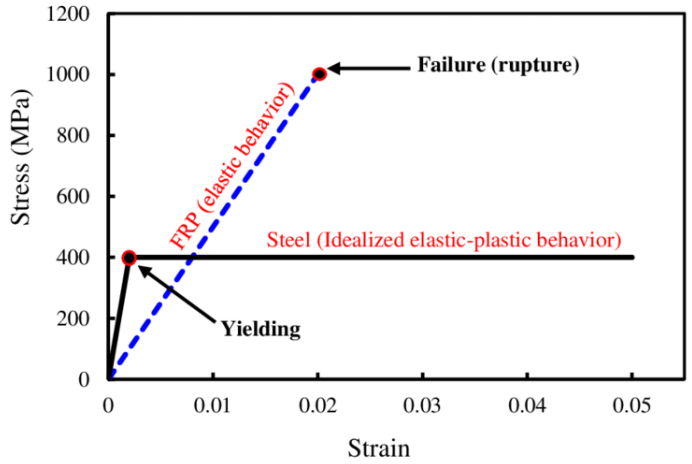
- 1997: JSCE - FRP bar Design and Construction
- 2004: ACI 440.4R-04 - Prestressing with FRP tendons
- 2007: *fib* Bulletin No. 40 - Technical report: FRP reinforcement
- 2015: ACI 440.1R-15 - FRP bar Design and Construction
- 2018: SP 405.1325800 - Design rules
- 2019: CSA 807 - FRP manufacturing requirements

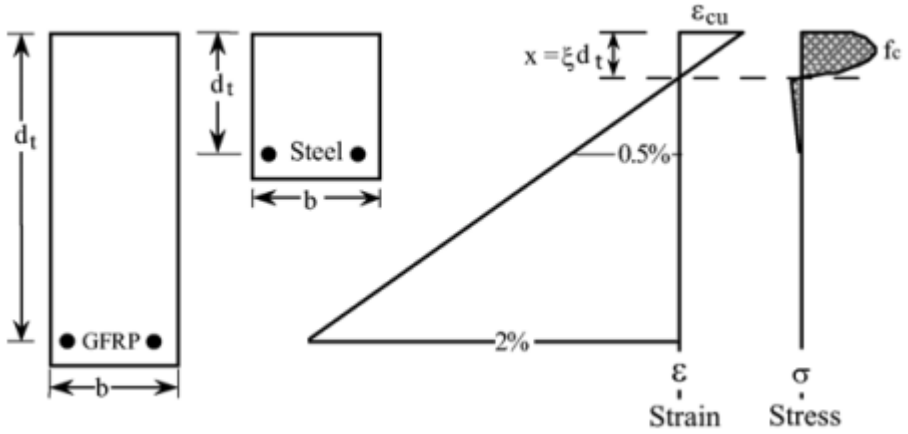
Countries: USA, Canada - Russia, Japan - Italy, Norway, UK, Germany,

DESIGN

- Focus on flexural behaviour
- Assumptions: plane sections remain plane + perfect bond
- Lower stiffness than steel
  - *Large portion tensioned + Larger flexural deflections*
  - *Big stiffness difference at crack → high demand on bond*

FRP fully utilised





RESEARCH NEEDS

- Material testing
  - *Data on durability and long-term behaviour*
- Technological development
  - *Development of prestressing and material testing systems*
  - *Improving bent bar manufacturing*
- Design-related
  - *Pseudo-ductility*
  - *Bond: bent bars*
  - *Hybrid reinforced RC members*
  - *Compression – columns*
  - *Effective shear reinforcement, punching shear*
  - *Design and construction guidelines and specifications*

Research direction: Design-related

Familiar

New

Etalon

Start from the basics

- Fundamental structural element: beam
- Which create different conditions: tension, shear, compression
- Resulting in different structural behaviour

How and to what extent is the structural behaviour different?
How can it be described? – modified and supplemented formulas

Compared to steel

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Thank you for your attention!

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