



Material development and testing

Qing Zhang, Holcim

Material development and testing

Objective: Develop 3DPC for maritime caisson and bio-receptive material or/and application method

3DPC:

- Establishment of material specification
- Recipe development & key performance
- Recipe refinement & full performance

Bio-receptive:

- Lab method validation
- Lab Solution screening , refinement and performance validation

Involvement of partners and their major contributions:



Lead material development



Material performance requirement

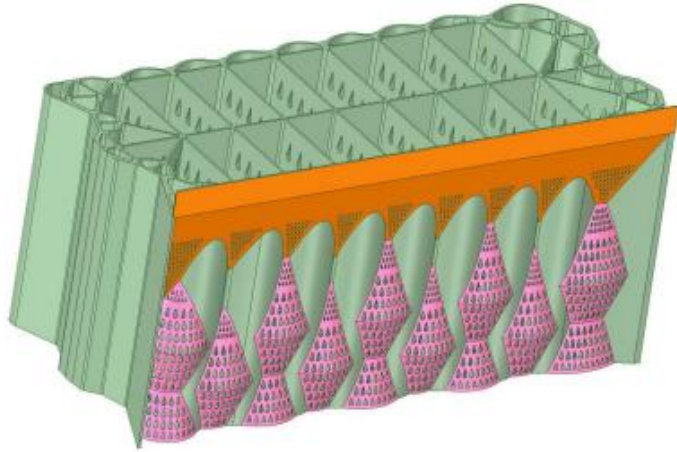


Material process requirement

Organization and resources:

- 2 workshops on material development and caisson construction with email exchanges for material specification
- Lab work for material development and method validation
- 2 printing trials organized for material processing through 3D printing

Material Specifications



Caisson structure



Bio-receptive wall



3D printable with adjustable buildability

Fiber reinforced concrete with $D_{max} = 10\text{cm}$

C50, ductile, XS3

Similar or lower shrinkage,
creep compared with reference
concrete

Bio-receptive

Similar E, shrinkage, and creep
as structural material

* From 3 point bending test on 15cm*15cm*60cm sample



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Printability of 3DPC with fiber is checked



Ensure good dispersion of fiber in the mix



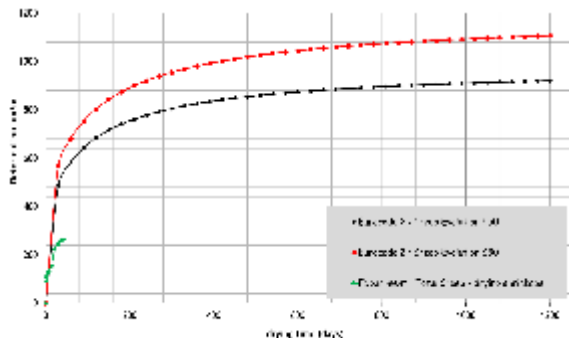
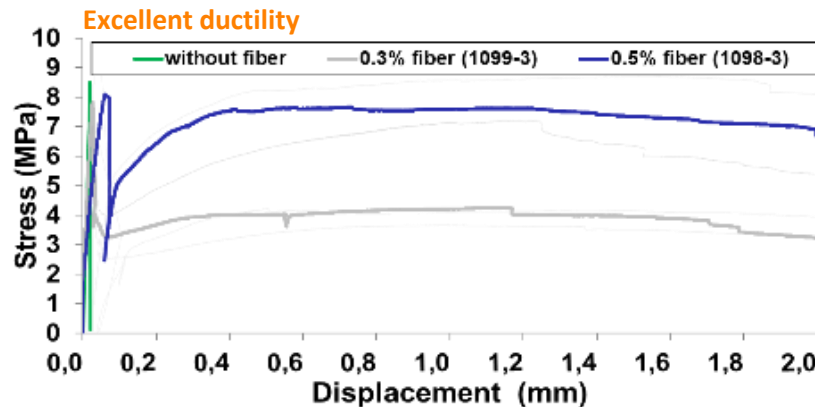
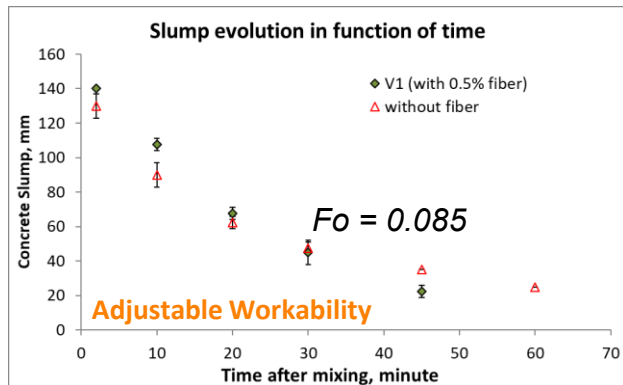
Fresh concrete after mixing



Printed structure for mechanical performance tests



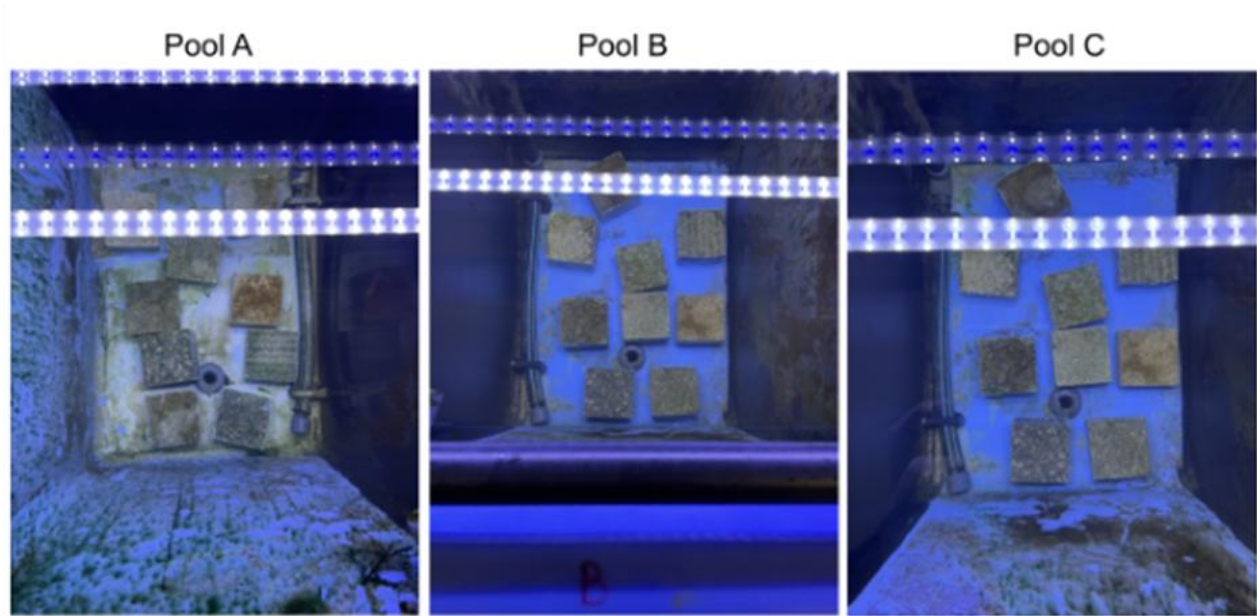
Lab Validation of Structural Material



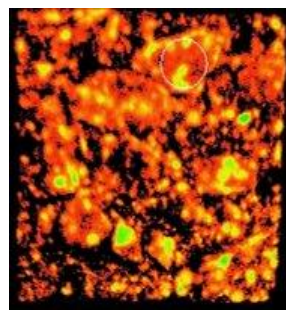
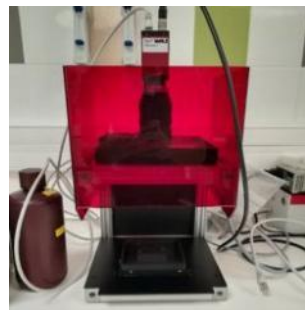
Good long-term deformability

Parameter, Unit	Average Standard Deviation	±
28-day Compressive strength, (MPa)	67.5±0.6	
28-day flexural properties		
Elastic limit FLOP (FLOP,k)	7.5±0.2 (7.0)	
FR1,k / FLOP,k	0.87	
FR3,k / FR1,k	1.0	
Ductility Class	6C	
28-day Young's modulus, GPa	33.6±0.5	

Lab Validation of bio-receptive Material



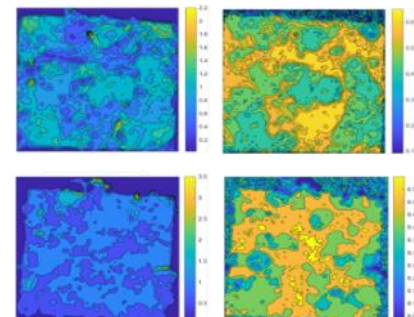
Lab Validation of bio-receptive Material



Microalgae

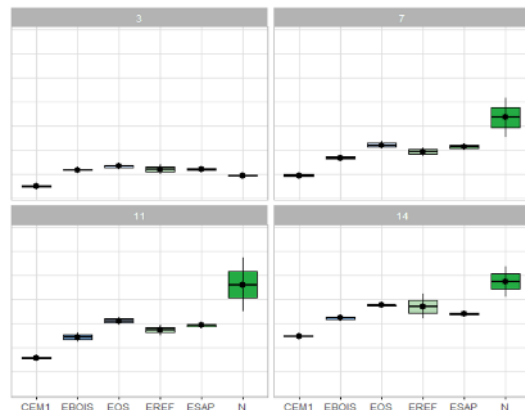


Health status



Biomass

Production capacity

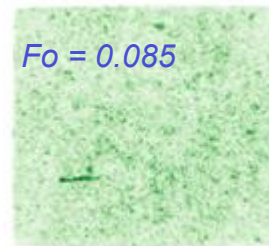


Sample
 CEM1
 EBOIS
 EOS
 EREF
 ESAP
 N



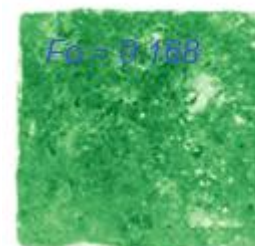
Reference

$F_0 = 0.085$



Bioreceptive 3DPC

$F_0 = 0.188$



Material In-Situ Performance

Material In-Situ Performance

- **Objective:** characterize “In the print” material performances. Set up a plan and methodology to monitor the structural integrity, and the marine life promotion function on an immersed prototype.
 - 3D printing trials were carried out to specific elements
 - Materials and structural test were done on printed elements

Involvement of partners and their major contributions:



Lead material development



Material performance requirement



Material process requirement



Sensor technologies for 3DP procedure

Concrete intelligence



Ecological consideration

Organization and resources:

- 4 printing trials organized
- Preparation meetings and debrief meetings organized

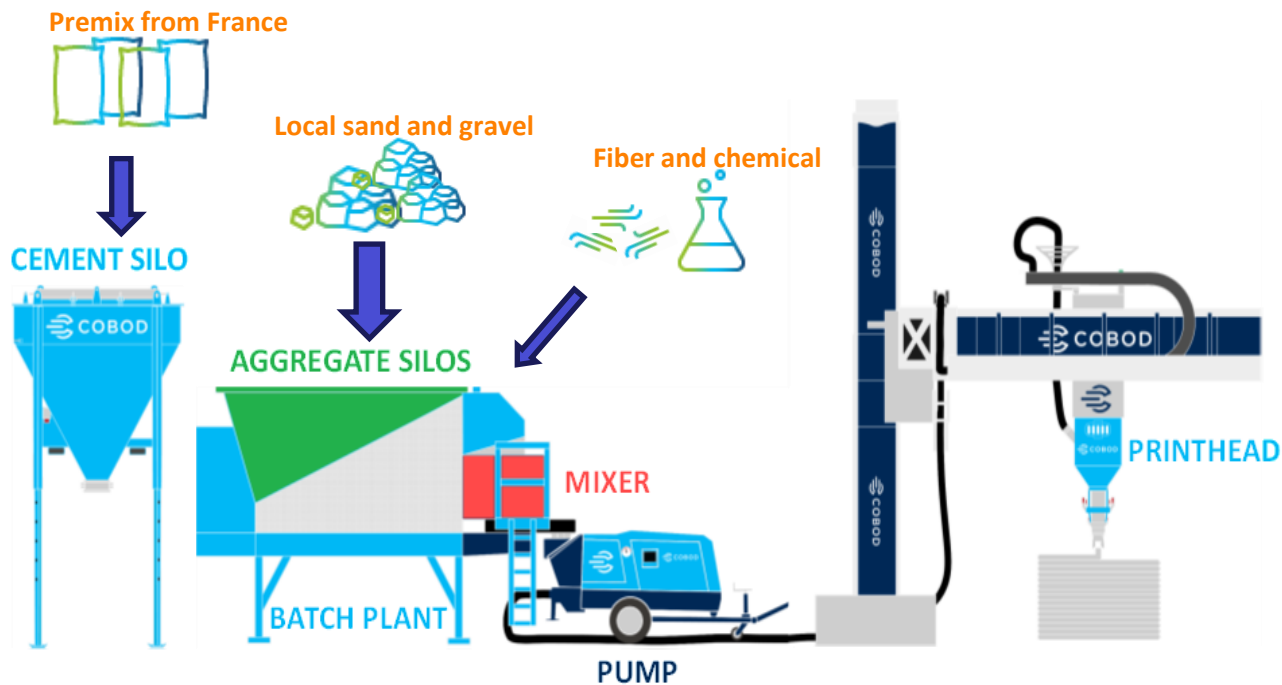


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Structural Material Production Scheme



Material In-Situ Performance

3D printing trial in April 2024:



Printed structure: straight walls with 20cm thickness

Printing parameters: 150L concrete/ batch, nozzle: 20cm*4cm, interlayer time 12-9 min

Temperature: 12°C-15°C, 9-12 mph wind

Curing condition: water spreading on the ground, wall covered in plastic film till cutting (>48 hours)

Sampling: cast and cut 60cm*15cm*15cm prisms, cast cylinders

Testing: 3 point bending test, compression test on cast samples and cut samples

3D printing trial in August 2024:



Printed structure: straight walls with 8cm thickness

Printing parameters: 150L concrete/ batch, nozzle: 8cm*4cm, interlayer time 12-9 min, layer thickness: 3cm, 4cm and 5 cm

Temperature: 20°C-22°C, 15-16 mph wind

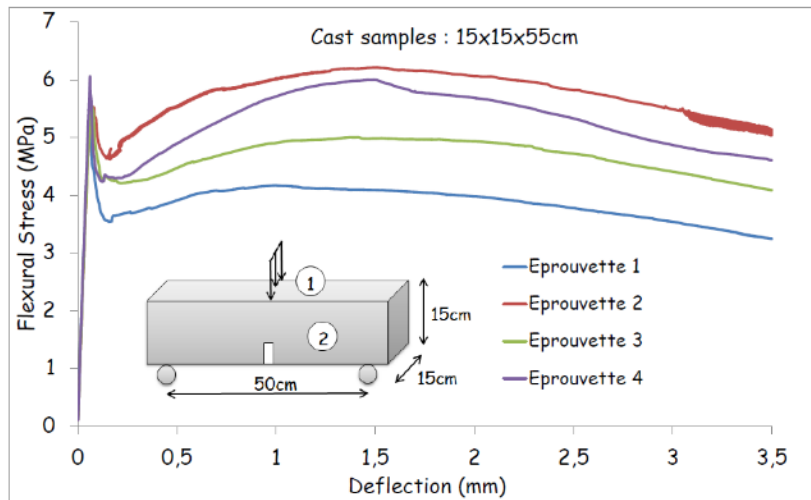
Curing condition: water spreading on the ground, wall covered in geopolymer film till cutting (>48 hours)

Sampling: cast 28cm*7cm*7cm prisms, D10cm*20 cylinders, cut 28cm*7cm*7cm prisms, Cut panels for structural test

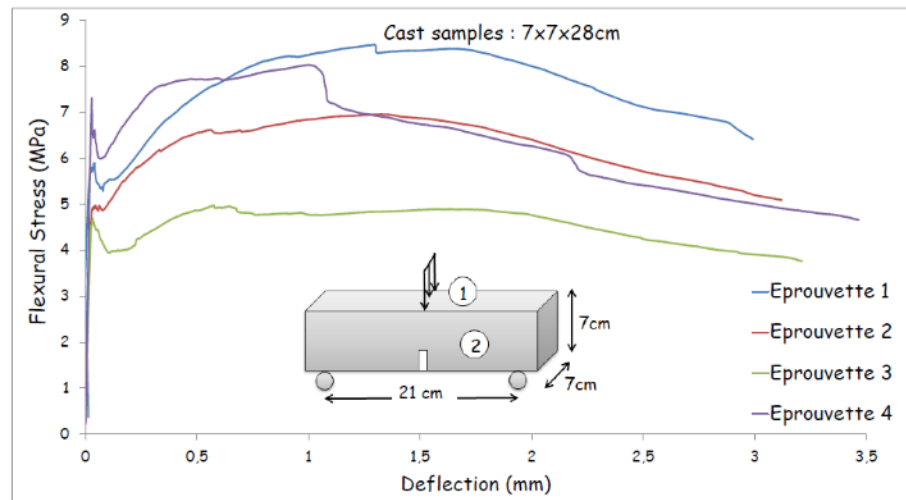
Testing: 3 point bending test, compression test on samples, flexural test on panels

In-Situ Performance (Structural Material)

In-situ environment casted and cured prisms: similar post-cracking behavior, due to samples size effect, smaller dimension gives better strength.



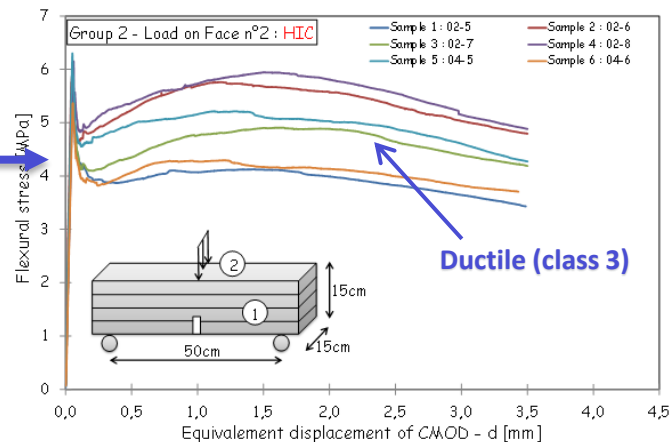
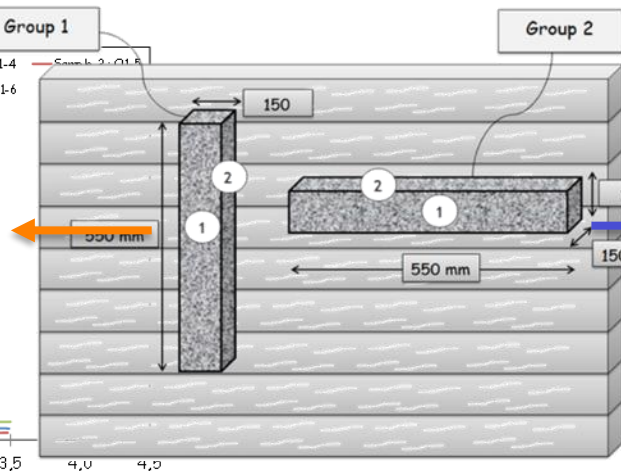
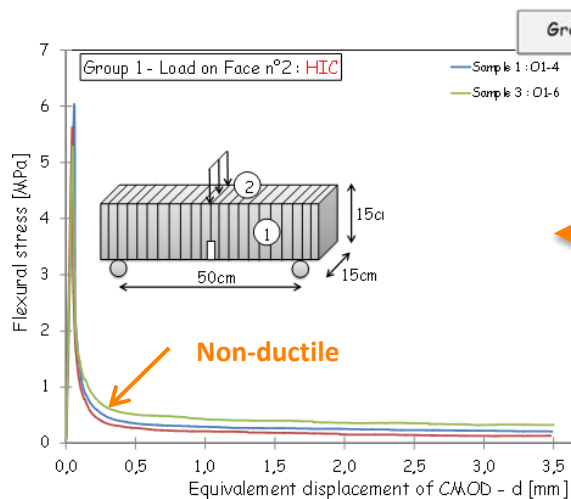
Cast 15cm*15cm*60cm prims from printing site, cured on site in sealed condition, tested at age of 28 days



Cast 7cm*7cm*28cm prims from printing site, cured on site in sealed condition, tested at age of 28 days

In-Situ Performance (Structural Material)

Anisotropic behavior due to fiber alignments: effective in horizon direction, non-effective on vertical direction



	FLOP	FR1	FR2	FR3	FR4
	Elastic Limit	CMOD = 0.5 mm disp = 0.47 mm	CMOD = 1.5 mm disp = 1.32 mm	CMOD = 2.5 mm disp = 2.17 mm	CMOD = 3.5 mm disp = 3.02 mm
Sample 1 (HIC)	6,04	0,36	0,27	0,25	0,22
Sample 2 (HIC)	5,63	0,28	0,19	0,15	0,13
Sample 3 (HIC)	5,29	0,52	0,40	0,36	0,33
Average	5,65	0,39	0,29	0,25	0,23

	FLOP	FR1	FR2	FR3	FR4
	Elastic Limit	CMOD = 0.5 mm disp = 0.47 mm	CMOD = 1.5 mm disp = 1.32 mm	CMOD = 2.5 mm disp = 2.17 mm	CMOD = 3.5 mm disp = 3.02 mm
Average	5,75	4,63	5,00	4,86	4,43
Standard Dev	0,40	0,62	0,74	0,73	0,61
Factor kn : 6 samples	2,18	2,18	2,18	2,18	2,18
Characteristic	4,87	3,28	3,39	3,27	3,09
FR1,k / FLOP,k	0,67 (> 0.4 → VALID first minimum requirement)				
FR3,k / FR1,k	1,00 (> 0.5 → VALID second minimum requirement)				
Ductility class	3,0 c				



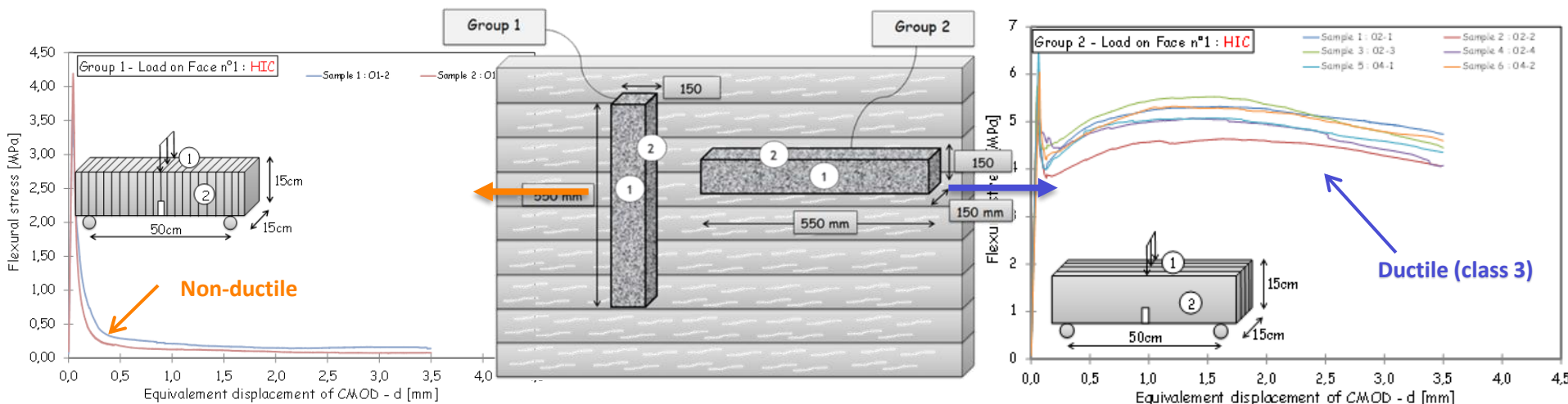
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In-Situ Performance (Structural Material)

Similar conclusion for the other loading direction



	FLOP	FR1	FR2	FR3	FR4
	Elastic Limit	CMOD = 0.5 mm disp = 0.47 mm	CMOD = 1.5 mm disp = 1.32 mm	CMOD = 2.5 mm disp = 2.17 mm	CMOD = 3.5 mm disp = 3.02 mm
Sample 1 (HIC)	3,67	0,30	0,18	0,14	0,16
Sample 2 (HIC)	4,19	0,19	0,12	0,09	0,08
Average	3,93	0,25	0,15	0,12	0,12

	FLOP	FR1	FR2	FR3	FR4
	Elastic Limit	CMOD = 0.5 mm disp = 0.47 mm	CMOD = 1.5 mm disp = 1.32 mm	CMOD = 2.5 mm disp = 2.17 mm	CMOD = 3.5 mm disp = 3.02 mm
Average	5,77	4,65	5,04	4,90	4,55
Standard Dev	0,41	0,60	0,61	0,57	0,53
Factor k_n : 12 samples	1,89	1,89	1,89	1,89	1,89
Characteristic	5,00	3,52	3,88	3,82	3,55
$FR1,k / FLOP,k$	0,70 (> 0,4 → VALID first minimum requirement)				
$FR3,k / FR1,k$	1,1 (> 0,5 → VALID second minimum requirement)				
Ductility Class	3,0 d				
Ratio Charact. / Average	0,87	0,76	0,77	0,78	0,78

In-Situ Performance (Structural Material)

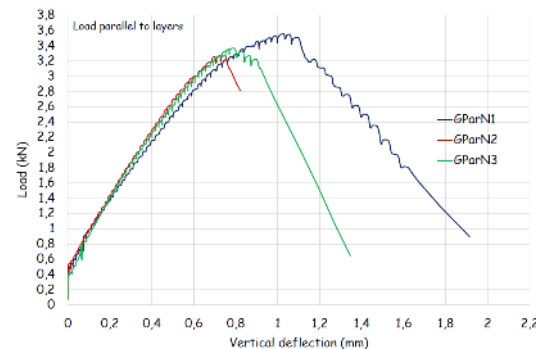
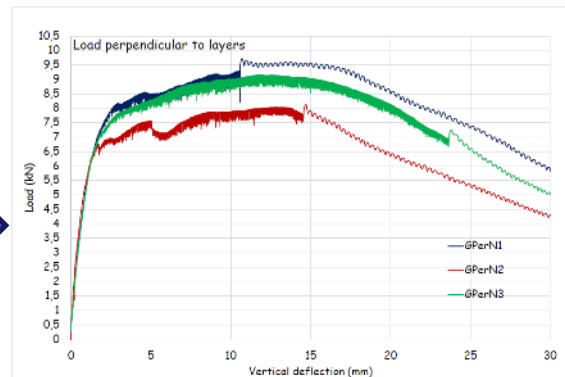
Structural tests on walls cut from 3D printed structures



Printing trial in August, 2024



Structural tests in September, 2024



In-Situ Performance (Structural Material)

Recommendation for design: when load is parallel to layers to consider a lower average tensile strength than that observed at the material scale, i.e. 3.0 MPa instead of 4.6 MPa, corresponding to a reduction of 52% at the structure scale, instead of 32% at the material scale, compared to the case where the load is perpendicular to the layers.

Material scale : Load parallel to layers

☐ Mean Stress value : 4.6 MPa



f_{LOP} (flexural cracking strength) lower by approximately 31% (4.6/6.7) compared to samples when loads are perpendicular to layers.

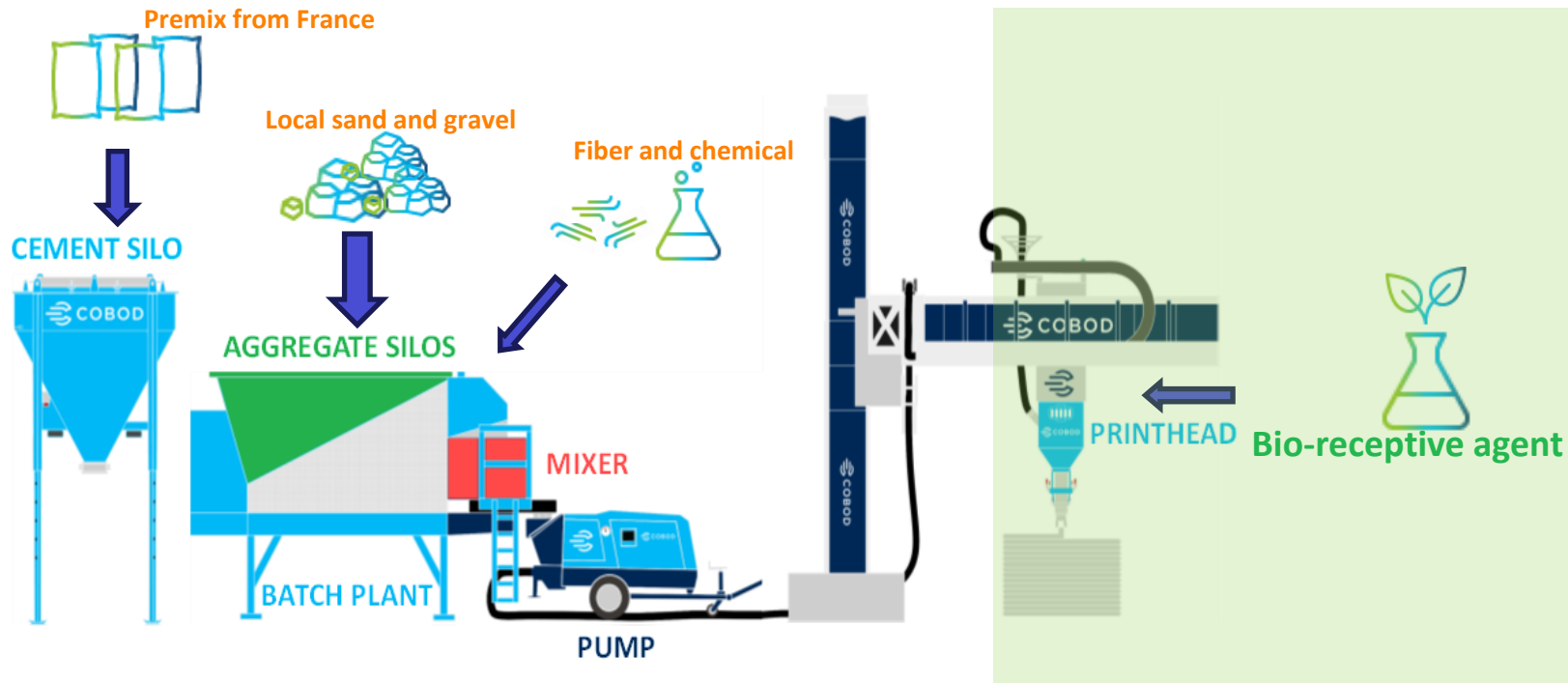
Structure scale : Load parallel to layers

- ☐ P_{cr_N1} = 3.56 kN
- ☐ P_{cr_N2} = 3.27 kN
- ☐ P_{cr_N3} = 3.37 kN
- ☐ P_{cr_Mean} value = 3.4 kN
- ☐ Effective thickness = 7.5 cm
- ☐ Effective width = 0.52 cm
- ☐ Moment capacity = 2.8 kN.m/m
- ☐ Stress capacity = 3.0 MPa



flexural cracking strength lower by approximately 52% (3.0/6.2) compared to samples when loads are perpendicular to layers. Difference more pronounced at struct scale.

Bio-receptive Material Production Scheme



In-Situ Performance (Bio-respective material)



Biowall printing, 1st trial



Biowall printing, 2nd trial