April 2-6, 2023

aci CONCRETE CONVENTION

REINFORCED CEMENTLESS CONCRETE: MECHANICAL PROPRIETIES AND STRUCTURAL PERFORMANCE

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SAN FRANCISCO, CALIFORNIA, USA

THE WORLD'S GATHERING PLACE FOR ADVANCING CONCRETE

Reducing the environmental impact of concrete structures

- Geopolymer concrete

- Concrete with calcium sulfoaluminate cement

- Concrete with recycled aggregates (rubberized concrete)

- FRC with recycled fibers

NATURAL:
- Kaolin
- Calcined clay

RAW MATERIALS

INDUSTRIAL WASTE:
- Silica fume
- Fly ash
- Ground Granulated Blast-Furnace Slag (GGBFS)

Catalytic liquid system is used as alkaline activator solution.

ACTIVATION

The activation requires no heat: CO_2 emissions are reduced up to **80%!**

Satisfactory mechanical and structural properties

GEOPOLYMER CONCRETE

Excellent performances in terms of chemical and fire resistance

MARE WIND

MAterials solutions for cost **R**eduction and **E**xtended service life on **WIND** off-shore facilities

CIRCE

UNIONE EUROPEA
REGIONE PUGLIA
PUGLIA FESR·FSE 2014/2020 *Il futuro alla portata di tutti*
INNO NETWORK

seCondary raw materIals foR a cirCular Economy in buildings

REGIONE PUGLIA
POR Puglia FESR-FSE 2014-2020
Asse prioritario 1 - Ricerca, sviluppo tecnologico, innovazione
Azione 1.6 *"Interventi per il rafforzamento del sistema innovativo regionale e nazionale e incremento della collaborazione tra imprese e strutture di ricerca e il loro potenziamento"*

GPC

MIX DESIGN | MECHANICAL CHARACTERIZATION | PULL-OUT TESTS | BEAM ELEMENTS

MIX DESIGN

GPC_1		
Components	Quantity	% Binder
Ground Granulated Blast-Furnace Slag	224 kg/m^3	56
Filler (natural calcium carbonate)	128 kg/m^3	32
Silica Fume	48 kg/m^3	12
Alkaline solution (sodium silicate)	170 kg/m^3	
Water	140 kg/m^3	
Additive (Plasticizer)	8 kg/m^3	
Sand	1092 kg/m^3	
Gravel	471 kg/m^3	

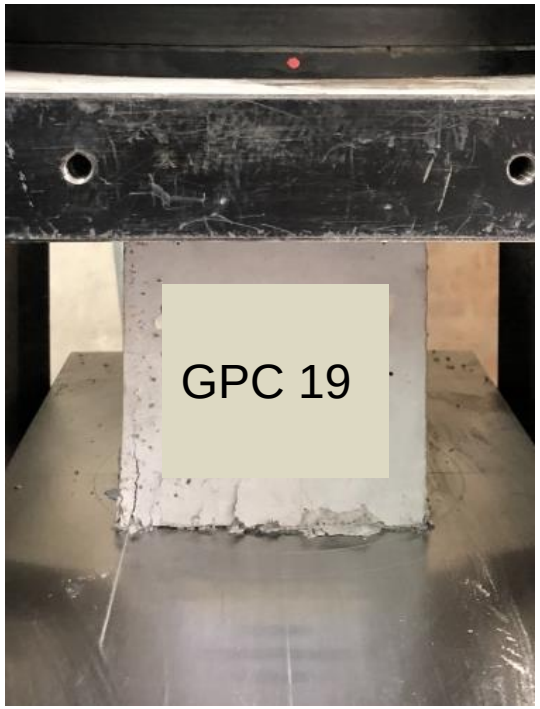
GPC_2		
Components	Quantity	% Binder
Ground Granulated Blast-Furnace Slag	222.2 kg/m^3	80
Expanded glass	55.6 kg/m^3	20
Alkaline solution (NaOH)	25.9 kg/m^3	
Water	122.2 kg/m^3	
Additive (Waterglass)	77.8 kg/m^3	
Natural sand (0-4 mm)	707.8 kg/m^3	
Gravel (4-8 mm)	354.0 kg/m^3	
Magnetite (0-2 mm)	689.0 kg/m^3	

GPC

MIX DESIGN | MECHANICAL CHARACTERIZATION | PULL-OUT TESTS | BEAM ELEMENTS

GPC_1

MECHANICAL CHARACTERIZATION



Compression

Constitutive law

Flexural strength

GPC_1

MECHANICAL CHARACTERIZATION

n

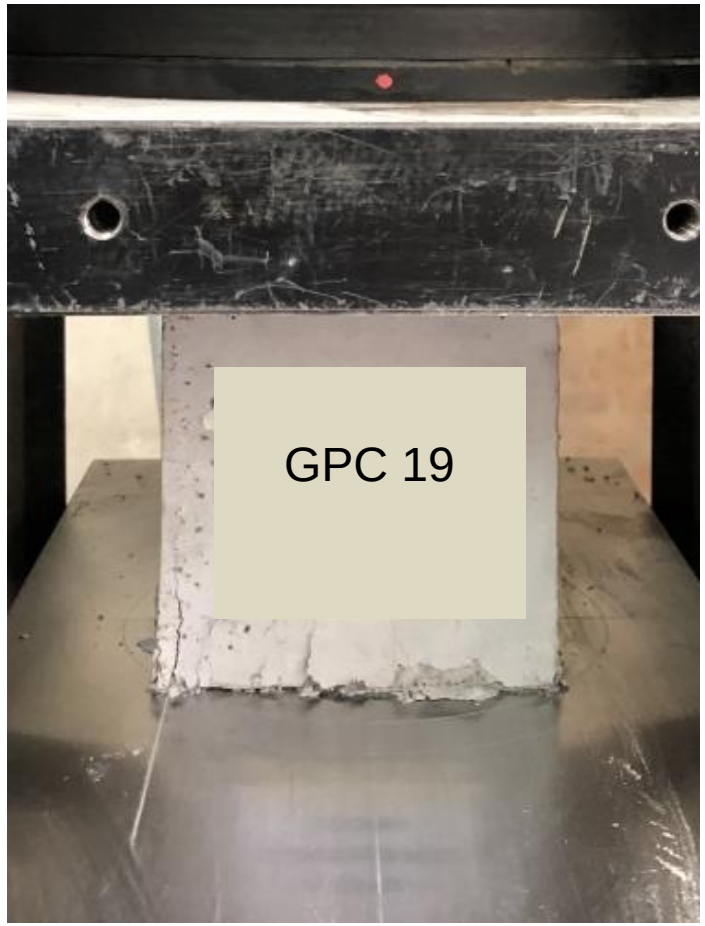
Constitutive law

Flexural strength

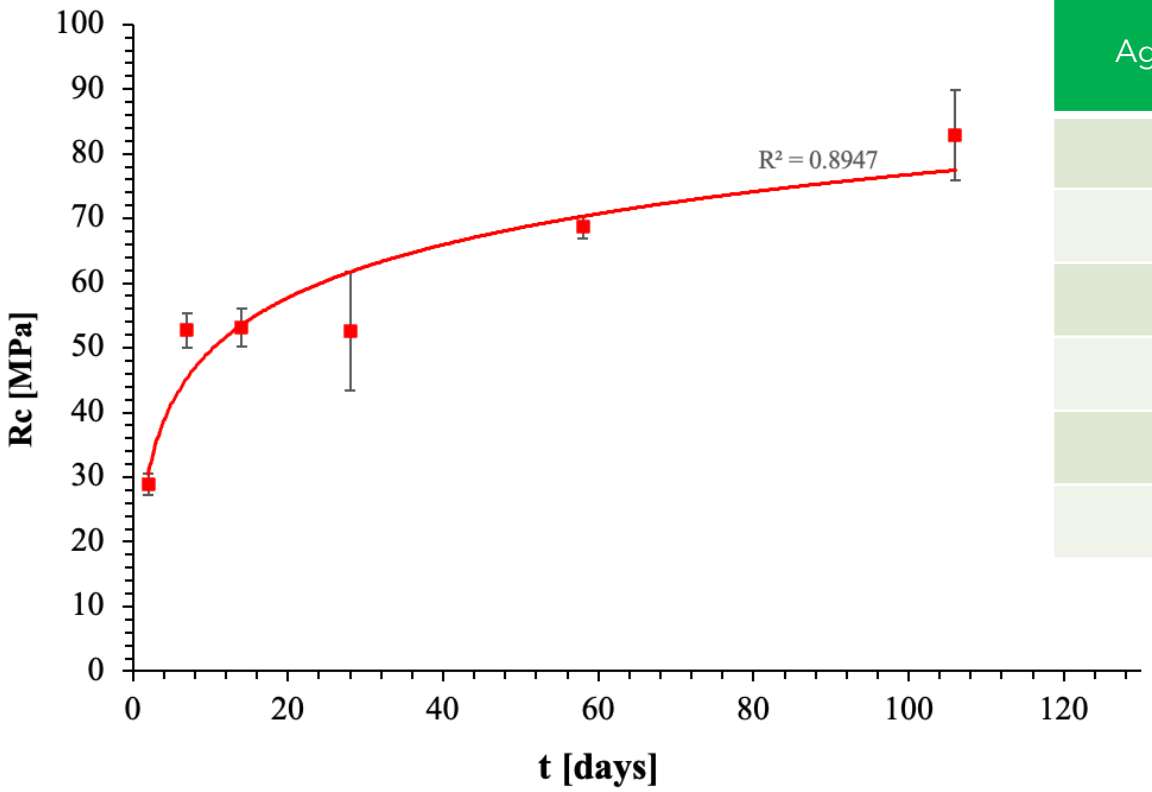
Modulus of Elasticity

GPC_1

MECHANICAL CHARACTERIZATION



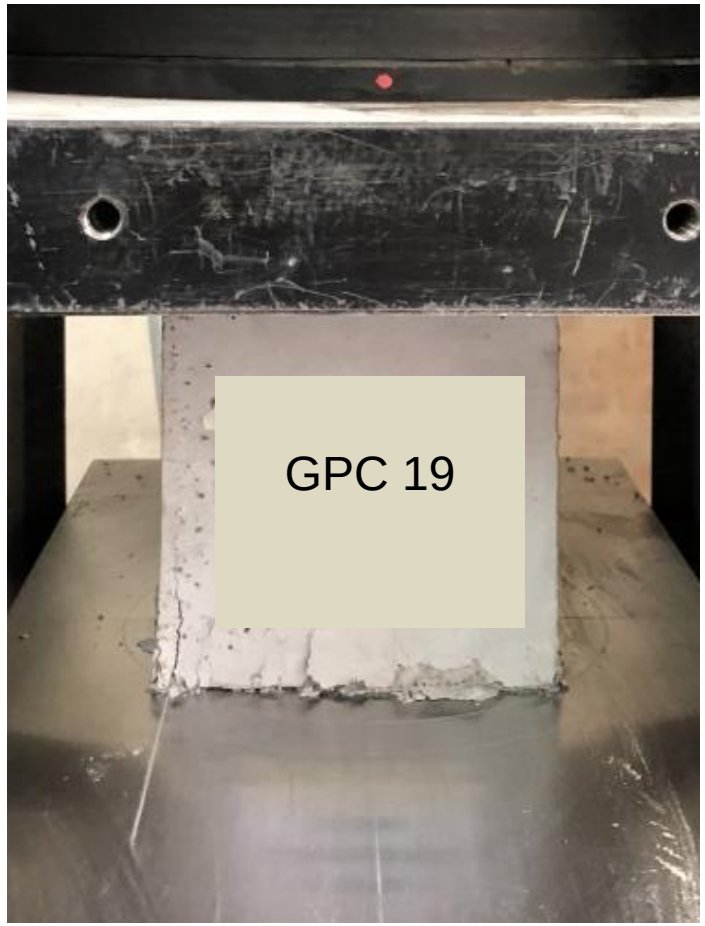
Compression



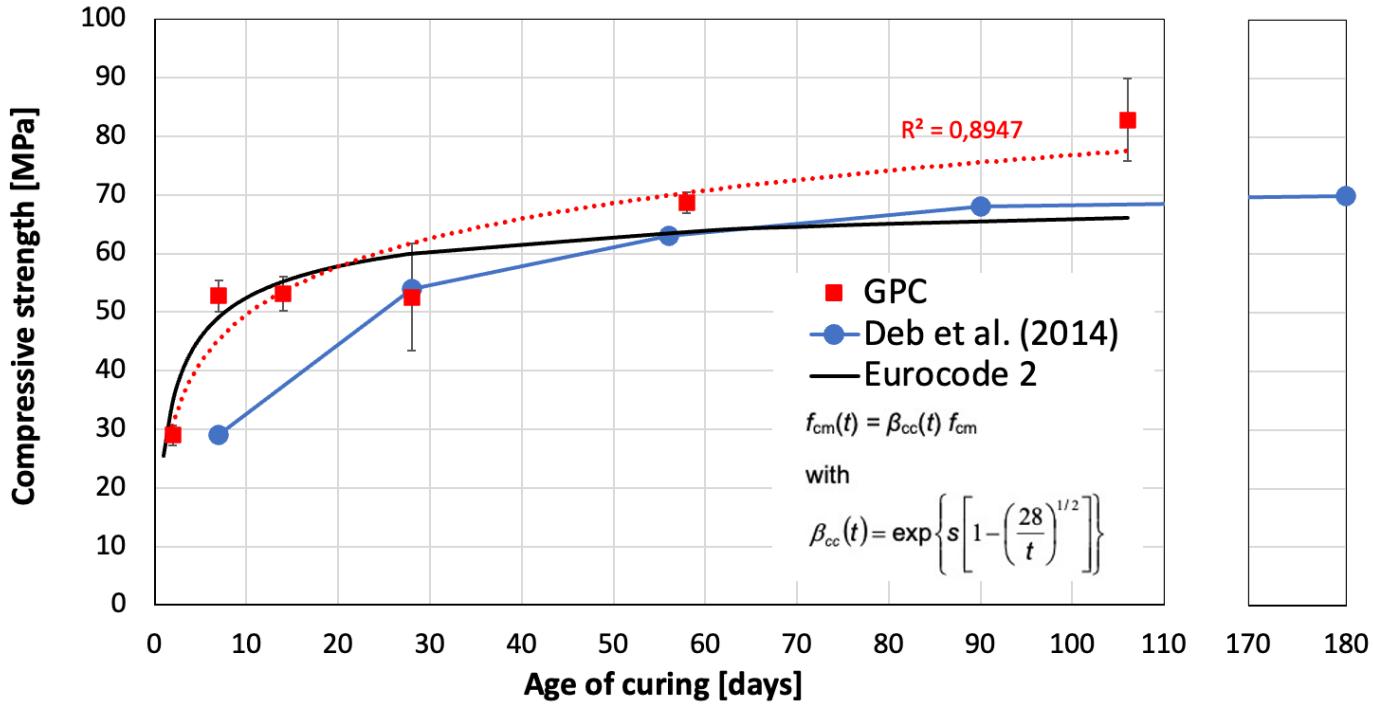
Age [days]	σ [MPa] (Average value)
2	29.0
7	52.7
14	53.1
28	**52.6**
60	68.7
106	82.8

GPC_1

MECHANICAL CHARACTERIZATION



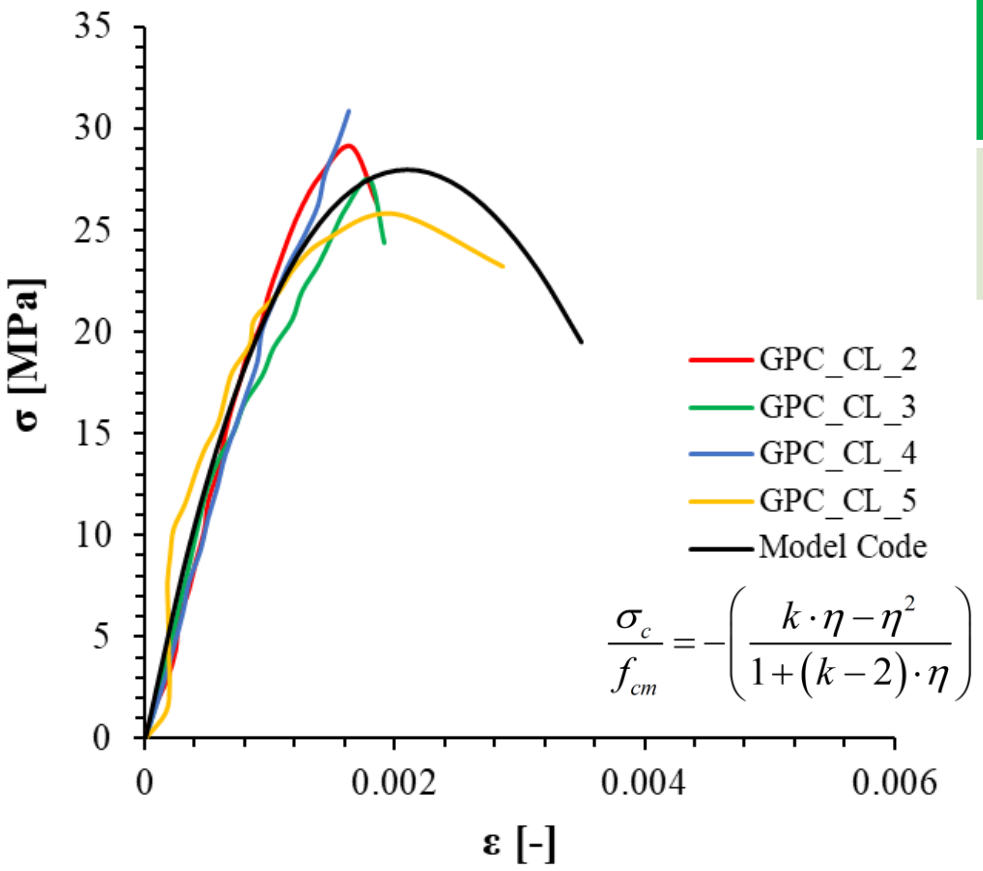
Compression



GPC_1

MECHANICAL CHARACTERIZATION

Constitutive law – average curves



	f_c [MPa]	ε_{cu} [-]
Average	**28,5** (CoV 7%)	**0,0019**

GPC

MIX DESIGN | MECHANICAL CHARACTERIZATION | PULL-OUT TESTS | BEAM ELEMENTS

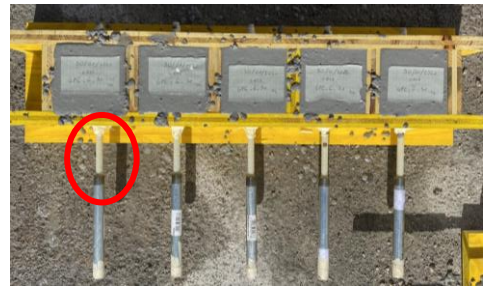
GPC_1 GPC_2

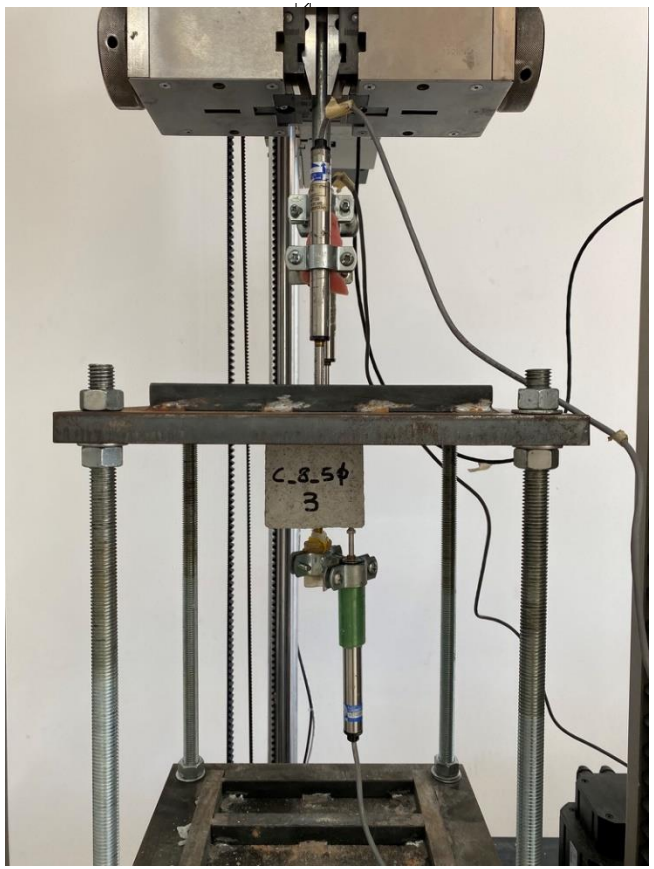
PULL-OUT TESTS

steel sGFRP rGFRP CFRP

Bar	Diameter	L_b	Number of samples	GPC mix R_c [Mpa]
steel	16mm	5ϕ	5	82.8
	12mm	5ϕ	4	68.7
sGFRP	12mm	5ϕ	4	27.1
steel	12mm	2.5ϕ	5	19.5
sGFRP	12mm	2.5ϕ	5	19.5

Bar	Diameter	L_b	Number of samples	GPC mix R_c [Mpa]
CFRP	8mm	5ϕ	5	40.0
		2.5ϕ	5	40.0
rGFRP	10mm	5ϕ	5	38.0
		2.5ϕ	5	38.0



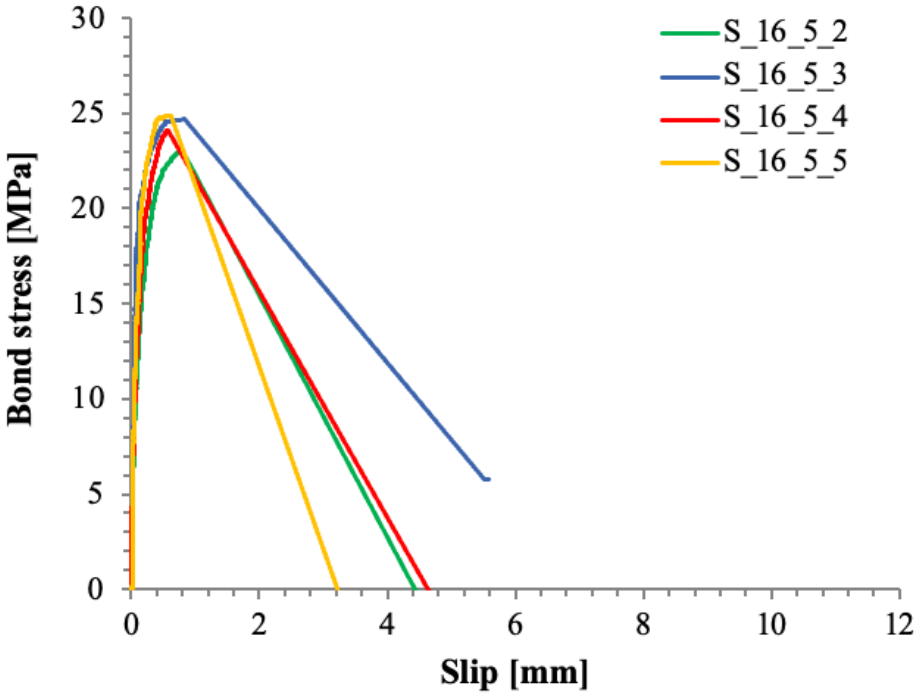


GPC_1

ϕ16mm steel bar | $L_b = 5\phi$

steel

Sample id	Bond strength [MPa]	Failure mode
S_16_5_2	23.0	Splitting
S_16_5_3	24.7	Splitting
S_16_5_4	24.1	Splitting
S_16_5_5	24.9	Splitting
average	**24.2**	
CoV	**6%**	

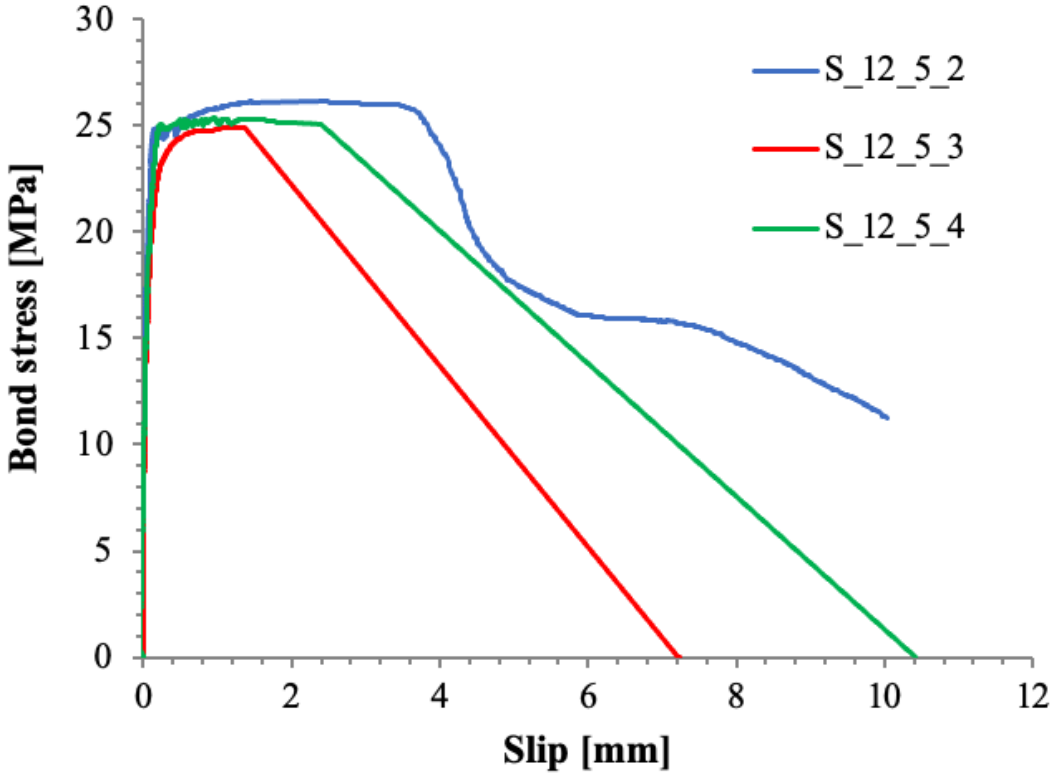


GPC_1

ϕ12mm steel bar | $L_b = 5\phi$

steel

Sample id	Bond strength [MPa]	Failure mode
S_12_5_2	26.2	Pull-out
S_12_5_3	24.9	Splitting
S_12_5_4	25.4	Splitting
average	**25.5**	
CoV	**3%**	



SPLITTING FAILURE

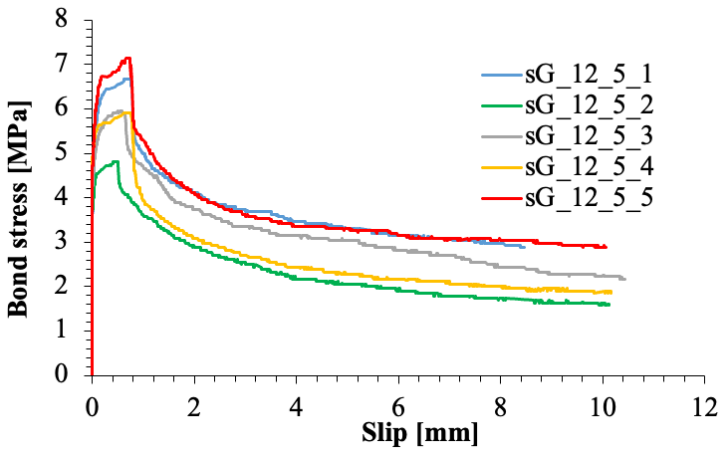
GPC_1

ϕ12mm sGFRP bar

sGFRP

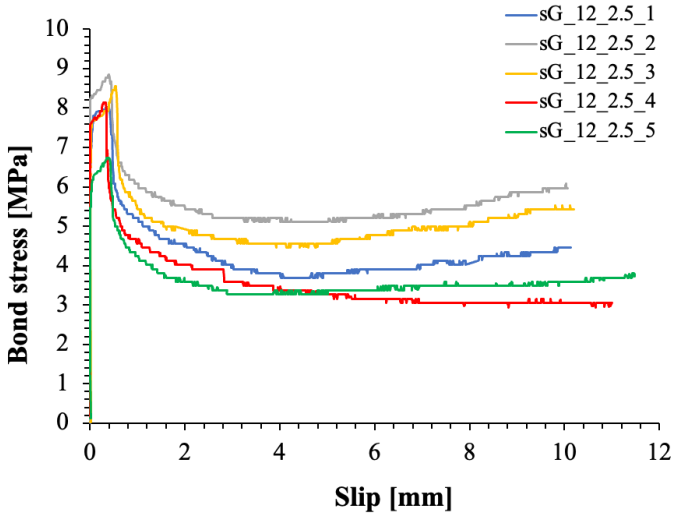
$L_b = 5\phi$

Sample id	Bond strength [MPa]
sG_12_5_1	6.7
sG_12_5_2	4.8
sG_12_5_3	6.0
sG_12_5_4	5.9
sG_12_5_5	7.2
average	**6.1**
CoV	**14%**



$L_b = 2.5\phi$

Sample id	Bond strength [MPa]
sG_12_2.5_1	8.0
sG_12_2.5_2	8.8
sG_12_2.5_3	8.6
sG_12_2.5_4	8.1
sG_12_2.5_5	6.7
average	**8.1**
CoV	**10%**



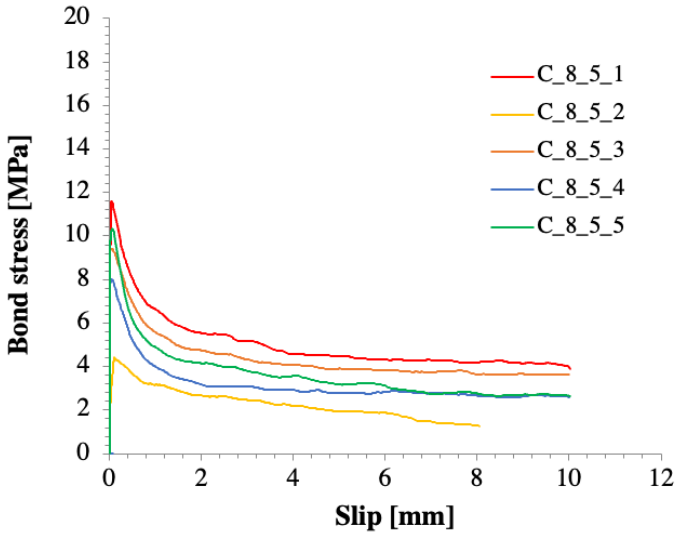
GPC_2

ϕ8mm CFRP bar

CFRP

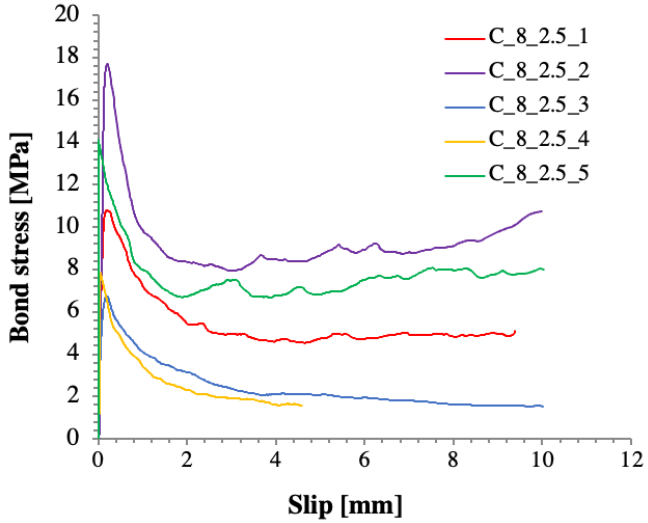
Sample id	Bond strength [MPa]
C_12_5_1	11.7
C_12_5_2	4.5
C_12_5_3	9.5
C_12_5_4	8.1
C_12_5_5	10.4
average	**8.8**
CoV	**31%**

$L_b = 5\phi$



Sample id	Bond strength [MPa]
C_12_2.5_1	10.8
C_12_2.5_2	17.7
C_12_2.5_3	6.7
C_12_2.5_4	7.8
C_12_2.5_5	14.1
average	**11.4**
CoV	**40%**

$L_b = 2.5\phi$



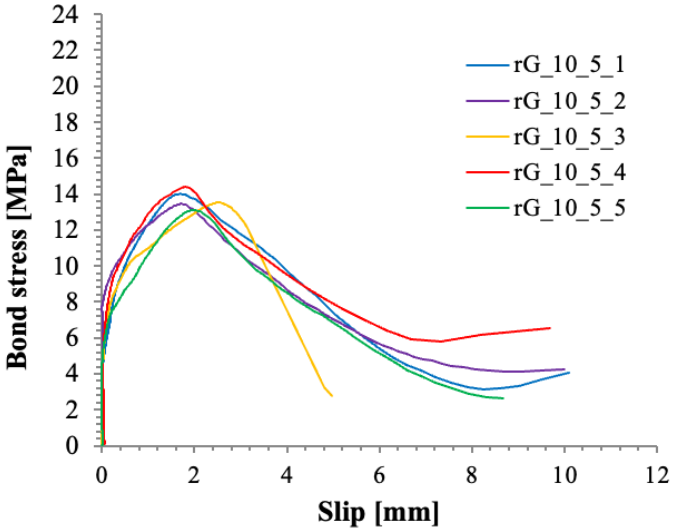
GPC_2

ϕ10mm rGFRP bar

rGFRP

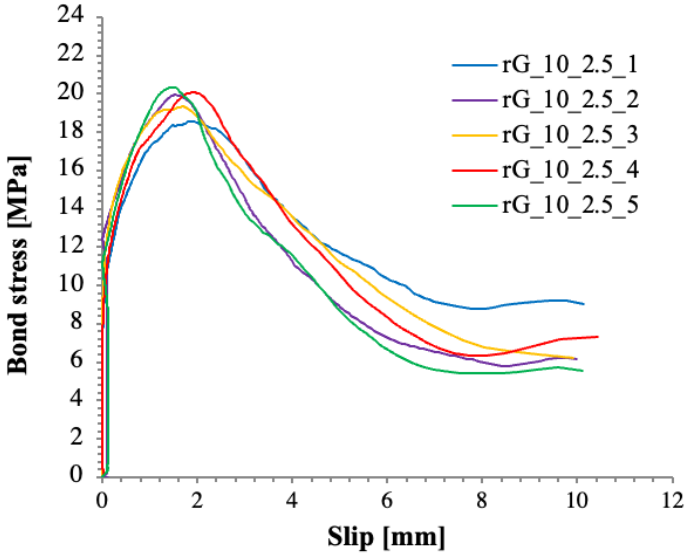
$L_b = 5\phi$

Sample id	Bond strength [MPa]	Failure
rG_12_5_1	14.0	Pull-out
rG_12_5_2	13.5	Pull-out
rG_12_5_3	13.5	Splitting
rG_12_5_4	14.4	Pull-out
rG_12_5_5	13.1	Pull-out
average	**13.7**	
CoV	**4%**	



$L_b = 2.5\phi$

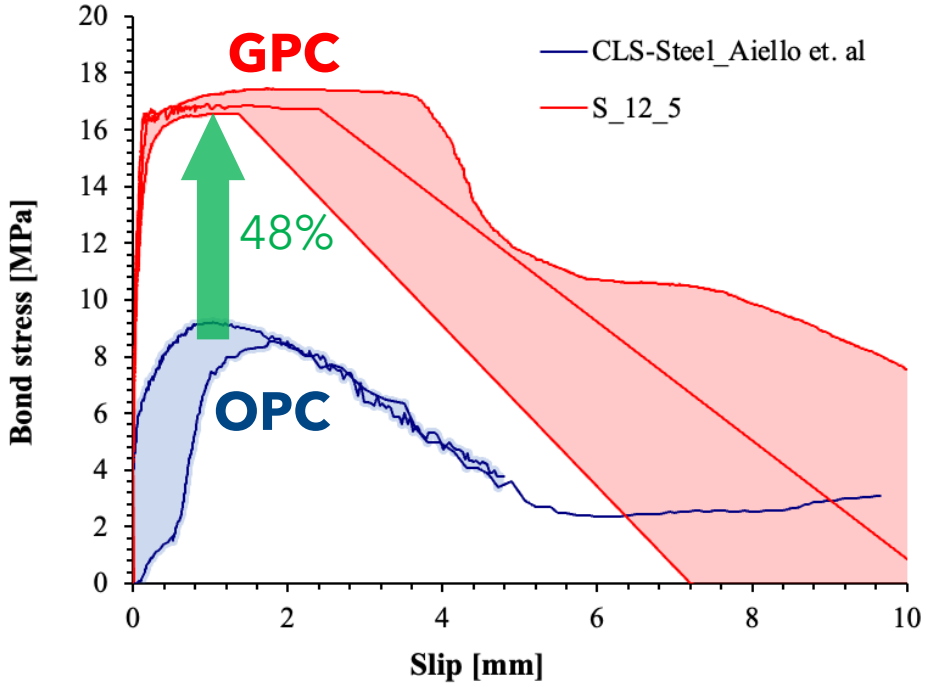
Sample id	Bond strength [MPa]
rG_12_2.5_1	18.6
rG_12_2.5_2	19.9
rG_12_2.5_3	19.3
rG_12_2.5_4	20.1
rG_12_2.5_5	20.4
average	**19.7**
CoV	**4%**



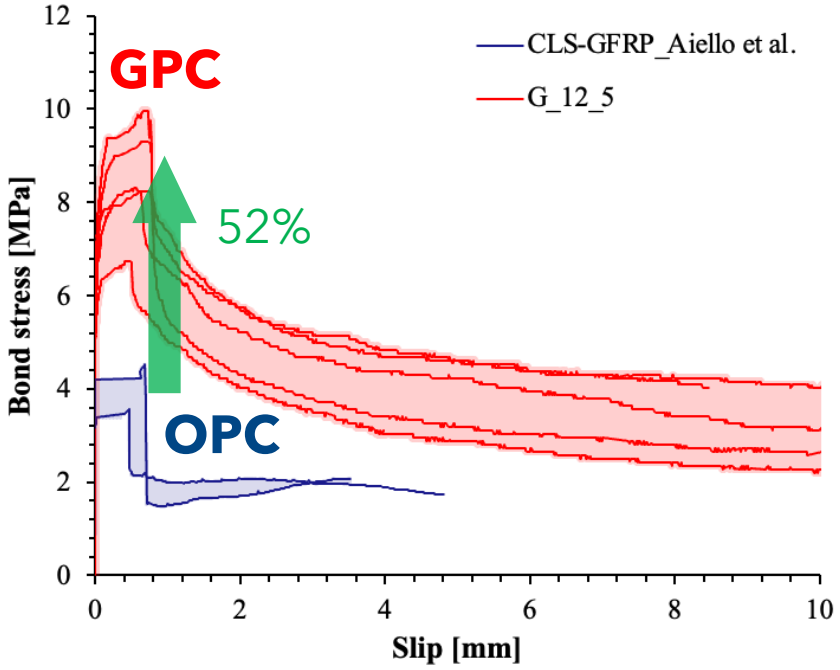
PULL-OUT TESTS

Comparisons with *Aiello et al. (2004)*

STEEL



Sanded GFRP

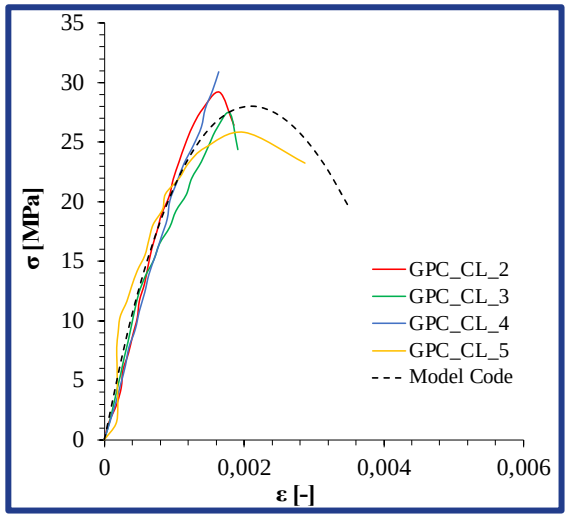


GPC

MIX DESIGN | MECHANICAL CHARACTERIZATION | PULL-OUT TESTS | BEAM ELEMENTS

BEAM ELEMENTS

The beams were designed considering the experimental GPC **constitutive law**.



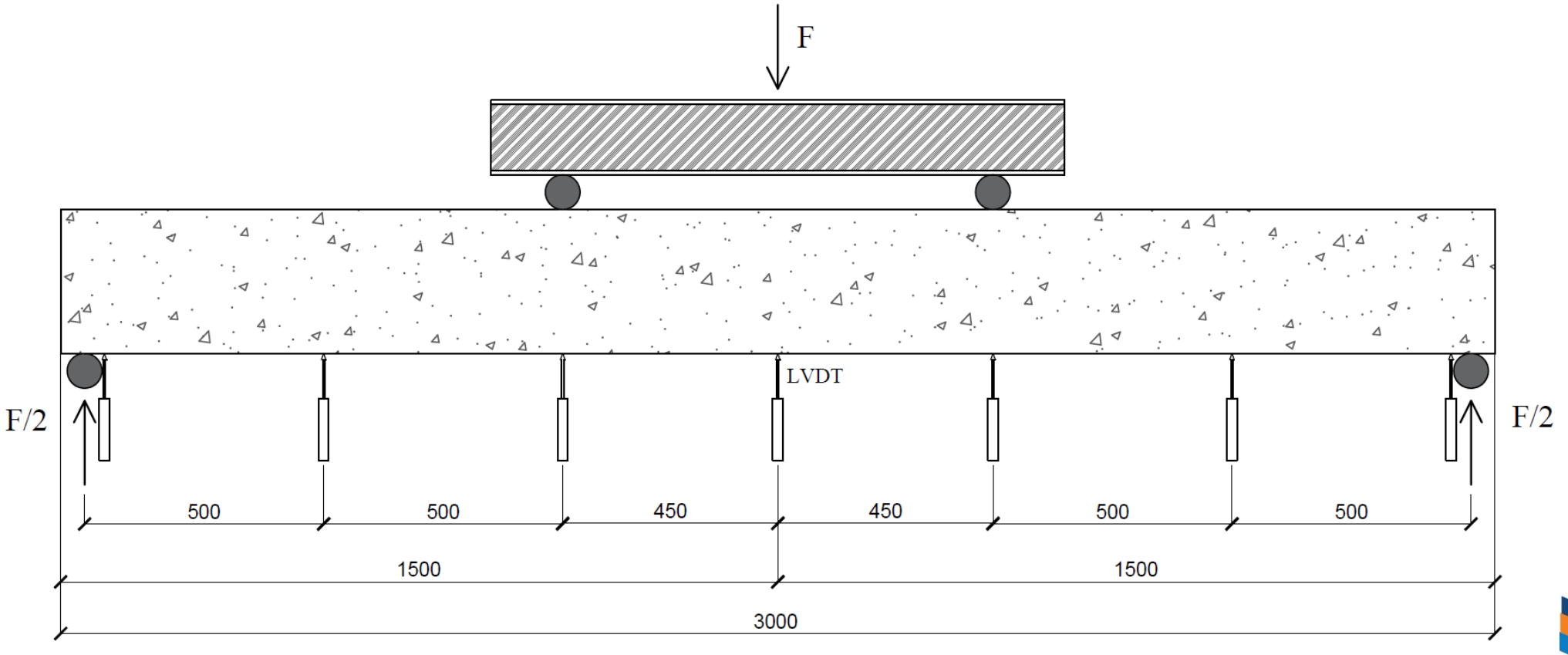
Design hyphotheses:

- Conservation of planar sections;
- Perfect bond between concrete and reinforced steel bar;
- Tensile strength of concrete is neglected

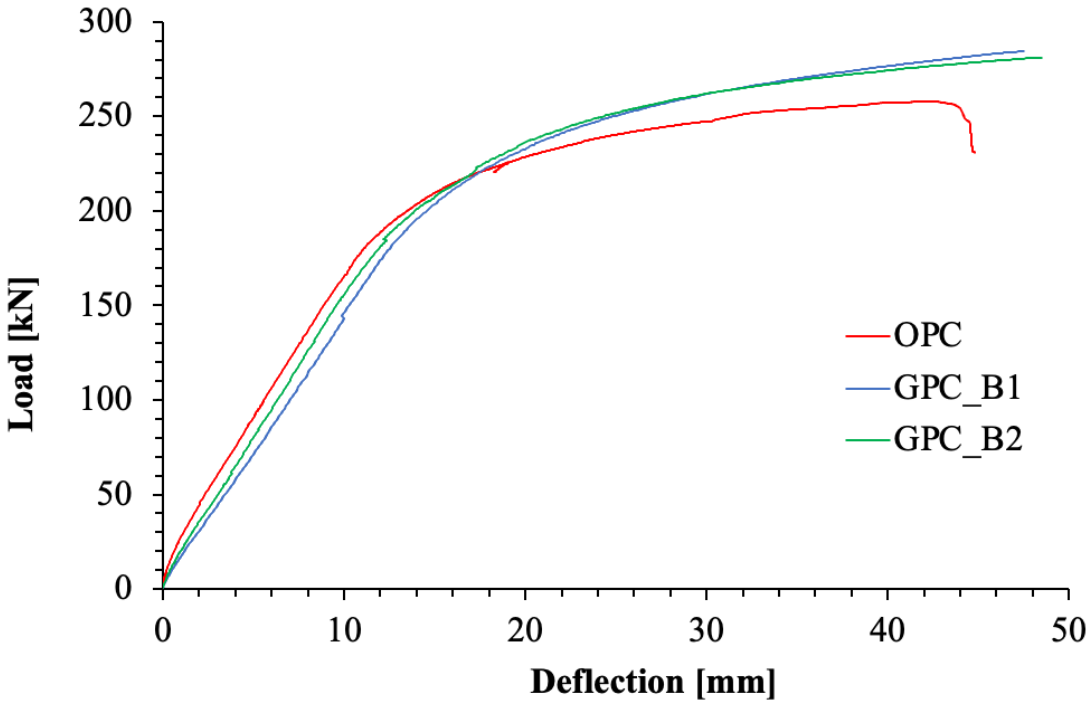
Number of beam casted:

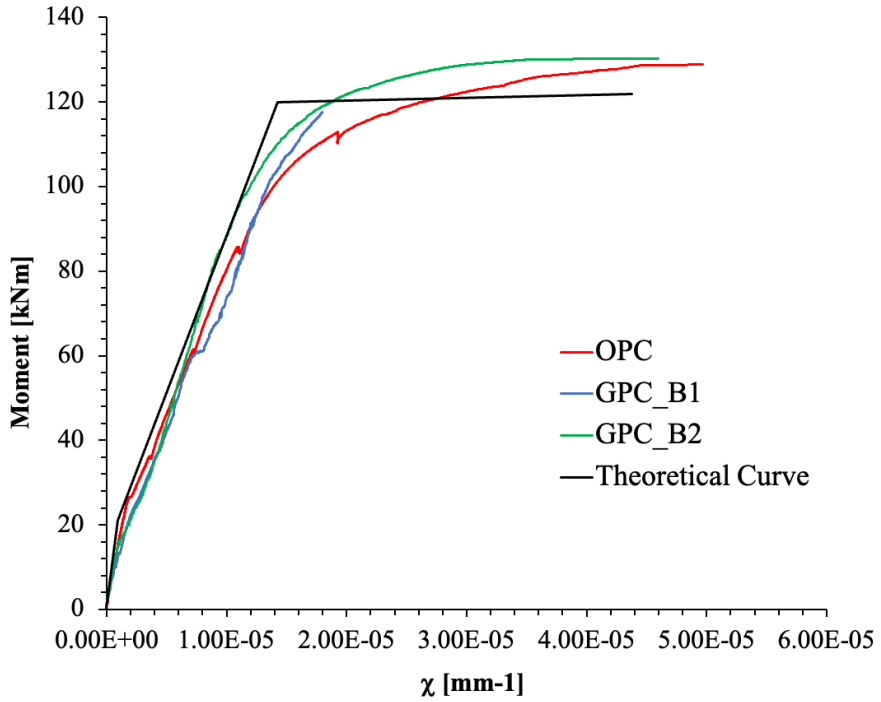
- 1 with OPC mix
- 2 with GPC mix

Four-points bending test setup

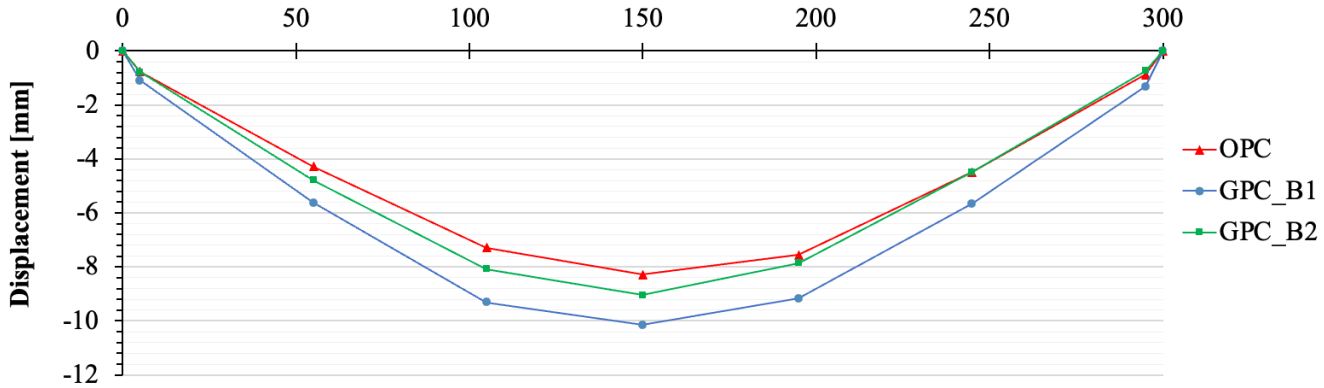


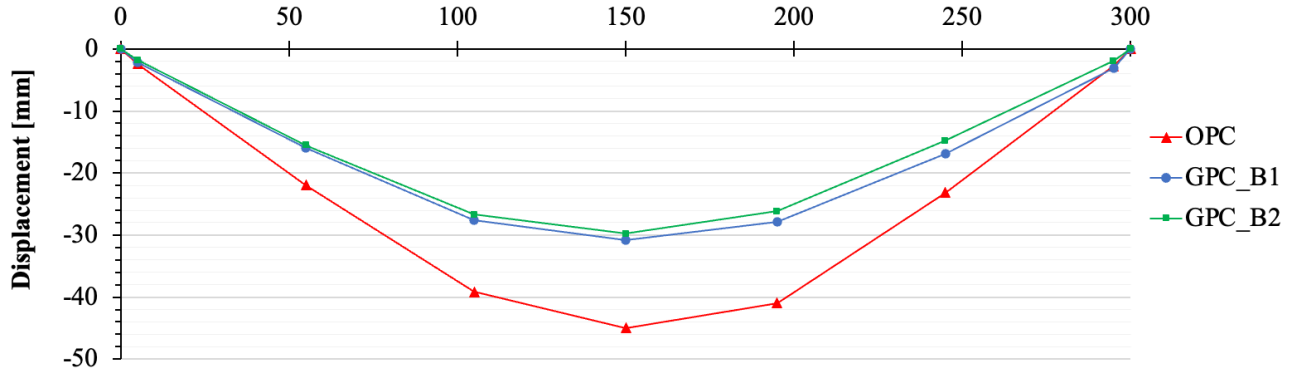
Results – bending behaviour





Results – deformed shapes





Conclusions

- The **compression strength** increases with time, far beyond the 28 days.
- **The constitutive law seems** characterized by a more brittle behavior if compared to OPC concrete
- An increase of the the maximum **bond strength** has been observed for both steel and non metallic rebar when using GPC due to the more dense microstructure of the material.
- As in OPC concrete the bond strength in case of **sand-coated FRP** rebars is mainly governed by chemical adhesion and friction .
- In case **of steel and ribbed FRP rebars** the contribution of the mechanical interlocking becomes significant

THANK YOU FOR YOUR ATTENTION!

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