HOLCIM

Performance Review of High Performance Fiber Reinforced Concrete (HPFRC)

Nicolas Ginouse, Ph.D, P.Eng.
Technical Director – ACM – Eastern Canada
nicolas.ginouse@lafarge.com

Outline

1. Benefits of HPFRC

2. Best Practices Review

3. Performance Review of High Performance FRC

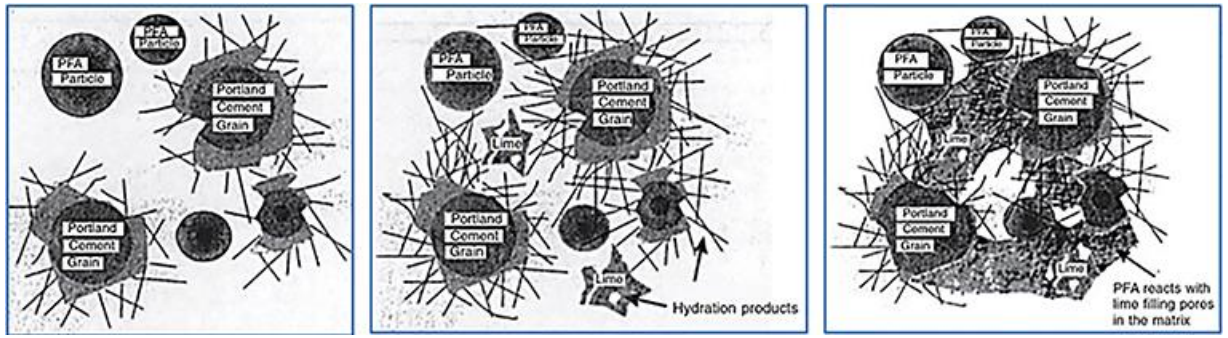
4. Conclusions & Perspectives

Benefits of High Performance Fiber Reinforced Concrete

1. Definition of HPFRC (from ACI Terminology)

High Performance Concrete

High-performance concrete (HPC) is concrete that has been designed to be more **durable** and, if necessary, **stronger** than conventional concrete.



[1]

Superior Microstructure & Matrix

Discrete Reinforcing Fibers

Fiber-reinforced concrete (FRC) is concrete made primarily of hydraulic cements, aggregates, and **discrete reinforcing fibers**.

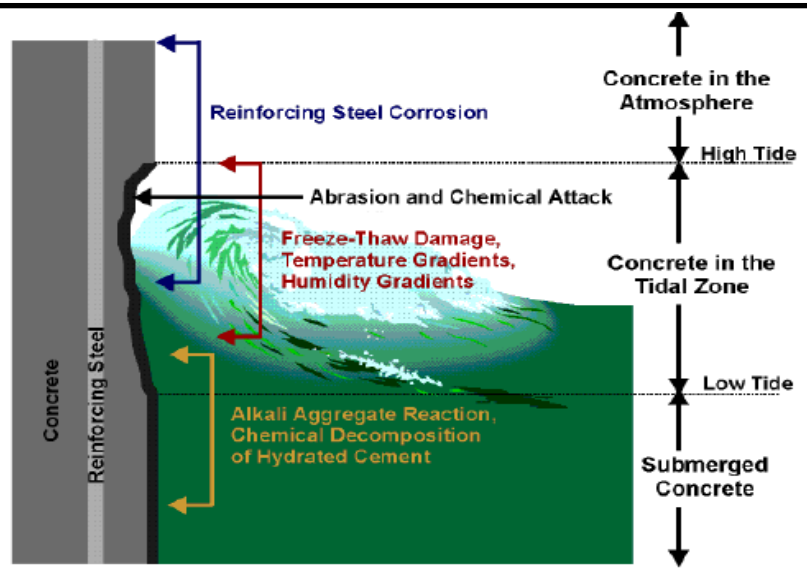
[2]

HOLCIM

2. Improved Structural Efficiency & Long-Term Serviceability

High Performance Concrete

High-performance concrete (HPC) is concrete that has been designed to be more **durable** and, if necessary, **stronger** than conventional concrete.

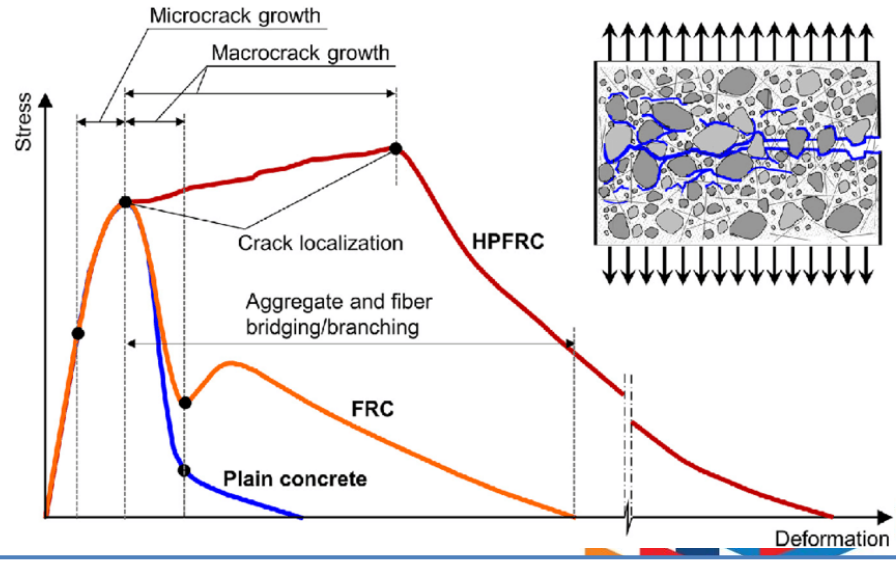


[3]

Superior Resistance to **Exposure Conditions**

Discrete Reinforcing Fibers

Fiber-reinforced concrete (FRC) is concrete made primarily of hydraulic cements, aggregates, and **discrete reinforcing fibers**.

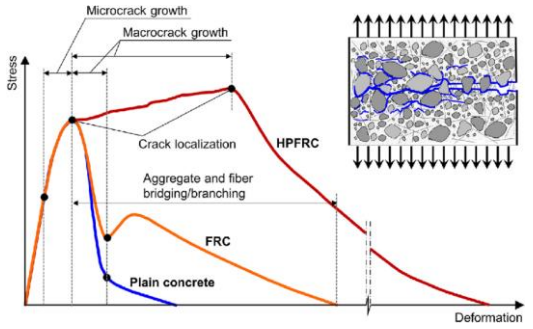


[4]

Superior **Cracking** & **Flexural** Resistance

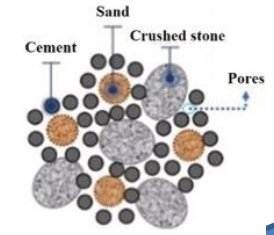
HOLCIM

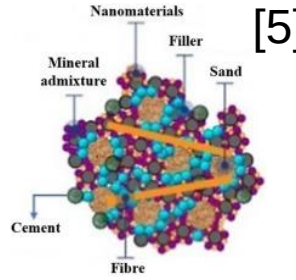
2. Improved Structural Efficiency & Long-Term Serviceability



Compressive Strength
Flexural Strength
MOE
Post Cracking Tensile

Structural Efficiency





[5]

FRC

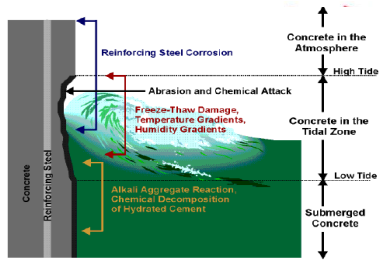
HPFRC

UHPFRC (UHPC)

Superior **Structural** Concrete Solutions

Penetrability to Chloride
Freeze & Thaw Resistance
Chemical Attack
Salts Scaling

Resistance to **Exposure Conditions**



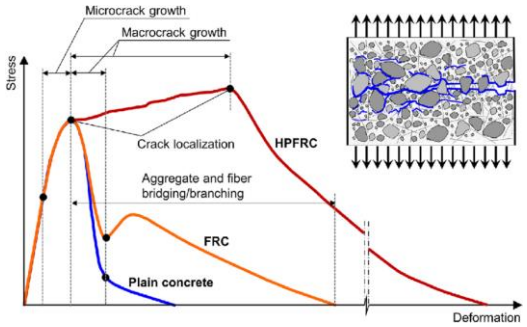
Benefits of High Performance Fiber Reinforced Concrete

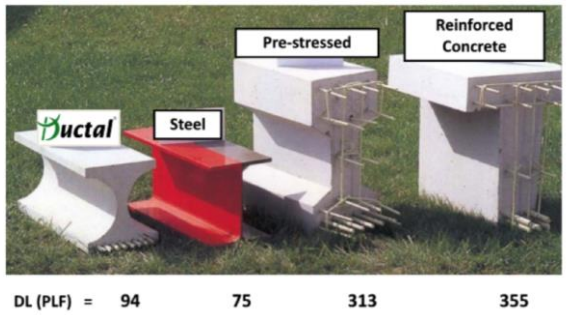
3. Superior Sustainability Benefits

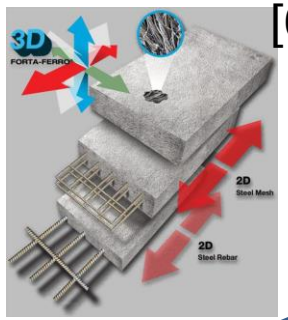
Structural Efficiency

Less Reinforcement
Reduced Sections
Less Materials

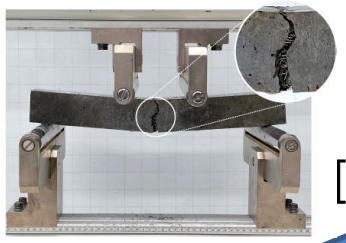
Superior **Sustainable** Concrete Solutions



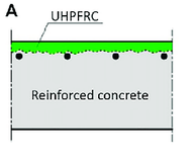




[6]



[7]



[8]

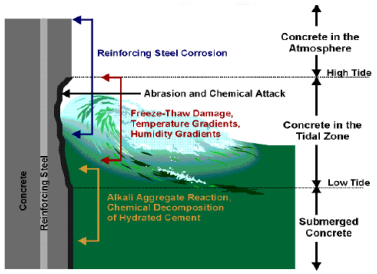
UHPFRC (UHPC)

HPFRC

FRC

Longer Service Life
Lower Maintenance

Resistance to **Exposure Conditions**



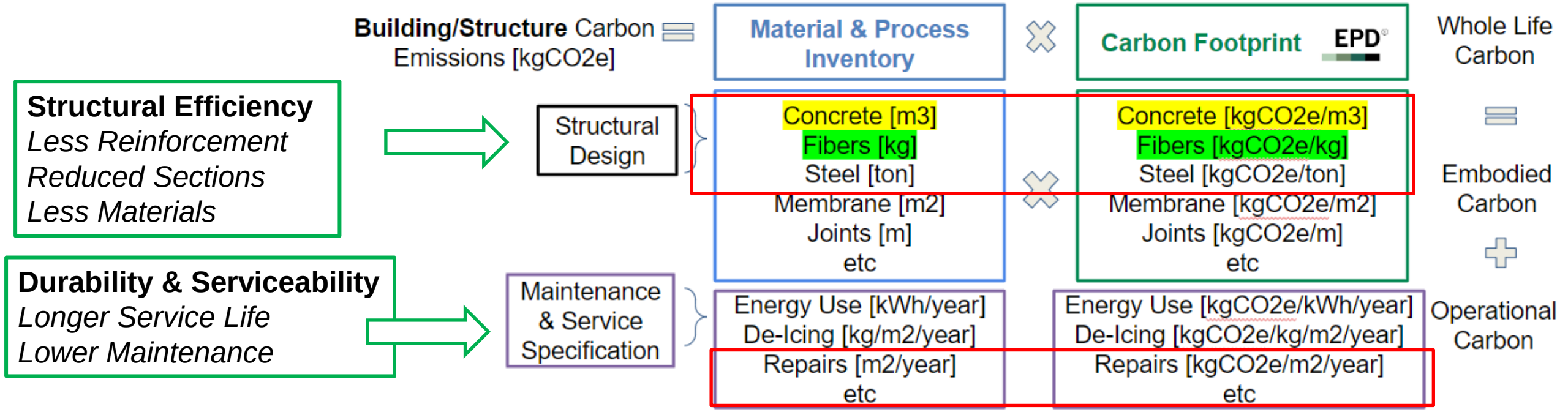
HOLCIM

3. Superior Sustainability Benefits

Superior **Sustainable** Concrete Solutions

How to capture it via an **Life Cycle Assessement (LCA)?**

a. From Material to **Whole Building/Structure** LCA



HOLCIM

3. Superior Sustainability Benefits

Superior **Sustainable** Concrete Solutions

How to capture it via an **Life Cycle Assessement (LCA)?**

b. Extend LCA Scope to **Cradle to Grave (A1 to C4)**

Structural Efficiency
Less Reinforcement
Reduced Sections
Less Materials

Durability & Serviceability
Longer Service Life
Lower Maintenance

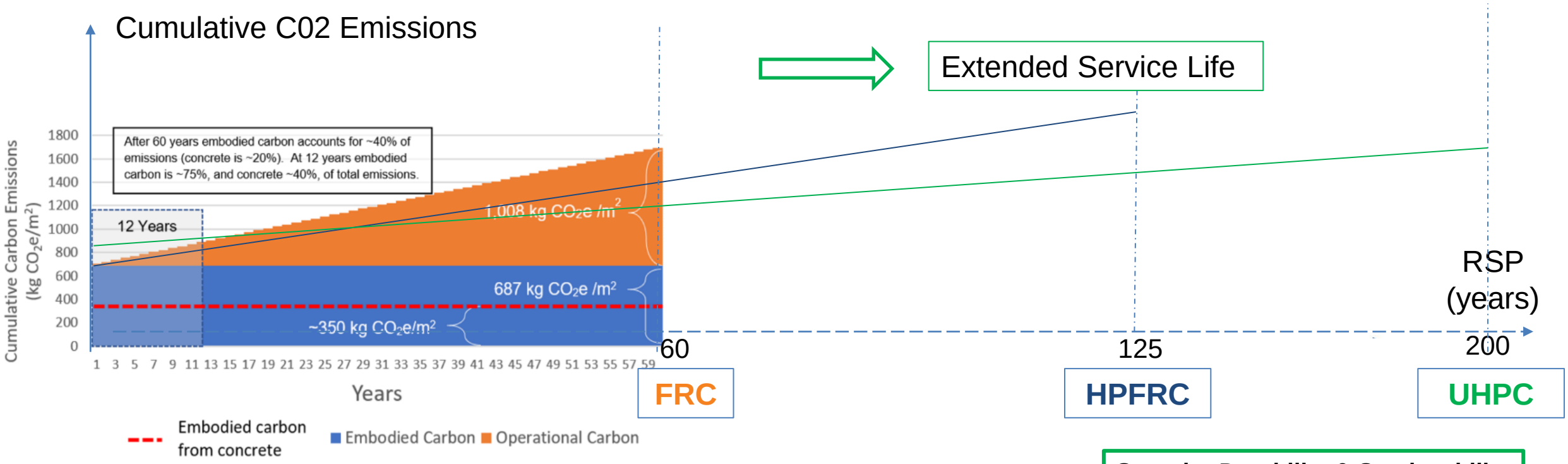
HOLCIM

3. Superior Sustainability Benefits

Superior **Sustainable** Concrete Solutions

How to capture it via an **Life Cycle Assessement (LCA)?**

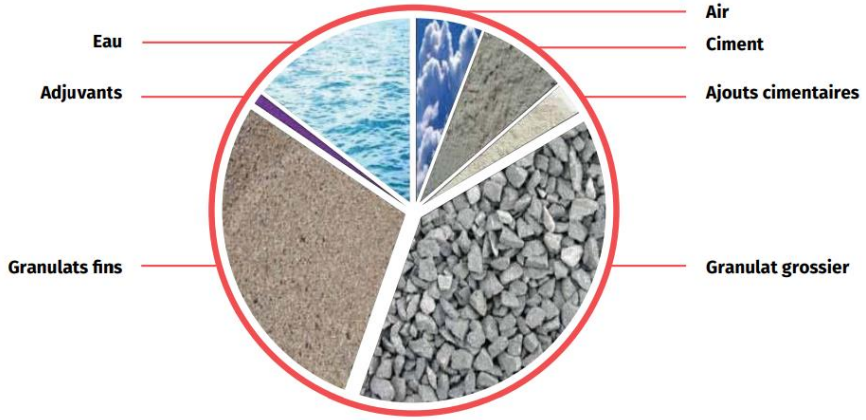
c. Increase the **Reference Study Period** (RSP)



Superior Durability & Serviceability
Longer Service Life
Lower Maintenance

1. Constituants & Mix Design

Matrix + Skeleton



Fibers




Key Levers:

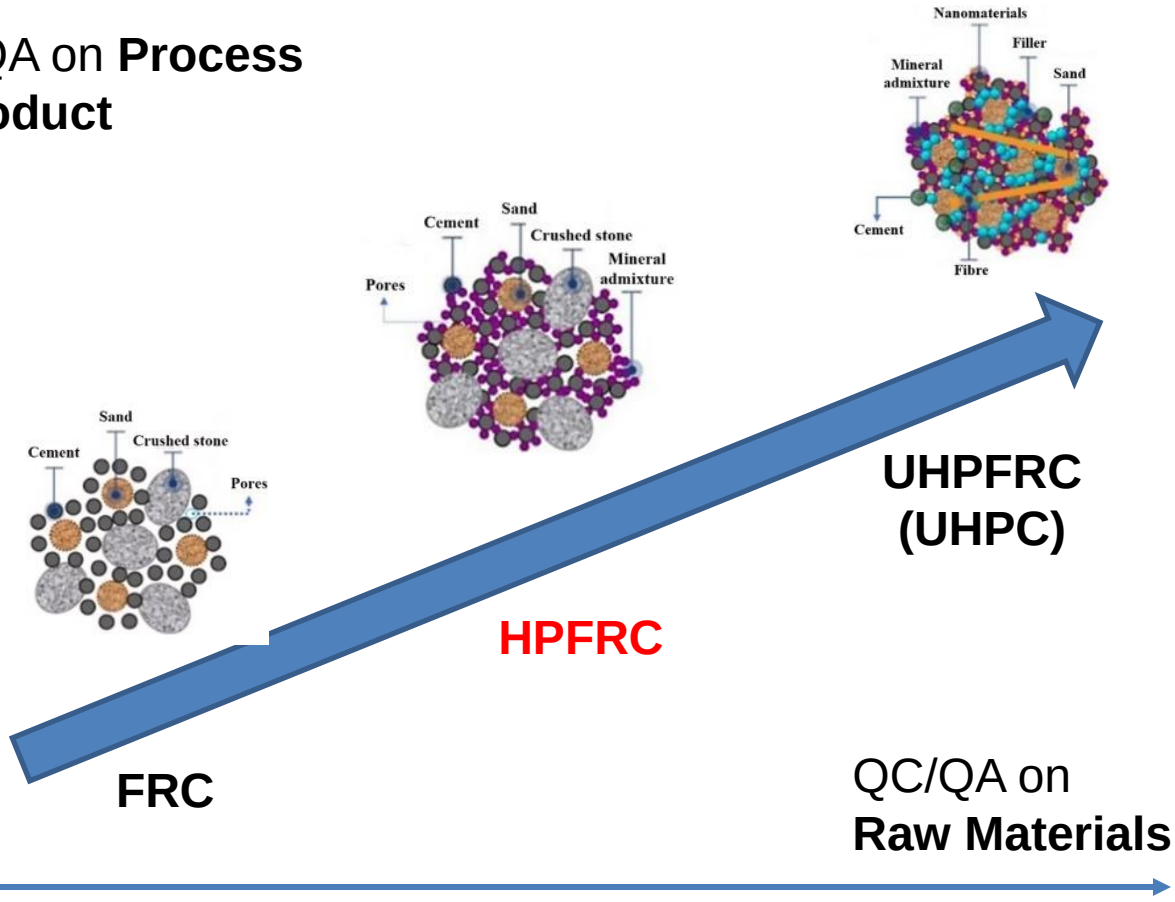
- W/B, SCMs and AEA for strength and durabiliy
- Agg Gradation Optimization (ACI 544)
- Fiber Length (placement method)
- l/d & dosage (performance & balling)
- Fiber Tensile Strength & Shape (perf.& behaviour)
- Rheology (mix stability & placement method)
- Special admixture (placement, shrinkage, etc)

MIX Type	fc' (Mpa)	W/B	SCMs	Max Agg Size (mm)	Fiber Dosage % Vol	Slump (mm)	Typical Applications
FRC_1	25 - 30	0.55	No	20 - 40	0.2 - 0.5	120 - 200	Slab on Ground/Steel Deck
FRC_2	35 - 45	0.40 - 0.50	if needed	20	0.2 - 0.5	120 - 200	Shotcrete, Slab on Ground, Fondation Walls, Precast
HPFRC	50 - 80	0.28 - 0.38	Yes	14	0.5 - 1	170 - 240	Precast Elements
UHPC	120 +	below 0.25	Yes	2	1.5 - 4	200 - 250*	Joint Filling, Repairs, Overlays
						*mini slump flow	

HOLCIM

2. Production & QC/QA

QC/QA on **Process** & **Product**



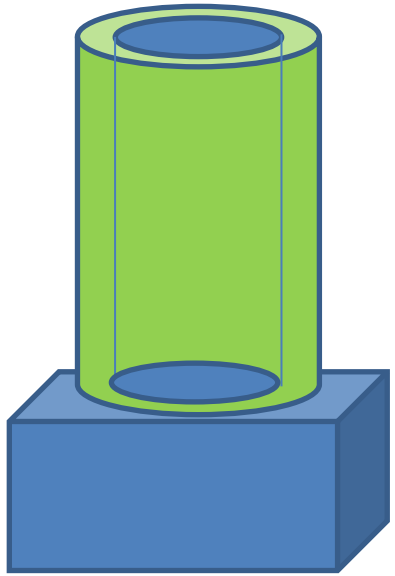
Goal (for mass production):
1. Ensure conformance
2. **Minimize coefficient of variation**

Key Drivers:
1. Raw Materials (variability)
2. **Batching Process** (proportions & dispersion)
3. Product at Plant (fresh & hardened prop.)
4. **Drivers Coaching** (mix stability)
5. Product on Site (fresh & hardened prop.)
6. Placement Method (fresh & hardened prop.)
7. **Curing** (degree of hydration, performance & durability)

HOLCIM

Example #1: HPFRC for Repairs

MIX Type	fc' (Mpa)	W/B	SCMs	Air (%)	Max Agg Size (mm)	Fiber Dosage %Vol (kg/m3)	Slump Flow (mm)	Special Admixtures
HPFRC	50 @ 56d	0.38	GGBS	6 - 9.	10	0.2 % (1.8 kg/m3)	650 +-50	SRA & SCA



HPC Column Repairs

Exposure Conditions:
- High Exposure to Chlorides
- Freezing & Thawing
- Highly Restrained Skrinkage

Special Considerations:
- High Stress Conditions
- High Compatibility Required

Key Success Drivers:
- Design of low cracking potential mix
- Heavy QC/QA of Production & **Sites Curing**

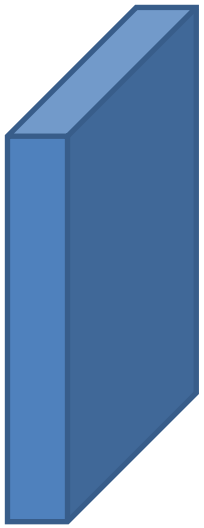
Performance:
- Mean fc' = 63 Mpa @ 56d
- CV (%) = 9.6 %
- AVS (L-Bar): 146 microns
- RCPT: 873 Coulombs @ 91d
- Drying Shrinkage: 0.029% @ 28d

Field Conditions:
- Maturity for early stripping & curing
- Wet curing for 14 days
- No cracking observed

HOLCIM

Example #2: HPFRC for Precast

MIX Type	fc' (Mpa)	W/B	SCMs	Air (%)	Max Agg Size (mm)	Fiber Dosage %Vol (kg/m3)	Slump (mm)
HPFRC	70 @ 56d	0.32	GGBS + SF	5 - 8.	14	0.7 % (40 kg/m3 Steel + 1.8 kg/m3 PP)	200 +-40



HPFRC Precast Elements

Exposure Conditions:
- High Exposure to Chlorides
- Freezing & Thawing
- Highly Restrained Skrinkage

Special Considerations:
- High Early Strain Gain
- Long Delivery Time (above 2h)
- Pumping & Placing

Performance:
- Mean fc' = 86 Mpa @ 56d
- CV (%) = 9.2 %
- CMOD 3.5 = 12.5 Mpa @ 28d
- AVS (L-Bar): 216 microns
- RCPT: 250 Coulombs @ 56d
- Drying Shrinkage: 0.034% @ 28d

Field Conditions:
- Maturity for early stripping & curing
- Wet curing for 7 days

Key Success Drivers:
- Agg Gradation Optimization using ACI 544
- **Heavy QC/QA** of Raw Material, Production & Sites

Conclusions & Perspectives

1. HPFRC provides superior structural and sustainability benefits

- Improve structural efficiency and durability due to superior cracking resistance in service
- Reduce the overall carbon footprint of the concrete element by reducing the amount of reinforcement
- Superior cost efficiency due to reduced amount of reinforcement and speed of execution

2. High Quality HPFRC is possible with tight QC/QA Protocol & Expertise

- Selecting and controlling the raw materials used and the batching process are critical
- Like for HPC, cementitious dispersion and curing are particularly important to ensure performance
- Strong QC/QA presence at the plant and on site is required to minimize variability

3. Further Work is Required to Expend the use of HPFRC in Standards & Codes

- To expend the use of HPFRC in further structural applications, new educational material
- Getting the sustainability benefits of FRC, HPFRC and UHPC recognized further remains critical
- Further work on circularity / recycling of FRC, HPFRC and UHPC are required

THANK YOU

Questions ?

nicolas.ginouse@lafarge.com

References

[1] Lewis, R., Sear, L., Wainwright, P. and Ryle, R.. Cementitious additions. In Newman, J. and Choo, B. S. Advanced Concrete Technology: Constituent Materials. Butterworth-Heinemann; 2003. Linacre House, Jordan Hill, Oxford OX2 8DP 200 Wheeler Road, Burlington MA 01803
[2] Cuadrf, F. (2017). Ultra High-Performance Fiber-Reinforced Concrete (UHPFRC) : a review of material properties and design procedures.
[3] Concrete Durability Lesson, University Laval, Benoit Bissonnette
[4] Choun, Young-Sun & Park, Hyung-Kui. (2015). Containment performance evaluation of prestressed concrete containment vessels with fiber reinforcement. Nuclear Engineering and Technology. 47. 884-894. 10.1016/j.net.2015.07.003.
[5] Jian Liu, and Al. (2024) A comprehensive review of ultra-high performance concrete (UHPC) behaviour under blast loads,Cement and Concrete Composites, Volume 148, 105449, ISSN 0958-9465.
[6] https://forta-ferro.com/engineers/
[7] Bertola, Numa & Schiltz, Philippe & Denarié, Emmanuel & Brühwiler, Eugen. (2021). A Review of the Use of UHPFRC in Bridge Rehabilitation and New Construction in Switzerland. Frontiers in Built Environment. 7. 769686. 10.3389/fbuil.2021.769686.