Sheffield Hallam University

Basalt fibres for concrete strengthening

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Citation:

SERBESCU, Andreea, PILAKOUTAS, Kypros and GUADAGNINI, Maurizio (2017). Basalt fibres for concrete strengthening. In: Seismic Loss, Rehabilitation and Post-earthquake Crisis Management of Critical Infrastructure 2017, Istanbul, Turkey, 20th November 2017 - 24th November 2017. (Unpublished) [Conference or Workshop Item]

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Seismic Loss, Rehabilitation and Post-Earthquake Crisis Management of Critical Infrastructure

2nd International Workshop

20-24 November 2017, Istanbul, Turkey

Basalt Fibres for concrete strengthening

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Work carried out at The University of Sheffield
Prof. K. Pilakoutas
Dr M. Guadagnini

The University Of Sheffield. ITU BRITISH COUNCIL Newton Fund TÜBİTAK

Contents

- Research Rationale
- Experimental work
- Findings and Conclusions

Strengthening

- **Traditional - Steel**

G. Nichols

- **Modern - Fibre Reinforced Polymers (FRPs)**

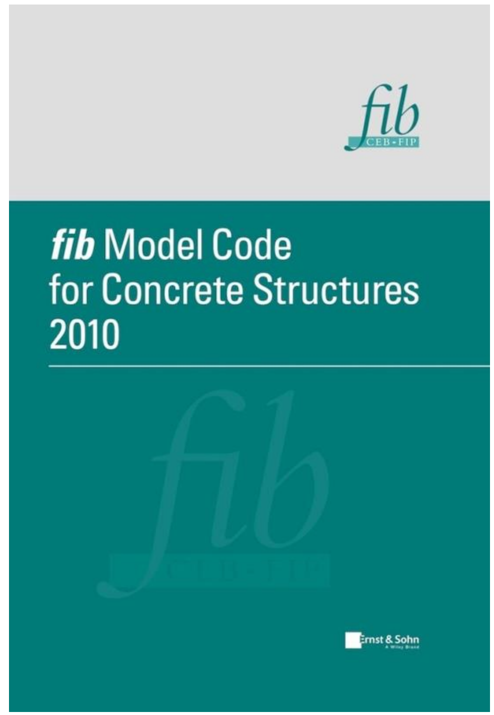
↓

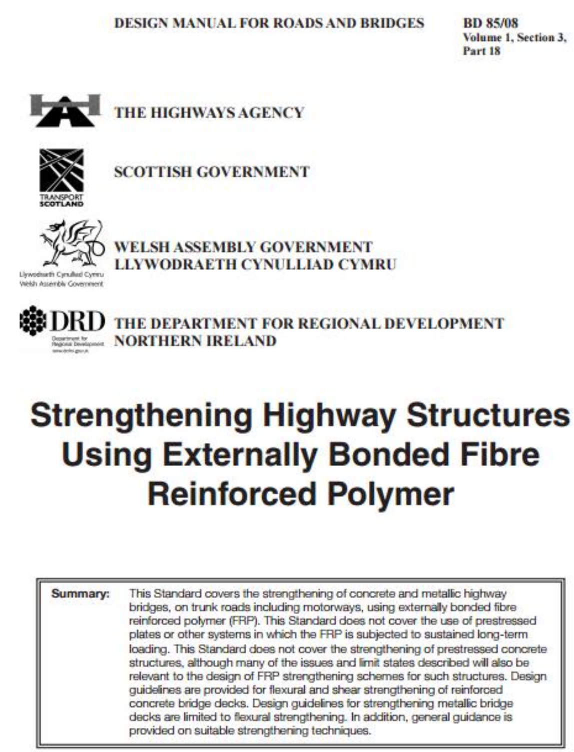
Carbon, Glass, Aramid

sika.com

buildera.com

FRP as reinforcement for concrete has already been validated!





DESIGN MANUAL FOR ROADS AND BRIDGES

BD 85/08
Volume 1, Section 3,
Part 18

THE HIGHWAYS AGENCY

SCOTTISH GOVERNMENT

WELSH ASSEMBLY GOVERNMENT
LLYWODRAETH CYNULLIAD CYMRU

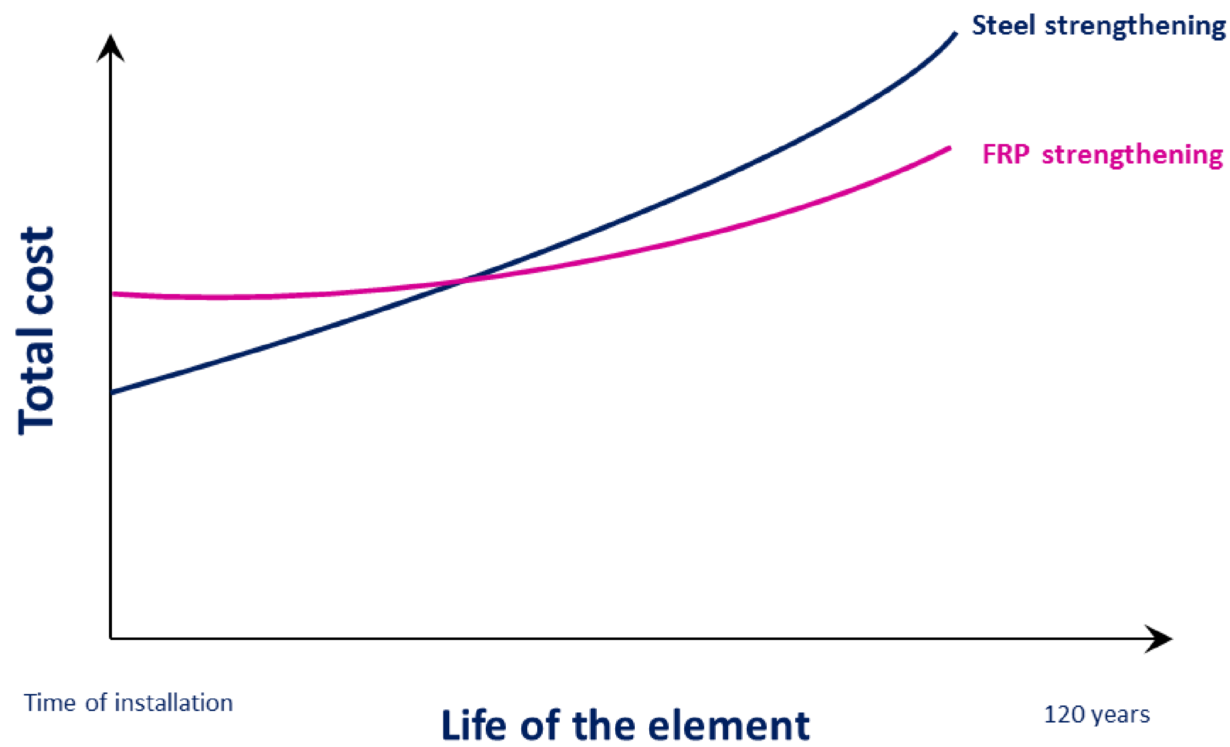
THE DEPARTMENT FOR REGIONAL DEVELOPMENT
NORTHERN IRELAND

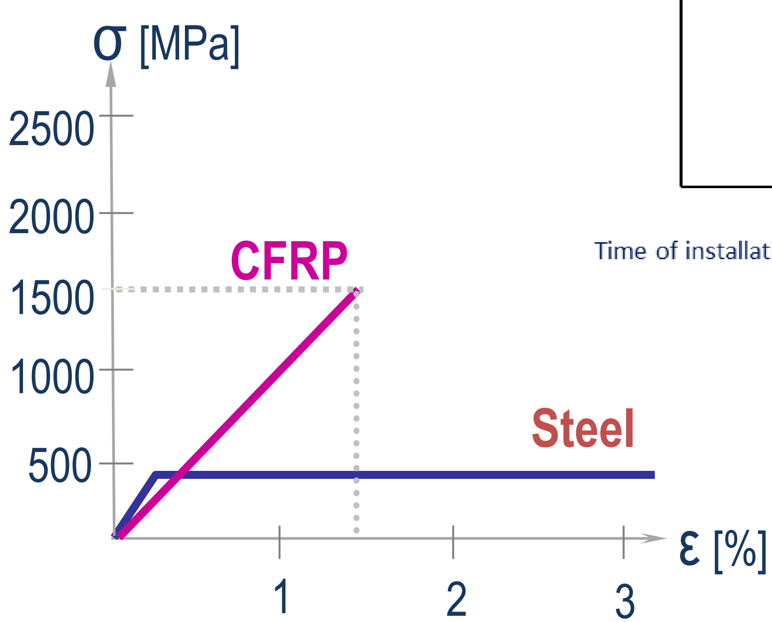
Strengthening Highway Structures Using Externally Bonded Fibre Reinforced Polymer

Summary: This Standard covers the strengthening of concrete and metallic highway bridges, on trunk roads including motorways, using externally bonded fibre reinforced polymer (FRP). This Standard does not cover the use of prestressed plates or other systems in which the FRP is subjected to sustained long-term loading. This Standard does not cover the strengthening of prestressed concrete structures, although many of the issues and limit states described will also be relevant to the design of FRP strengthening schemes for such structures. Design guidelines are provided for flexural and shear strengthening of reinforced concrete bridge decks. Design guidelines for strengthening metallic bridge decks are limited to flexural strengthening. In addition, general guidance is provided on suitable strengthening techniques.

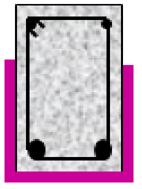
- Cost Issue
- Debonding Issue

FRP Cost Issue

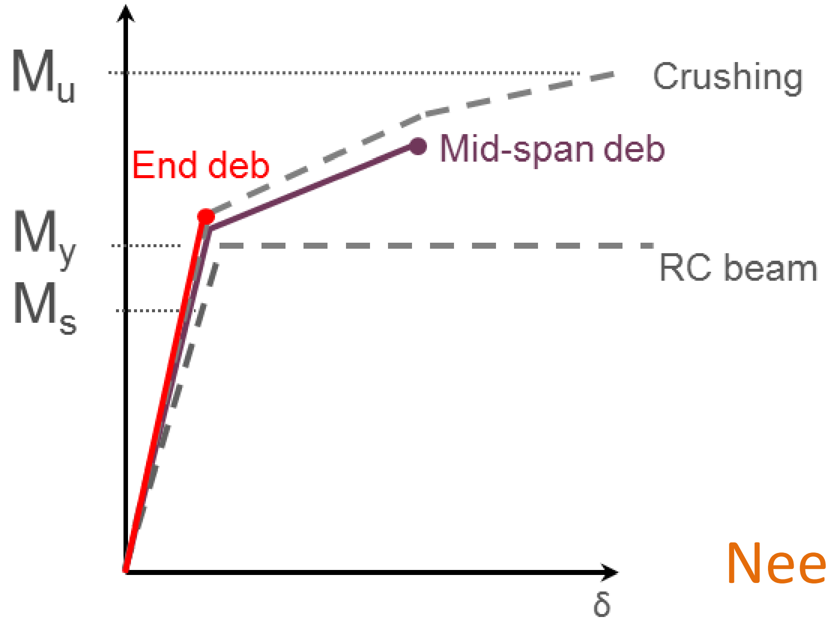


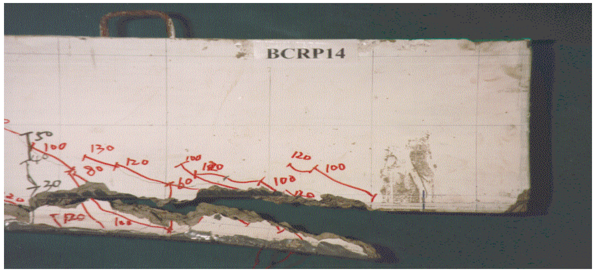


FRP Debonding Issue



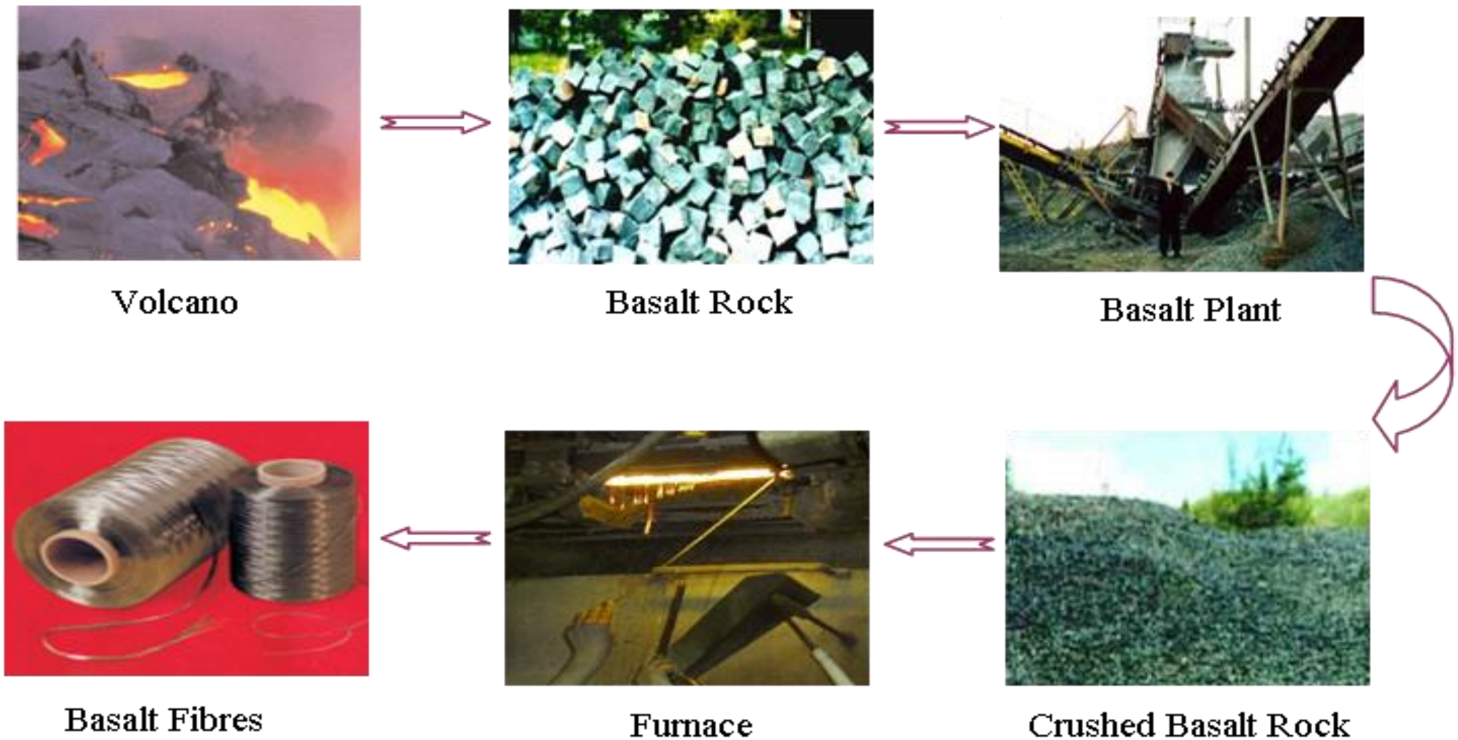
U – strips (235x90) mm





Need for a more cost effective fibre!

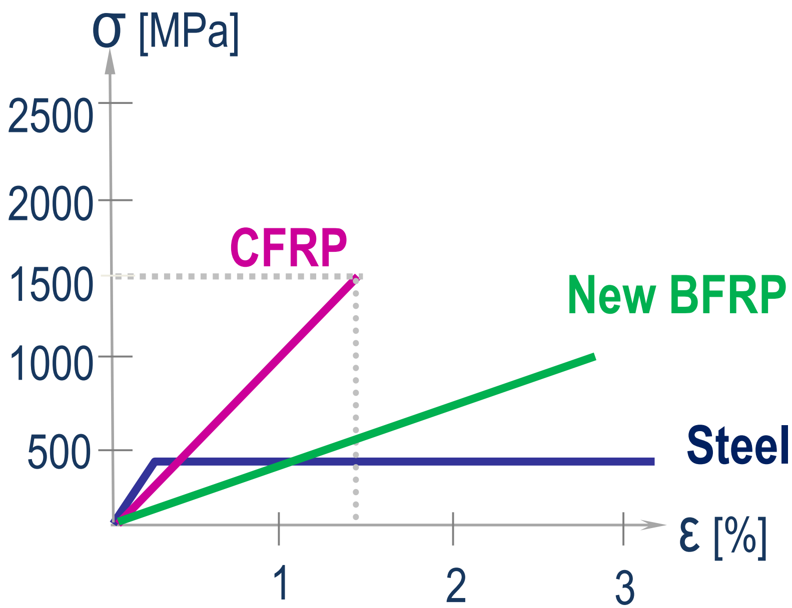
Relatively new Basalt Fibers

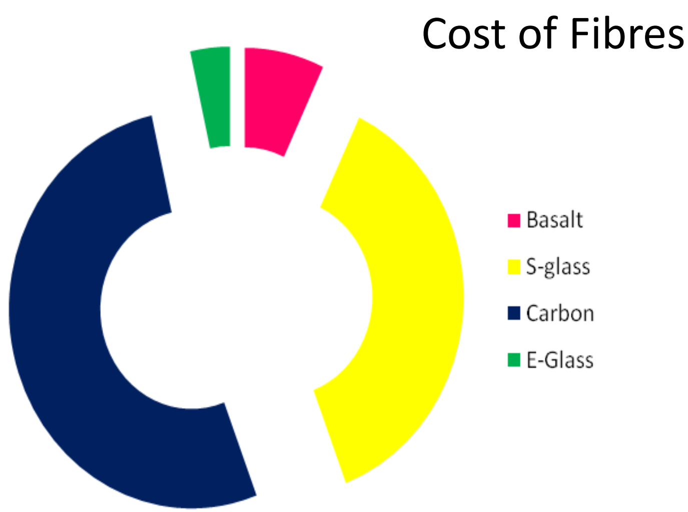


Basalt fabric

Basalt FRP (BFRP) bars/plates/strips

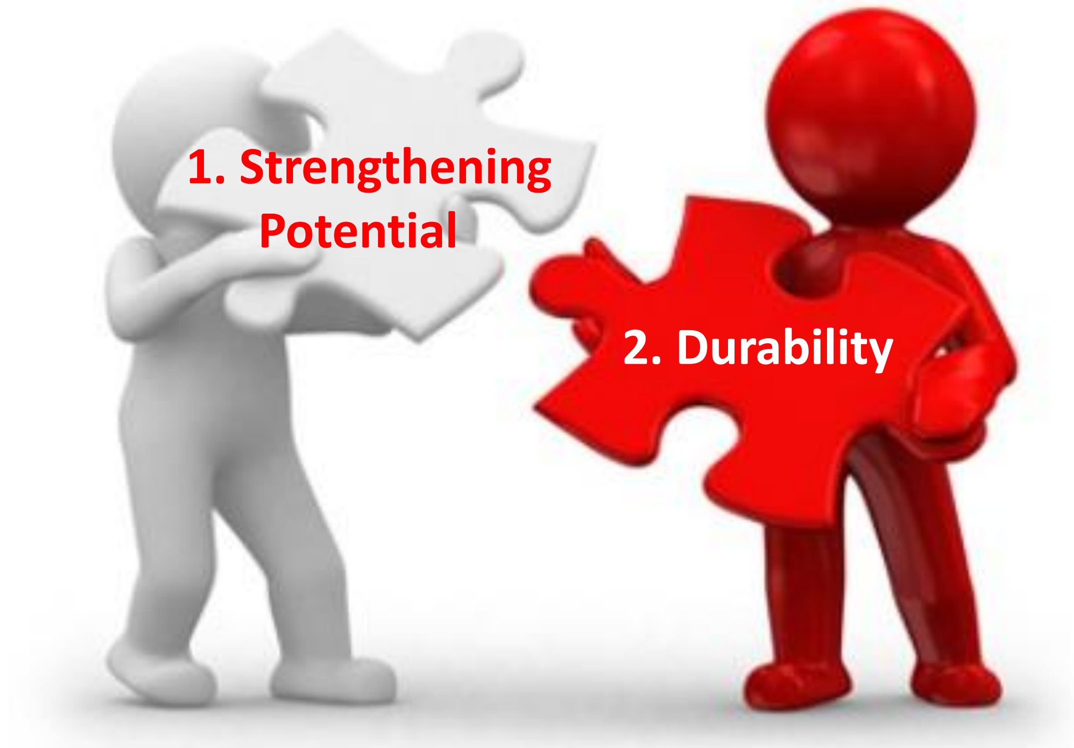
Relatively new Basalt Fibers



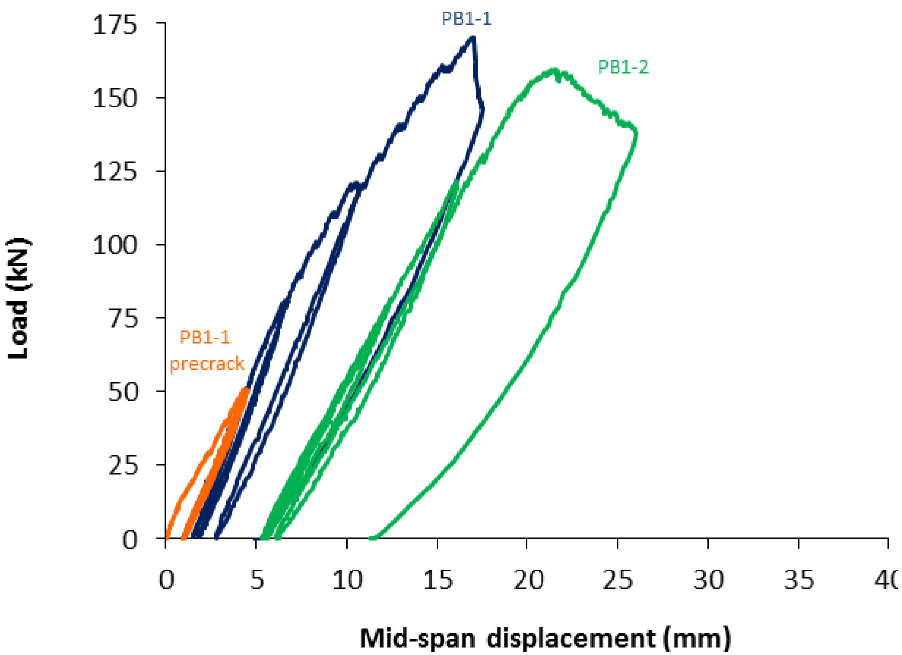


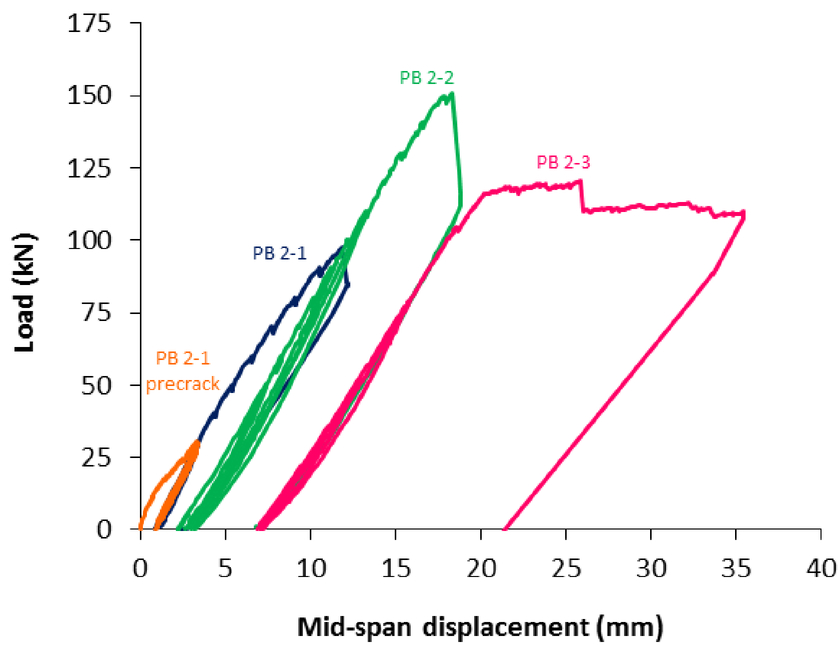
Characteristic of fibres	Basalt	E-Glass	S-Glass	Carbon
Tensile Strength (MPa)	3000~4840	3100~3800	4020~4650	3500~6000
Elongation at break (mm)	3.1	4.7	5.3	1.5~2.0
Elastic modulus (GPa)	79.3~93.1	72.5~75.5	83~86	230~600
Temperature of use (°C)	-260~+500	-50~+380	-50~+300	-50~+700

Can Basalt FRP represent an economic alternative to the traditional fibres?



Experimental Program - Overview





PB1-1 - end debonding

↓ *added BFRP strips, stronger concrete*

PB1-2 - crushing

PB2-1 – end debonding

↓ *changed with wider CFRP plate, added BFRP strips, stronger concrete*

PB2-2 – end debonding

↓ *steel strapped failed side, longer anchorage length*

PB2-3 – end debonding

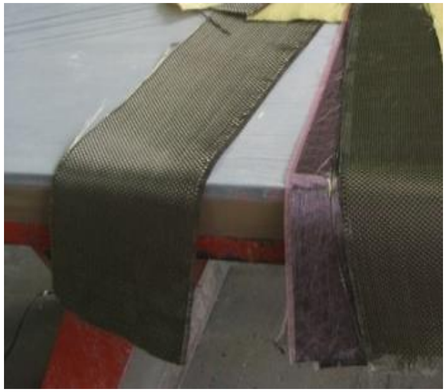
SB5 – control

CB0 - control

By N. Pesic

1. Strengthening potential of Basalt FRPs

BFRP strips - preparation

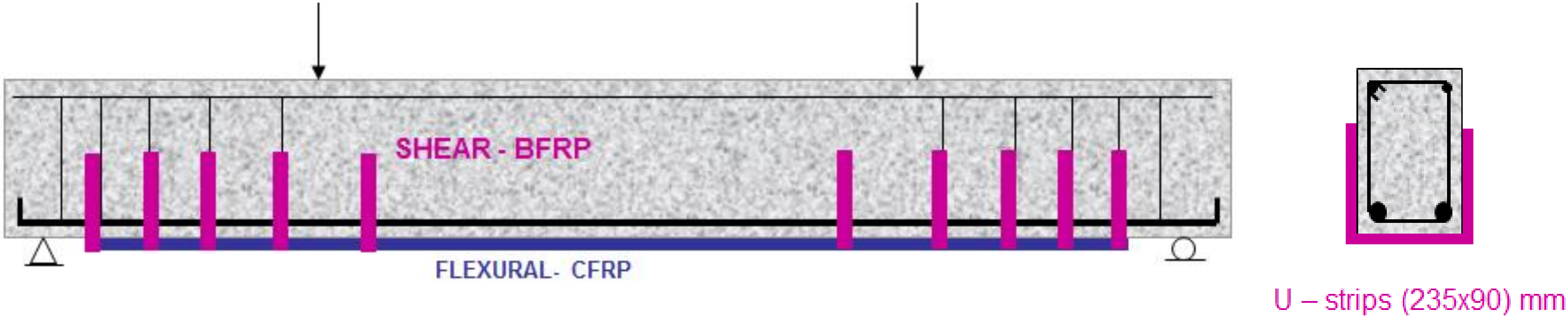


Basalt fabric

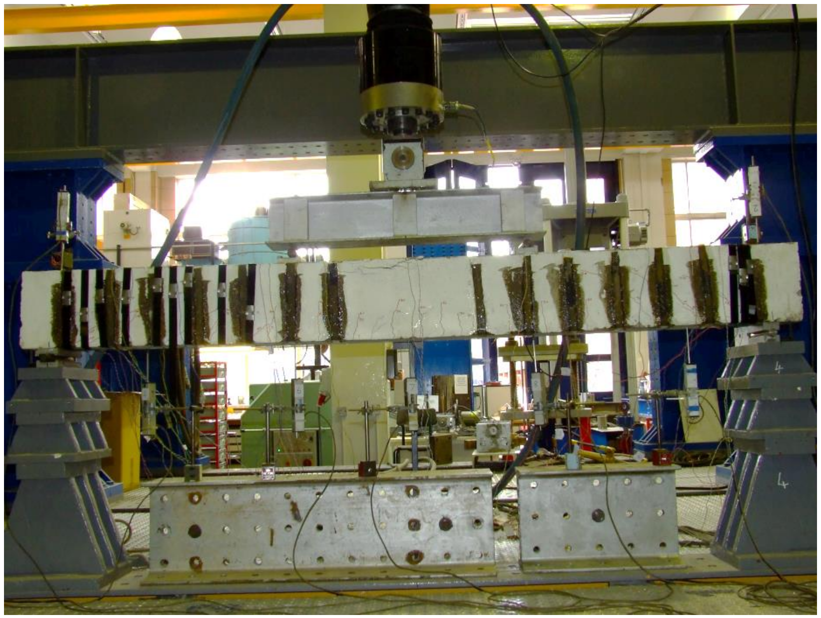
Basalt strips

Impregnate - BFRP

Bond onto concrete

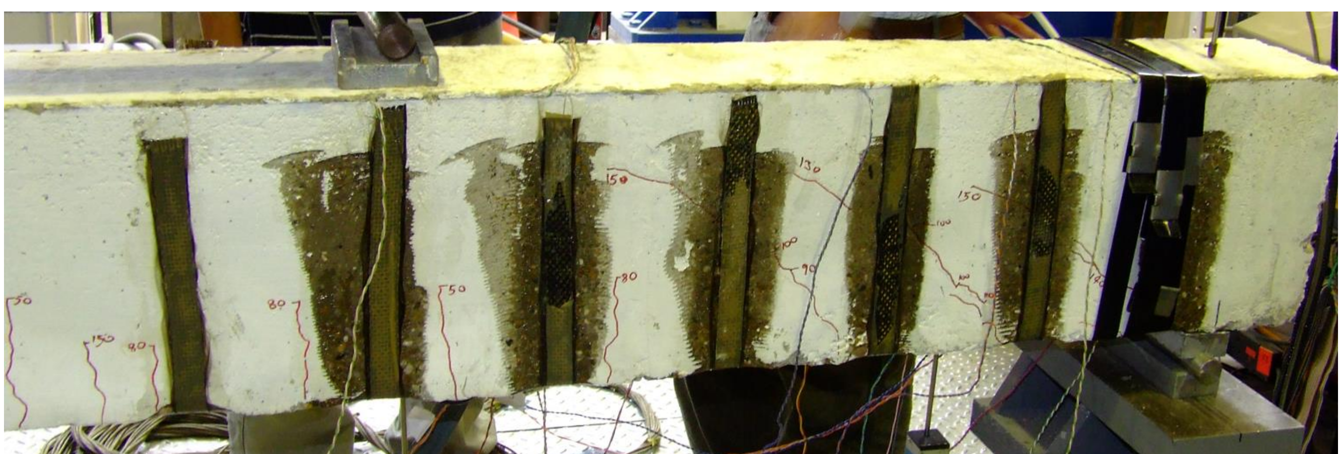


Beam tests



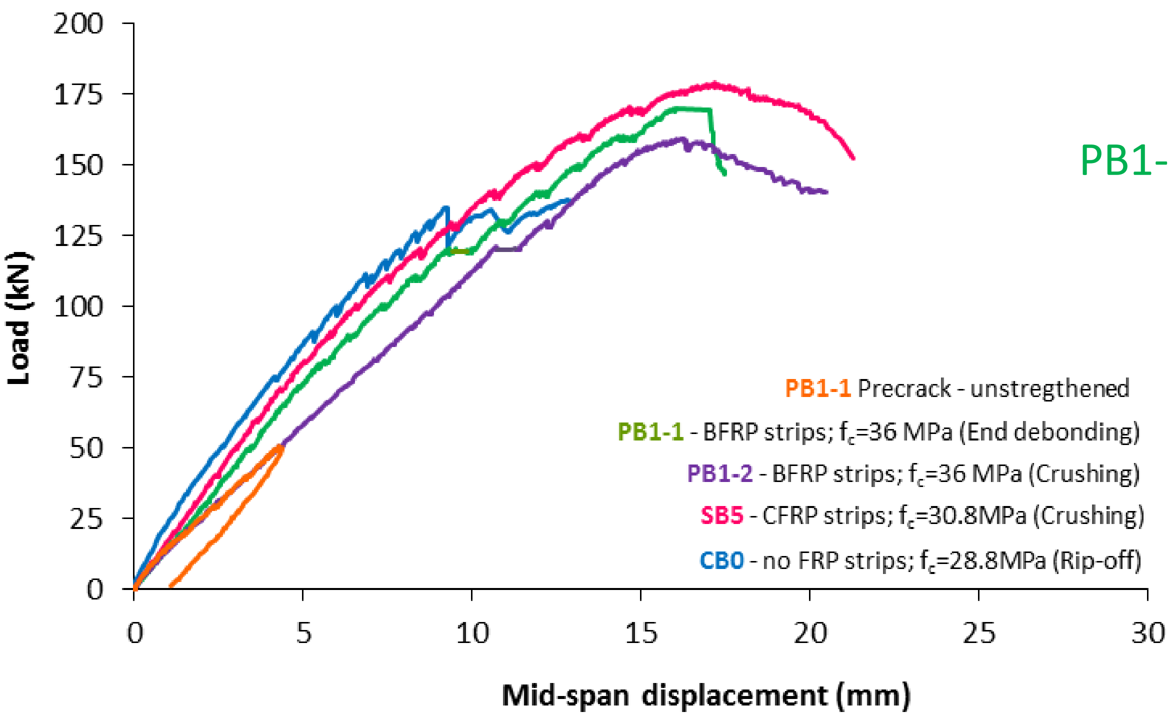
Beam	P_{ult} (kN)	M_{ult} (kNm)	P_y (kN)	M_y (kNm)	V_f (kN)	V (kN)	P_{deb} (kN)	Failure mode	P_{exp} (kN)
PB1-1	224	86	208	80	20	196	119	End debonding	171
PB1-2	209	80	-	-	20	196	119	Crushing	160
CB0	198	76	196	75	-	150	110	Rip-off	134
SB5	207	79	204	78	34	219	112	Crushing	179

Beam	P_{ult} (kN)	M_{ult} (kNm)	P_y (kN)	M_y (kNm)	V_f (kN)	V (kN)	P_{deb} (kN)	Failure mode	P_{exp} (kN)
PB2-1	164	63	120	46	-	398	59	Peel-off	98
PB2-2	216	83	153	59	20	482	97	End debonding	151
PB2-3	206	80	158	60	20	482	62	End debonding	121



1. Strengthening potential of Basalt FRPs

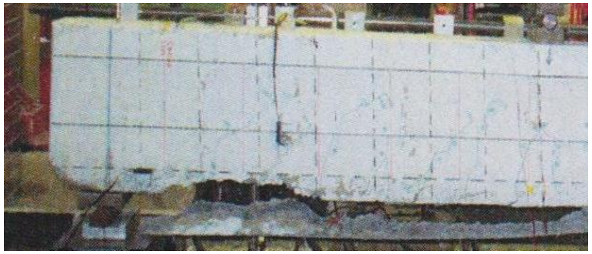
Results



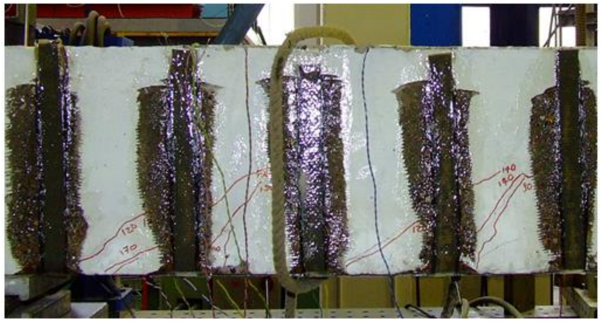
- Increase in debonding load (~27%)
- Pseudo-ductility

Plate end – crack patters

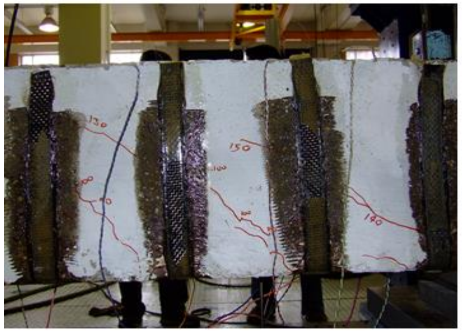
CB0 beam (brittle)



PB1-1 beam (distributed cracking)



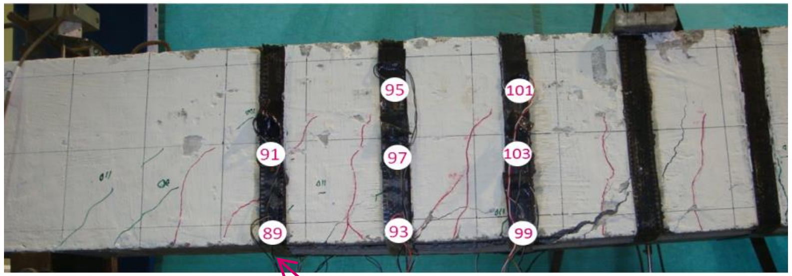
PB1-1 beam (distributed cracking)

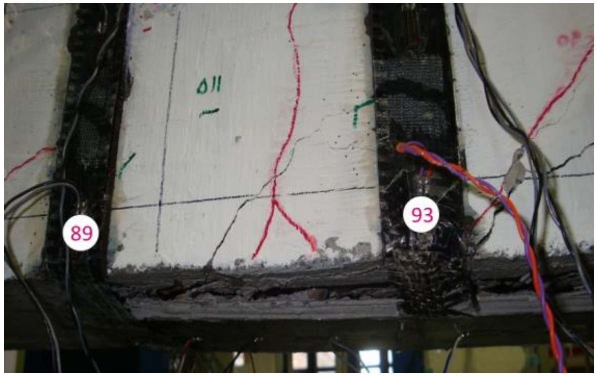


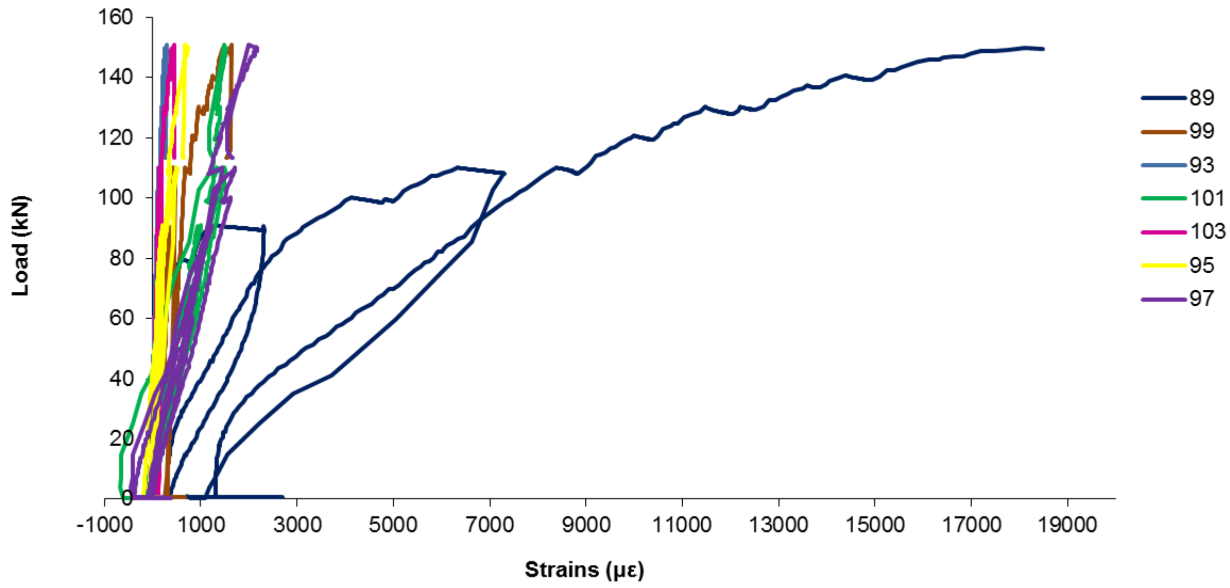
1. Strengthening potential of Basalt FRPs

Results

- High strain in Basalt FRP strips
- No debonding of BFRP strips







Experimental Program - Overview

Set bar type	Tests		No. of bars per diameter	Nominal diameter (mm)	Actual area	Total no. of bars
1[1]	Tensile test (**TT1**)		5	3	9.6	20
			5	5	23.8	
			5	8	57.1	
			5	10	86.8	
2[1]	Tensile test (**TT2**)		5	3	9.4	5
	Durability test (**DT2**)	Water/20°C/1000h	5	3	9.5	20
		Water/60°C/1000h				
		pH13/20°C/1000h				
		pH 13/60°C/1000h				
		Water/60°C/200h	3	3	9.1	3
3[2]	Tensile tests (**TT3**)		9	6	33.3	24
			5	4	15.5	
			5	5	23.6	
			5	7	44.4	
	Durability test (**DT3**)	pH 9/20°C/100h	5	6	33.2	5
		pH 9/20°C/1000h	5	6	32.9	5
		pH 9/40°C/100h	5	6	33.2	5
		pH 9/40°C/1000h	5	6	30.1	5
		pH 9/60°C/100h	5	4	15.8	20
			5	5	22.9	
			5	6	32.6	
			5	7	44.4	
		pH 9/60°C/1000h	5	6	32.7	5
		pH 9/20°C/5000h	5	6	32.6	5
		pH 9/40°C/5000h	5	6	33.2	5
		pH 9/60°C/5000h	5	6	32.5	5

Note: the nominal diameters were verified and used for stress calculations for bars without strain

132 Basalt FRP bars

- Time:
100h, 200h, 1000h and 5000h

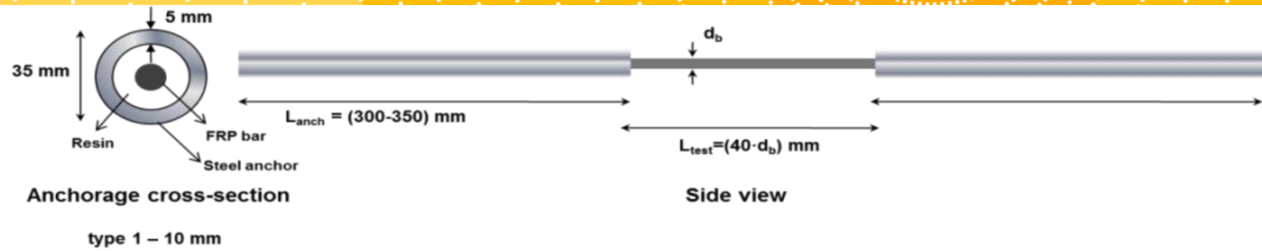
- Alkalinity:
pH7, pH9 and pH13

- Temperature:
20°C, 40°C and 60°C

2. Durability of Basalt FRPs

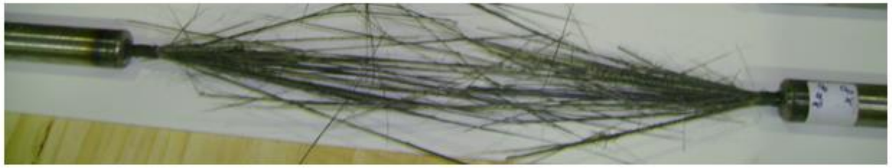
Conditioning

Basalt FRP bars



Conditioning

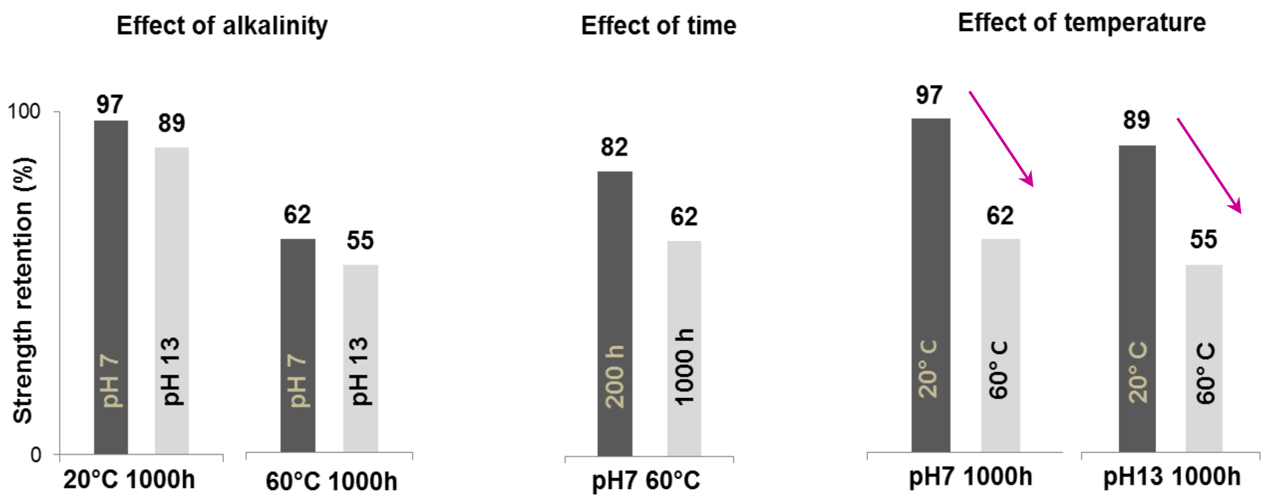
Tensile testing



2. Durability of Basalt FRPs

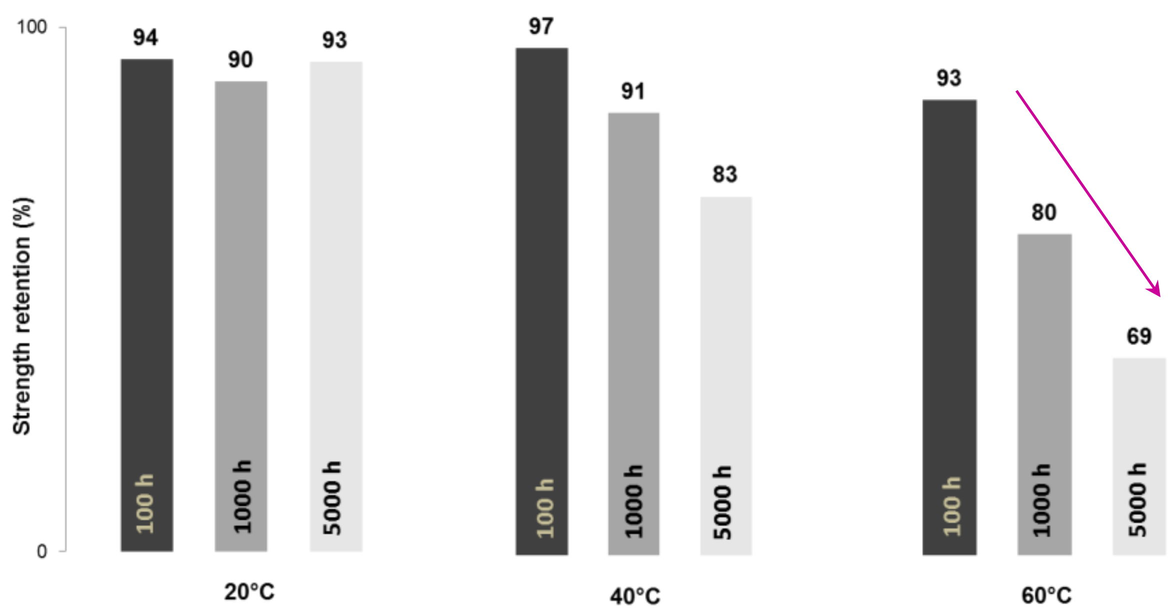
Results

type 1 bars

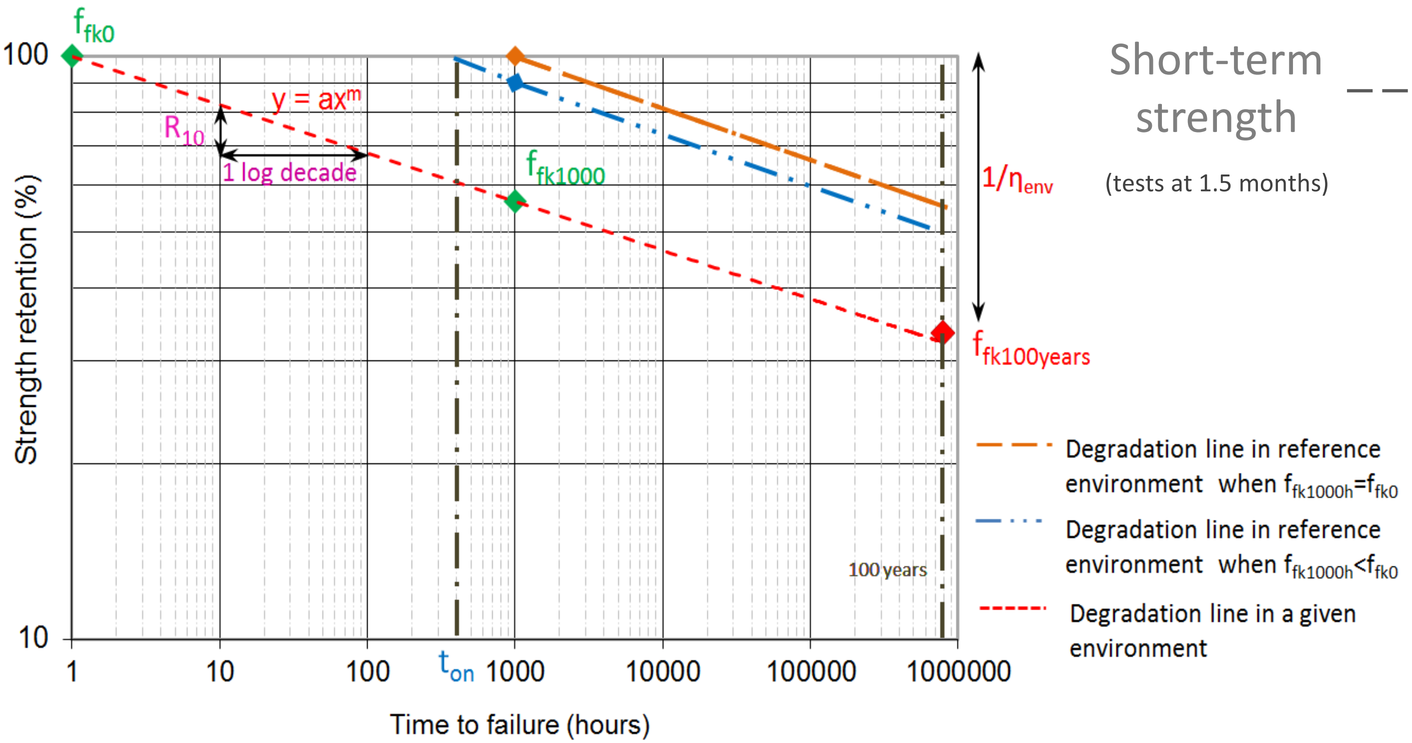


- pH – less effect
- Temp – high effect

type 2 bars in pH9



Long-term strength prediction in any environment



Short-term strength (tests at 1.5 months) → Long-term strength (100 years service life)

fib 40 (2007) $n = n_{mo} + n_T + n_t + n_d + n_{pH} + n_{on}$

R_{10} - cst. n_{on} - changes

Long-term strength prediction in any environment

Step 1. Condition specimens — 1000h, 20°C, 40°C, 60°C, water, pH13

Step 2. Measure short term-strength — Tensile testing

Step 3. Establish degradation parameters — Use Table

Step 4. Determine the reference degradation curve — Find n_{on} and R_{10}

Step 5. Estimate the long-term strength

analytically

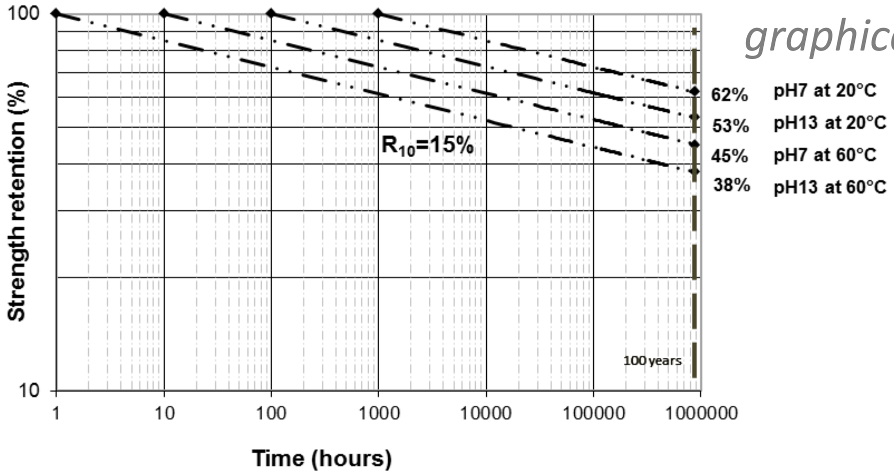
- environmental strength reduction factor

$$\eta_{env,t} = 1/((100 - R_{10})/100)^n$$

- percentage of the long-term strength retained

$$f_{fkt\%} = (1/\eta_{env,t}) \cdot 100$$

graphically



Conclusions

Strengthening Potential

- 27 % strength enhancement
- Enabled pseudo-ductile behaviour

Durability

- BFRP ~ GFRP tensile properties
- Temp - high effect; pH - less effect
- 53% strength retention after 100 yrs in concrete

Q: Can Basalt FRP represent an economic alternative to the traditional fibres?

A: BFRP – economic solution for concrete when strengthening demand is moderate

Thank you!

Acknowledgments

- Magmatech Ltd


Any questions?