Sustainable ultra-high performance glass concrete

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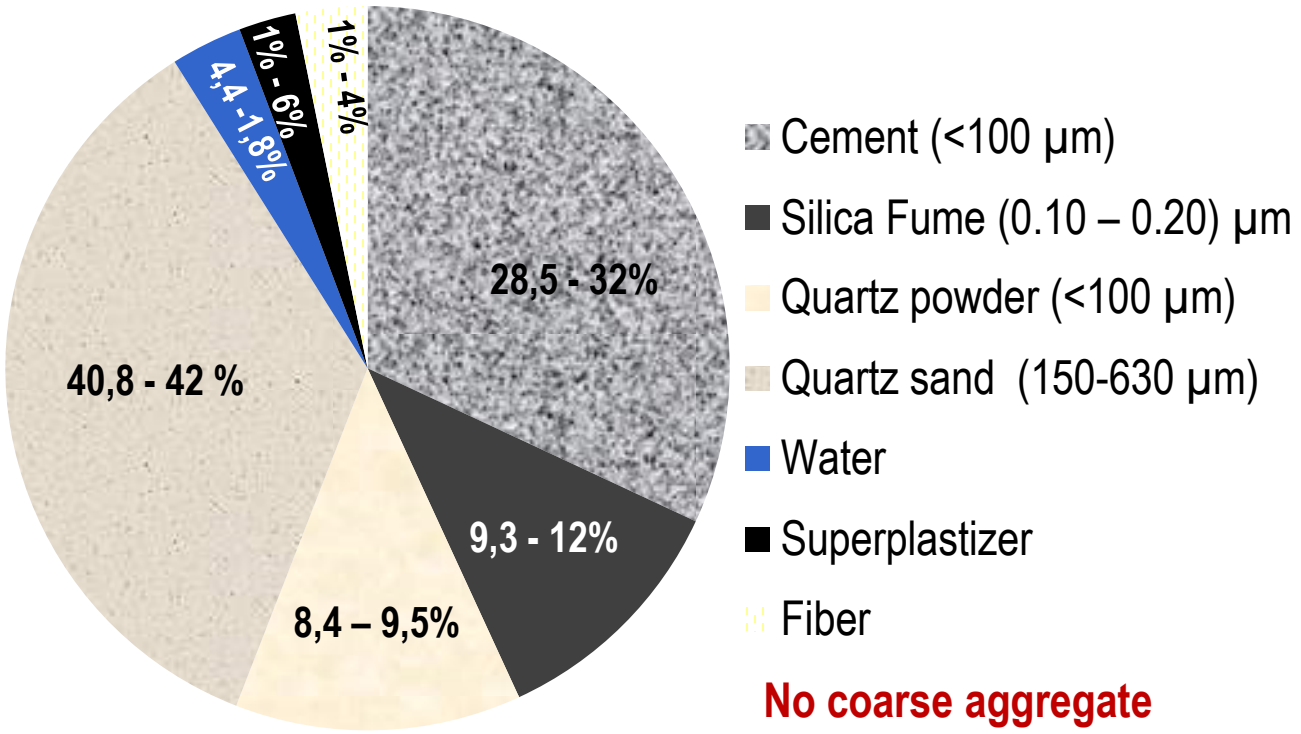
Session: Sustainable Building Solutions with UHPC Case Studies

What Ultra-High performance concrete

UHPC is a type of concrete that provides:

- ultra-high strength
- high ductility
- excellent durability

Typical composition of UHPC



No coarse aggregate

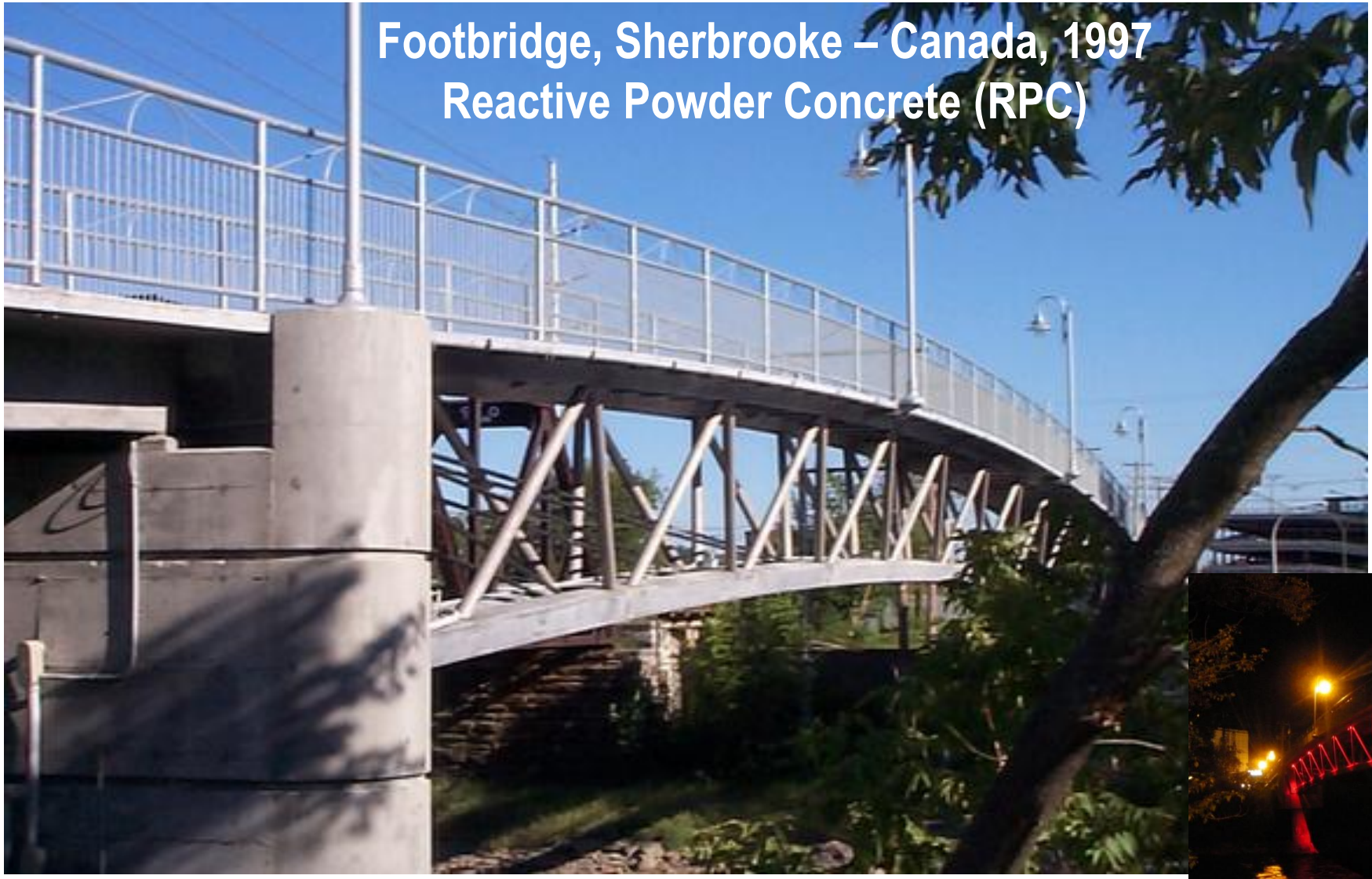
(Richard & Cheyrezy, 1995)

Applications of UHPC

Structural Applications

BOUYGUES CONSTRUCTION

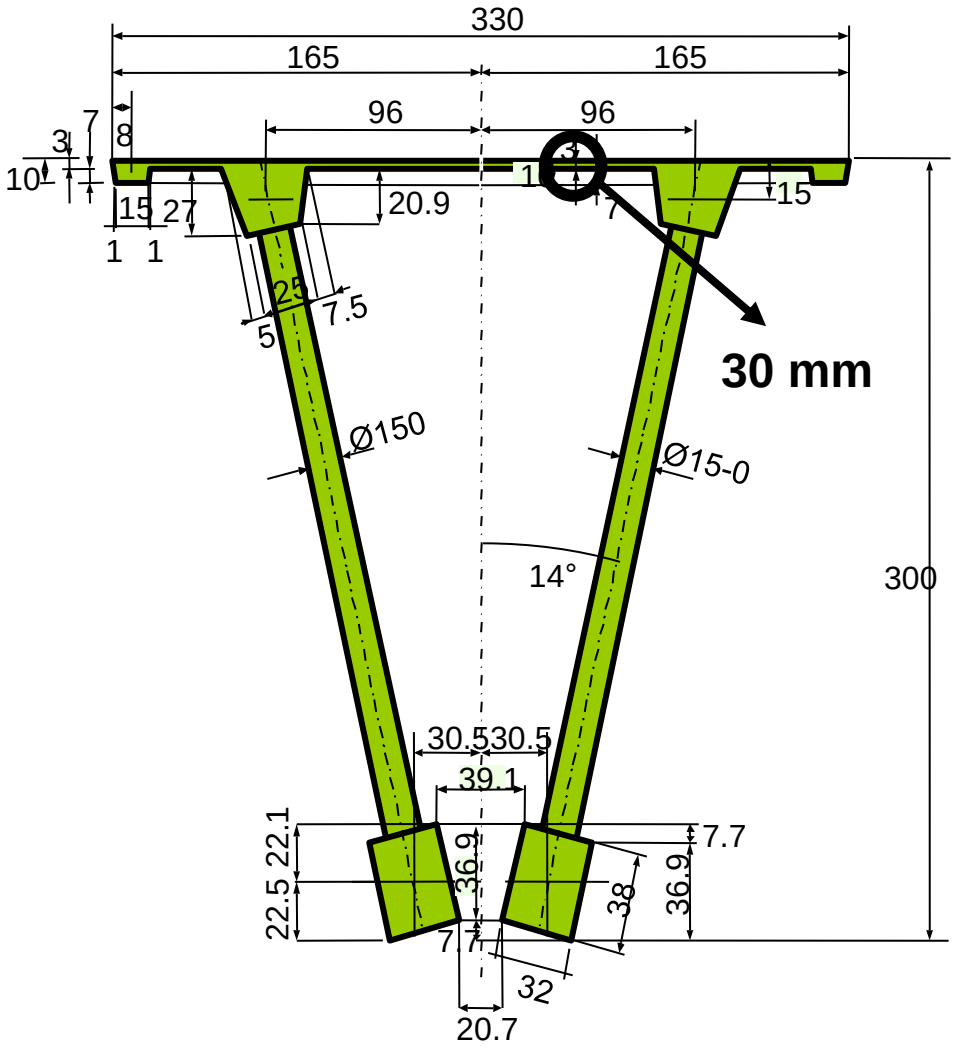
Footbridge, Sherbrooke – Canada, 1997
Reactive Powder Concrete (RPC)



UDS Université de Sherbrooke

Applications of UHPC

Structural Applications

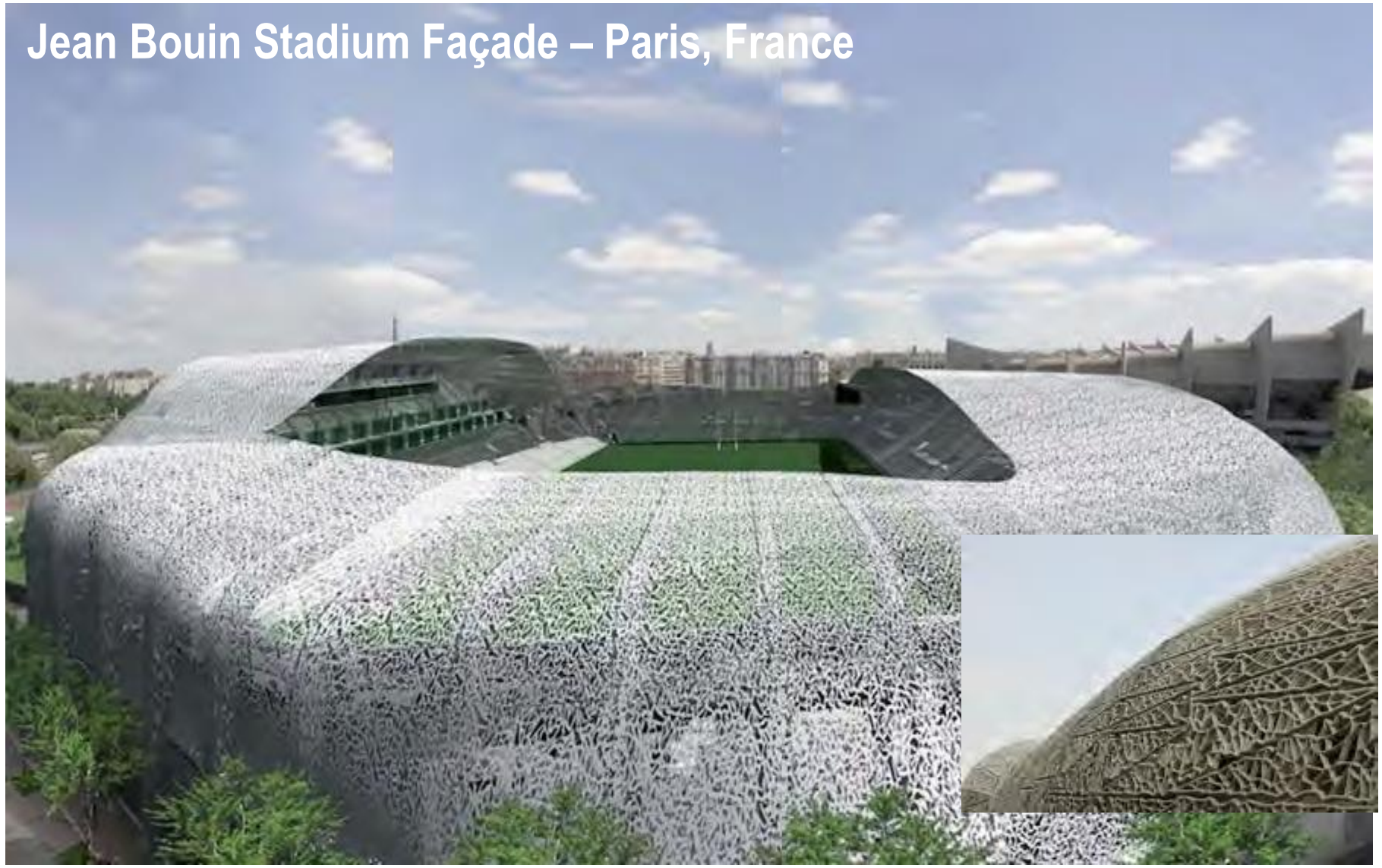


Foot Bridge of Peace – Seoul, South Korea, 1998 - 2002

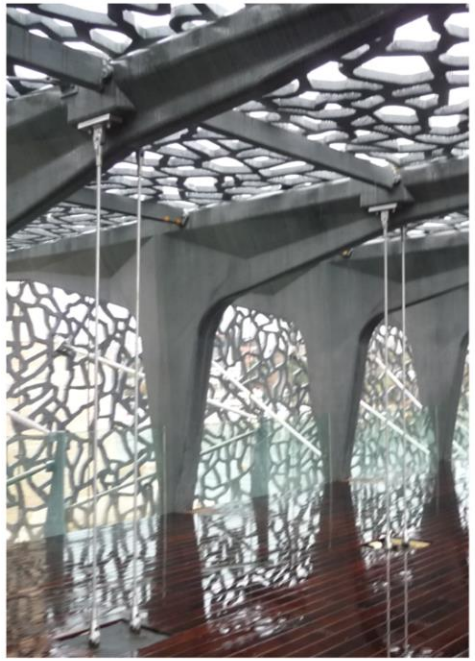
https://www.facebook.com/photo?fbid=138623642822548&set=seonyu-bridgealso-known-as-the-footbridge-of-peace-this-bridge-is-used-only-for-

Applications of UHPC

Architectural Applications



Mucem Marseille, France



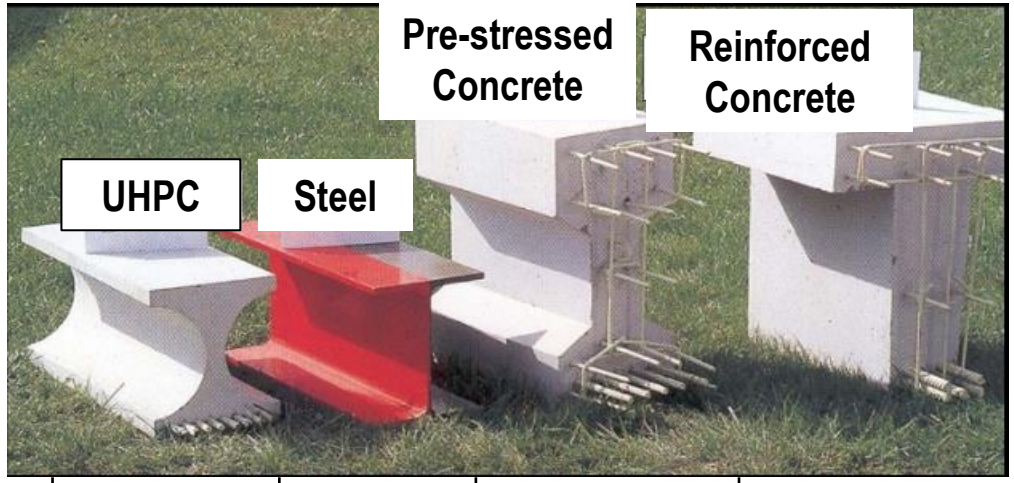
Museum – Louis Vuitton, France

Sustainability of ultra-High performance concrete

(A) Material requirements

- UHPC can be used as conventional HPC with less passive reinforcement
- UHPC can lead to longer span structures with reduced member size and self weight (< **70 %** NC or HPC)

Beams with equal moment capacities



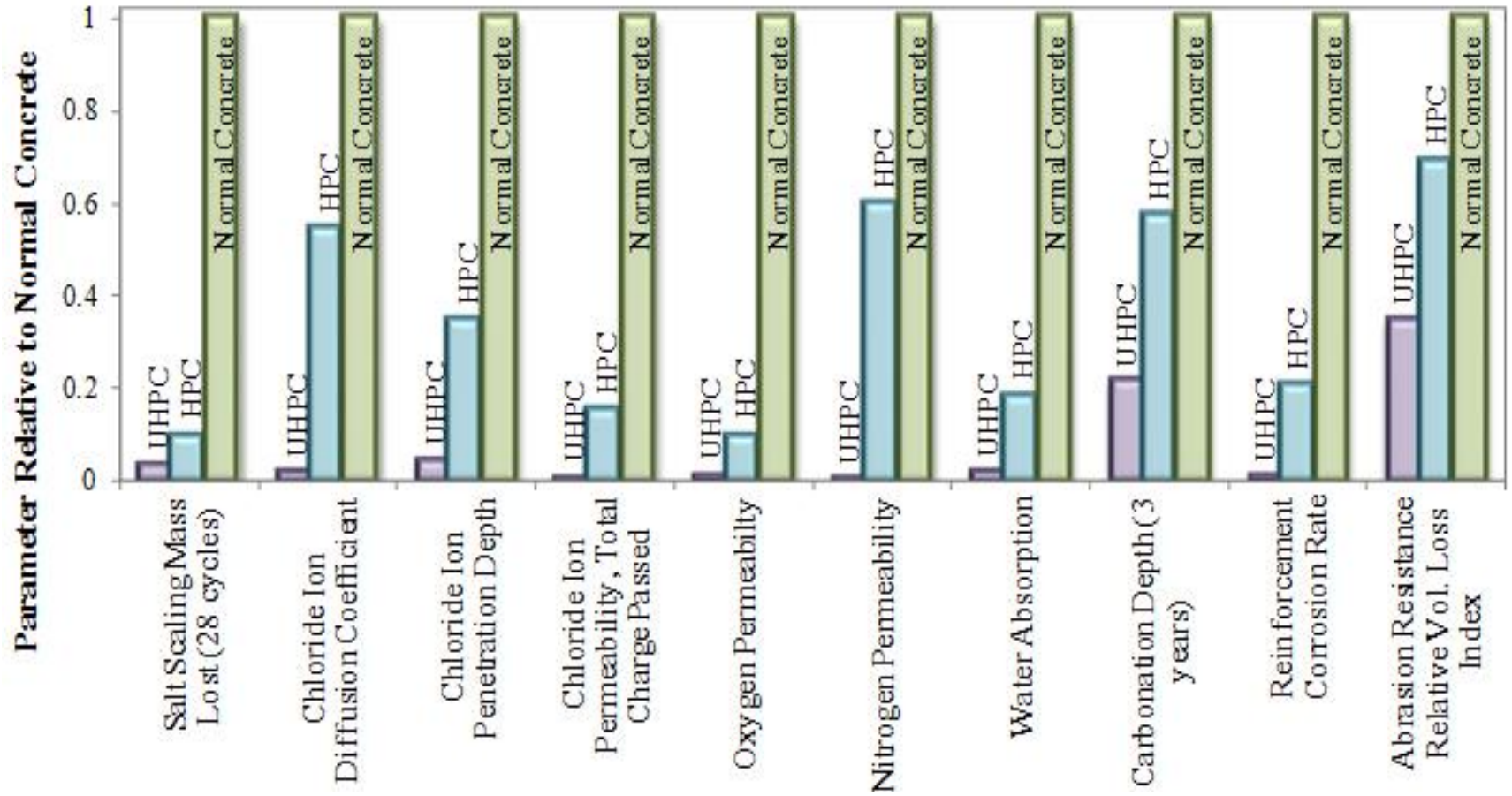
Depth (mm)	360	360	700	700
Weight (kg/m^3)	141	110	466	528

(Perry, 2006)

Sustainability of ultra-High performance concrete

Durability

- UHPC has superior durability properties ➔ longer service life and reduced maintenance cost



(Racky, 2004; Blais and Couture, 1999)

Sustainability of ultra-High performance concrete

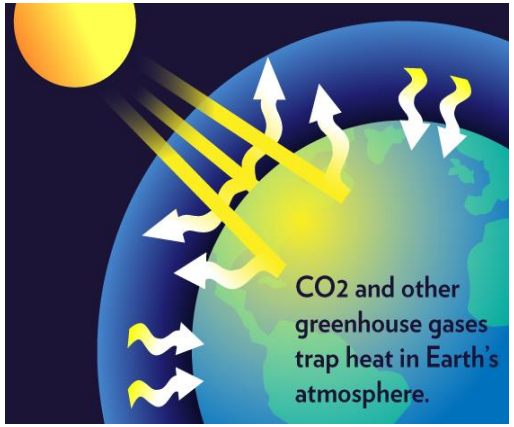
However !

1. Higher cement content (800 -1000 kg/m^3)

- Requires higher energy
- consumes natural resources

- high CO_2 (1000 kg cement releases ≈ 864 kg CO_2)
- Greenhouse gases
- global warming

✓ high heat of hydration
✓ develop shrinkage
✓ decrease rheology



Sustainability of ultra-High performance concrete

However !

2. High amount of crystallized silica (Quartz sand and powder)

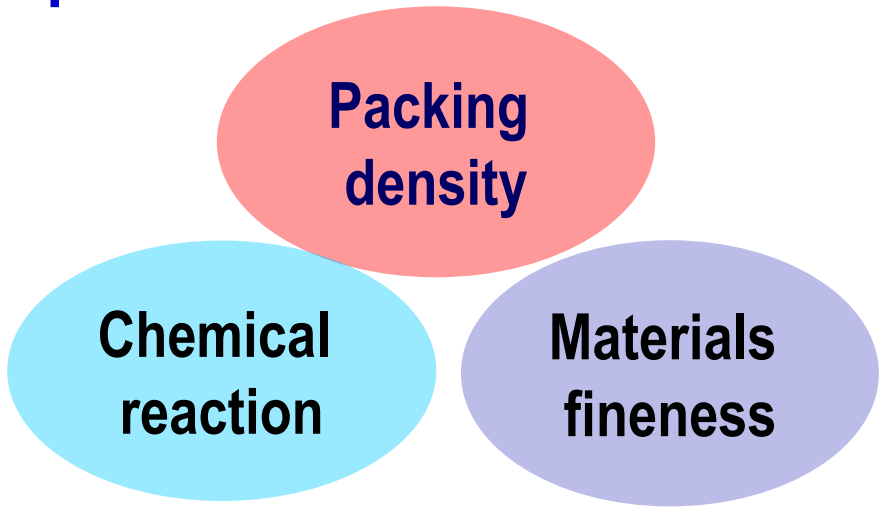
   - ✓ high cost
   - ✓ consume natural resources
   - ✓ carcinogenic to humans
   - ✓ biological diversity

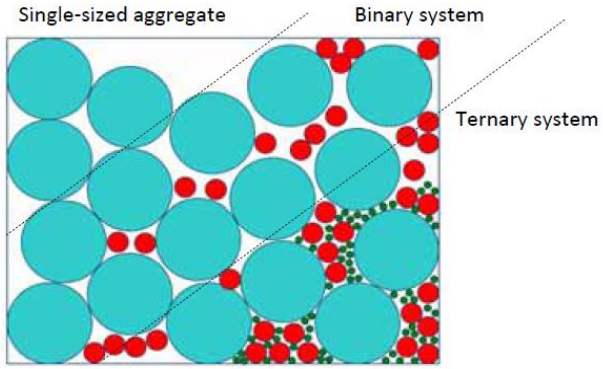
3. High SF content (25% - 35% wt. of cement)

   - ✓ limited available resources
   - ✓ High cost

How to solve the problem?

1. Optimum use of materials





2. Partial or total replacement of materials by other cost effective and sustainable mineral admixtures

Recycled glass

Why Recycled Glass?

- Excellent mechanical properties and pozzolanicity
- Zero absorption
- Sustainable
- Healthy (Glass is amorphous material)
- Low cost

SAQ Industriel Chair on Valorization of Glass in Materials

2004 to 2024 (4 terms: 20 years)

Glass Producers

Structure Owners

Concrete producers

Admixtures producers

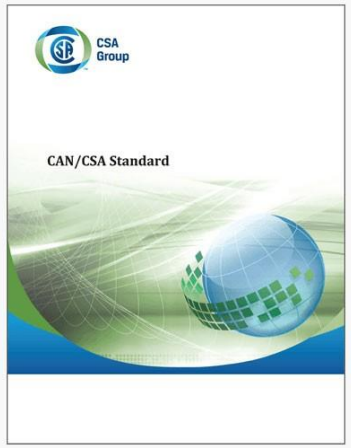
Citizens' group

https://www.cvvm-saq.ca/

Research

Standardiztion of Ground Glass Pozzolan

PASSION
SAVOIR-FAIRE
INNOVATION
SAO



CSA A3001 Cementitious Materials for Use in Concrete

2018: Ground-Glass Pozzolan is recognized as an SCM in Canada (CSA A3000)

This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.

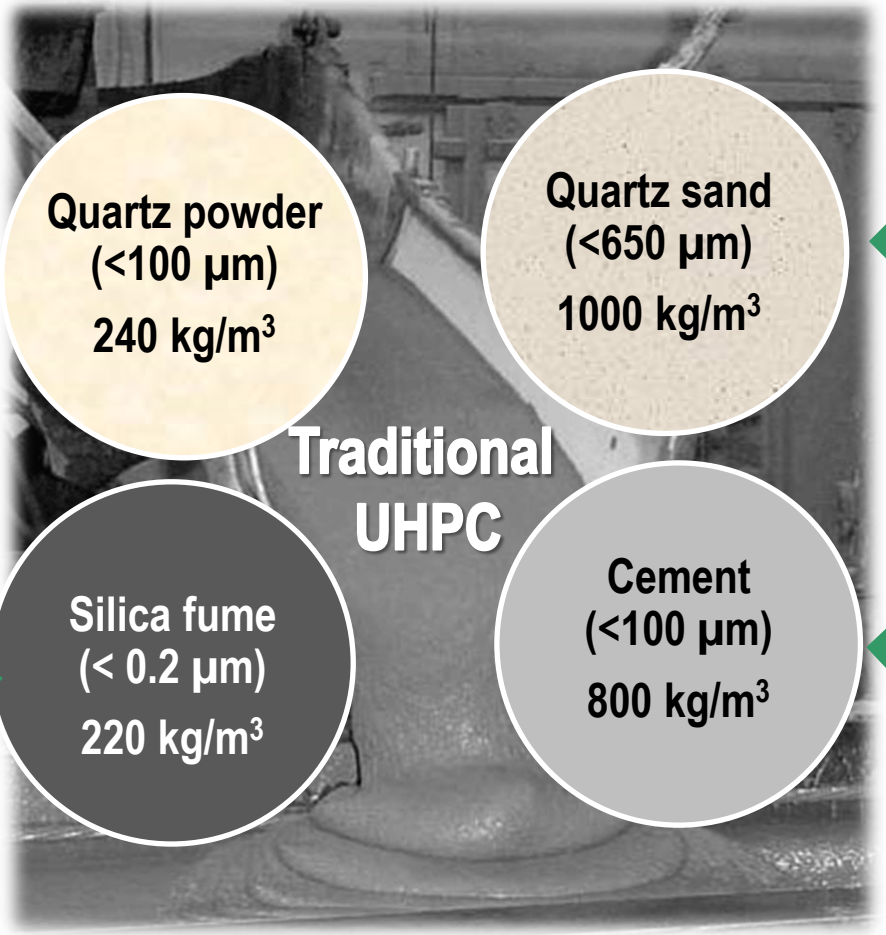
Designation: C1866/C1866M – 20

2020: Ground-Glass Pozzolan is recognized as an SCM in USA (ASTM C1866/1866M-20)

Standard Specification for Ground-Glass Pozzolan for Use in Concrete[1]

First SCM after more than 40 years in the world!

Green Ultra High performance glass concrete (UHPGC)



Glass powder
<100 µm

Quartz powder
(<100 µm)
240 kg/m^3

Quartz sand
(<650 µm)
1000 kg/m^3

Glass sand
<650 µm

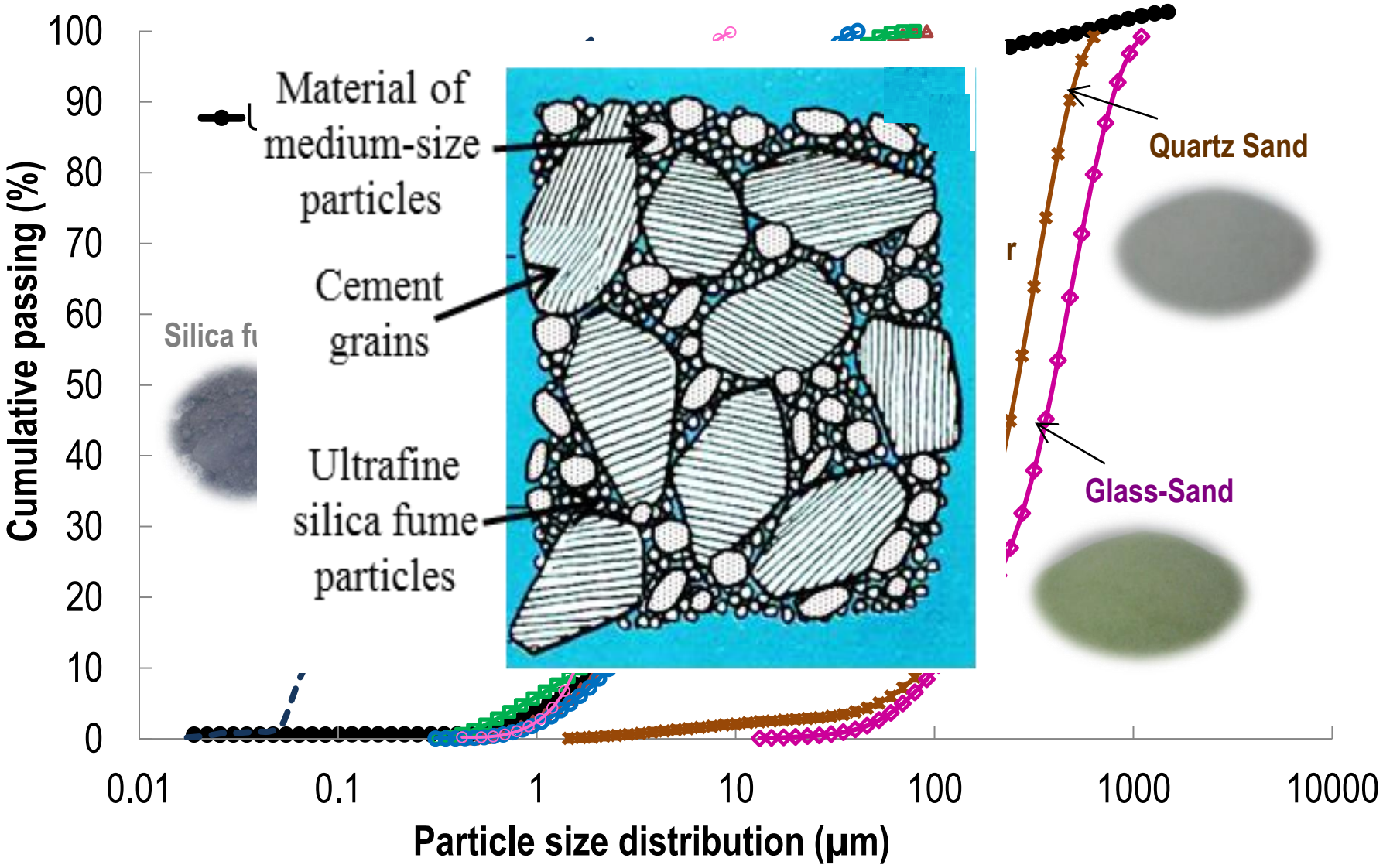
Fine-glass powder
<10 µm

Silica fume
(< 0.2 µm)
220 kg/m^3

Cement
(<100 µm)
800 kg/m^3

Glass powder
<100 µm

PSD of materials used and UHPGC



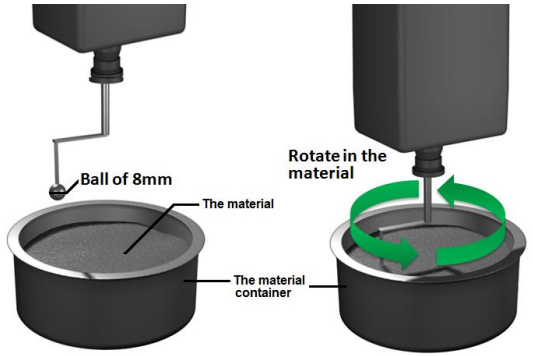
Parametric study using glass materials

A: Cement replacement by Glass powder

B: quartz powder replacement by Glass powder

C: Synergetic effect

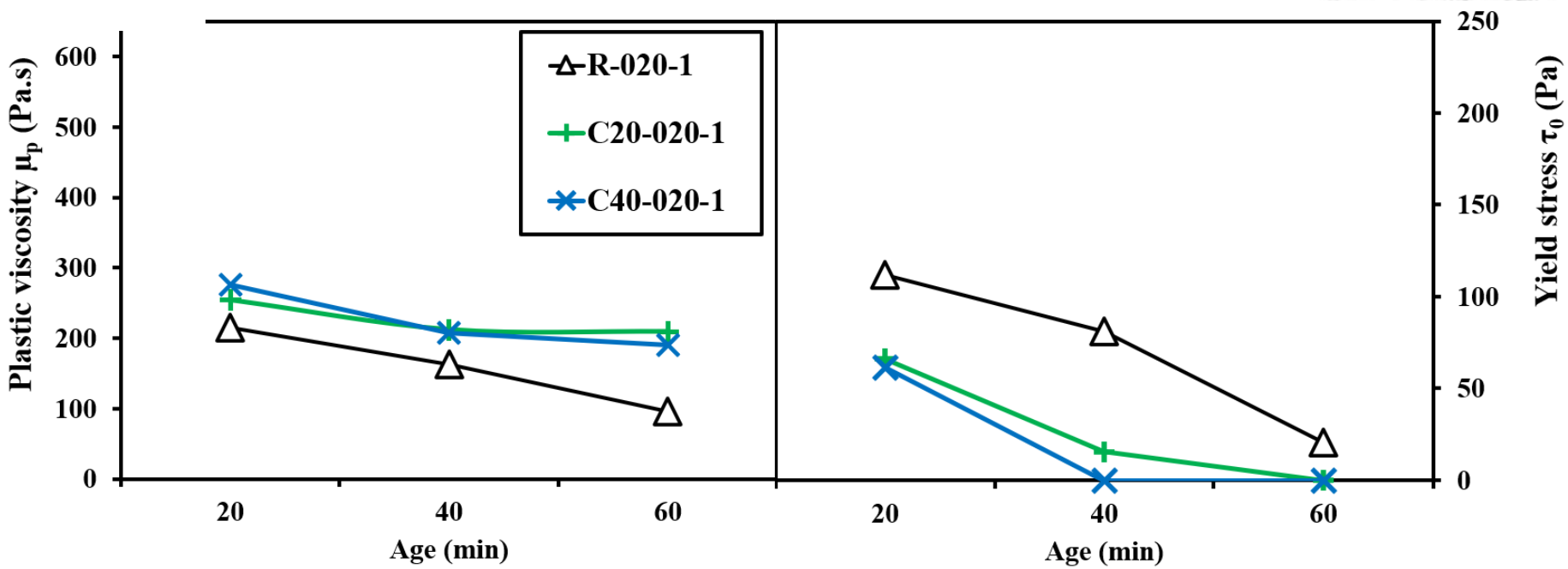
Rheology of ultra-high Performance Glass pozzolan concretes



Rheology

Flow Curves

Replacing cement with glass powder



Glass pouzzolan increase the viscosity, but decrease the yield stress

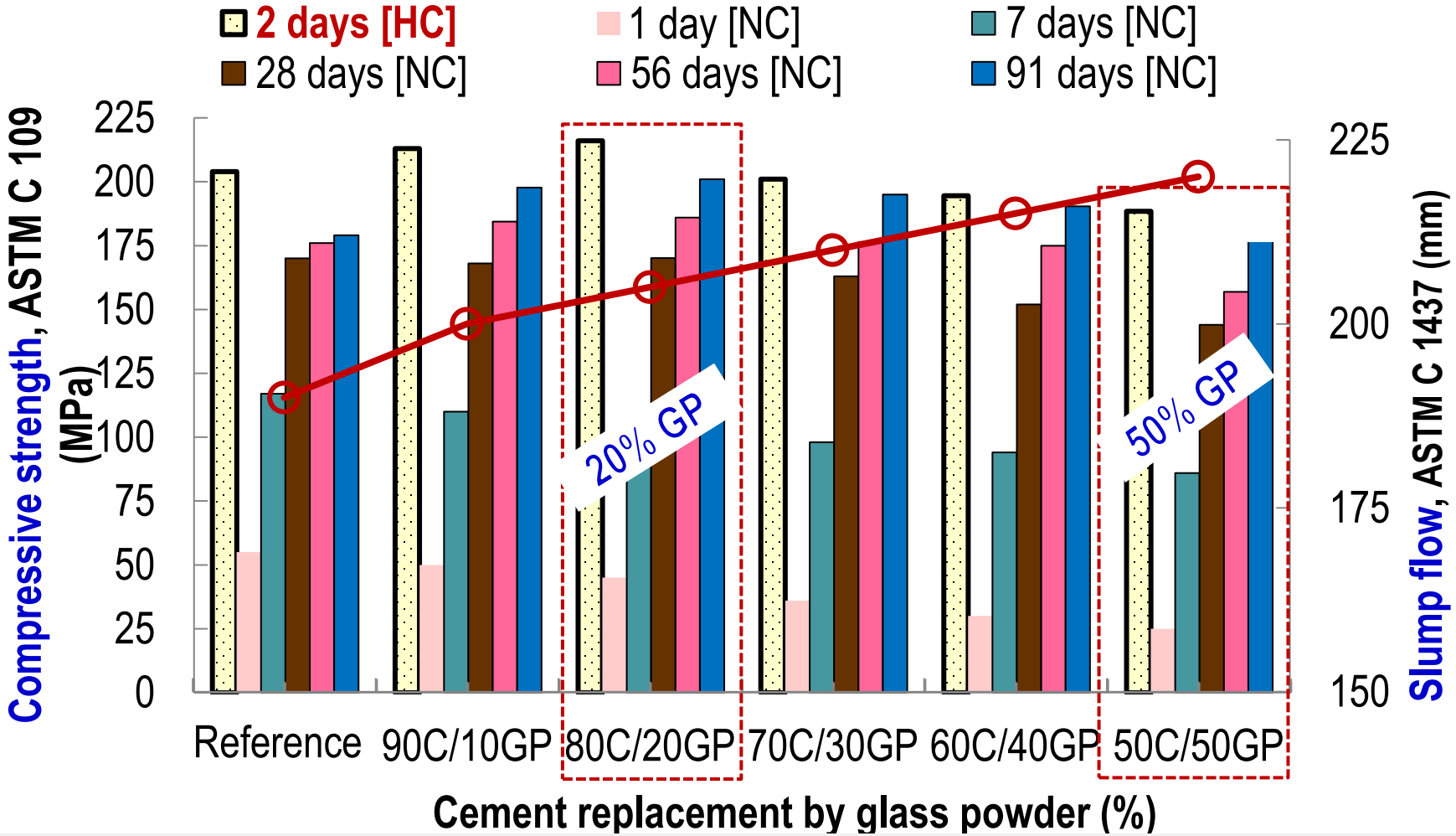
A. Begriche

A: Cement replacement by glass powder

0%, 10%, 20%, 30%, 40%, 50% traditional GP

HC: Hot curing

NC: Normal curing



Based on compressive-strength ➔ optimum replacement of cement with GP = **20%**

Based on flowability and sustainability ➔ optimum replacement of cement with GP = **50%**

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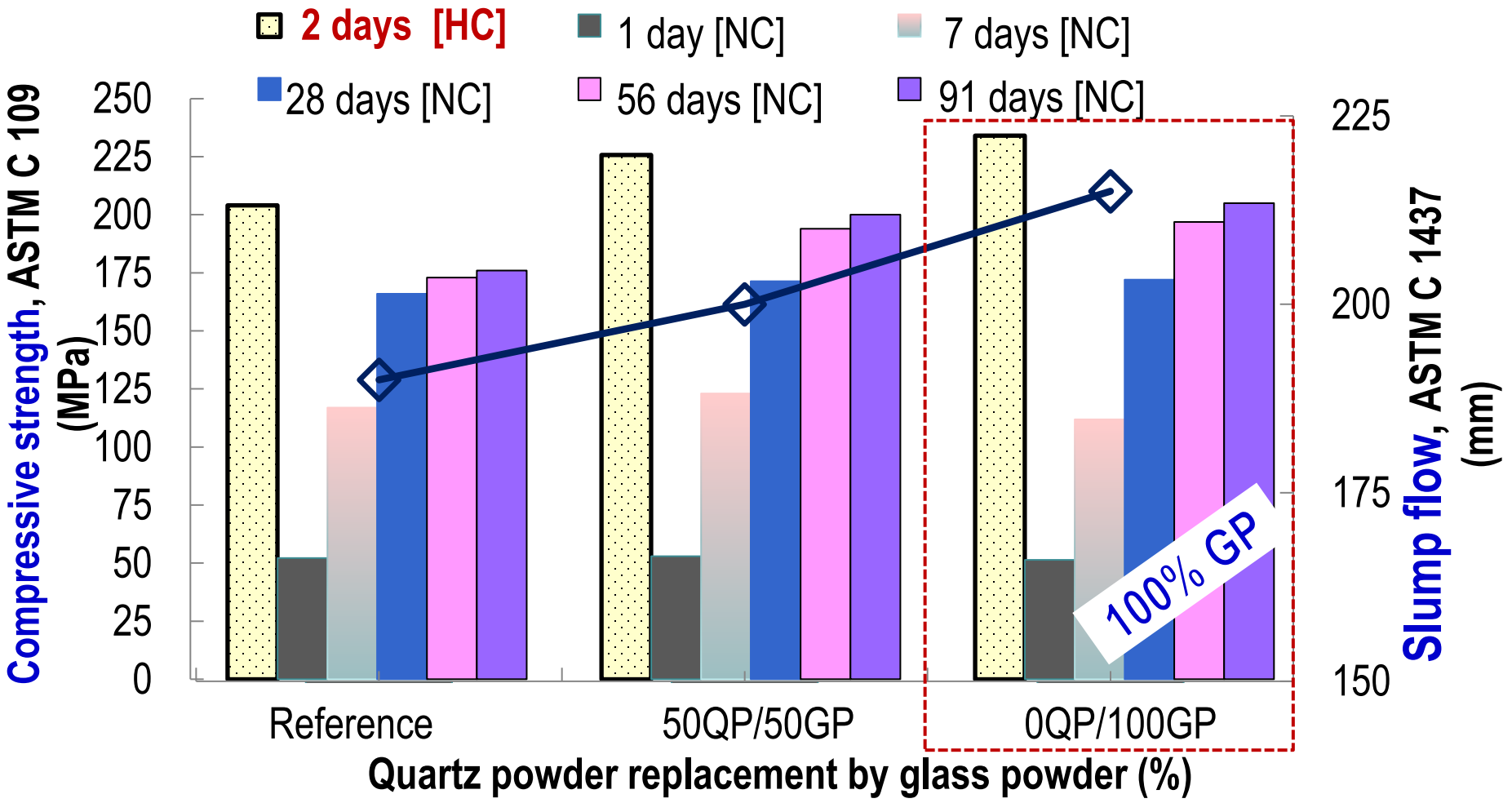
B: Quartz powder replacement by glass powder

0%, 50%, 100% traditional GP



100% GP replacement ➔ higher strength 15% @2dHC, 17%@91dNC than reference

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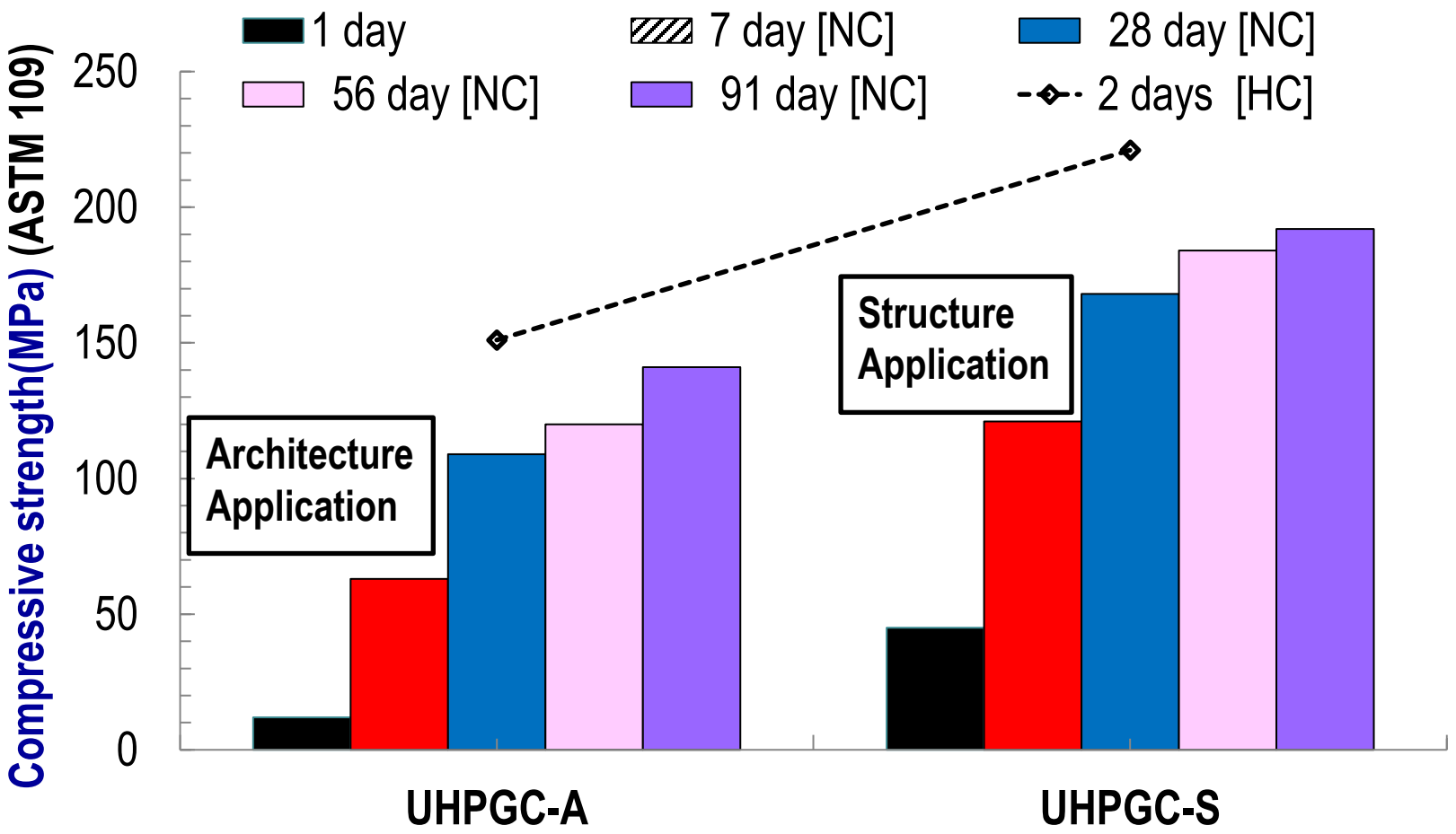
C: Synergetic effect

C: Synergetic effect

Cement and Quartz powder replacement by Glass powder



Synergetic Effect of Cement and QP Replacement with GP

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Domain classifications of UHPGC

Depending on material contents (GP, FGP, GS), curing conditions and ages, different UPHGC can be obtained:

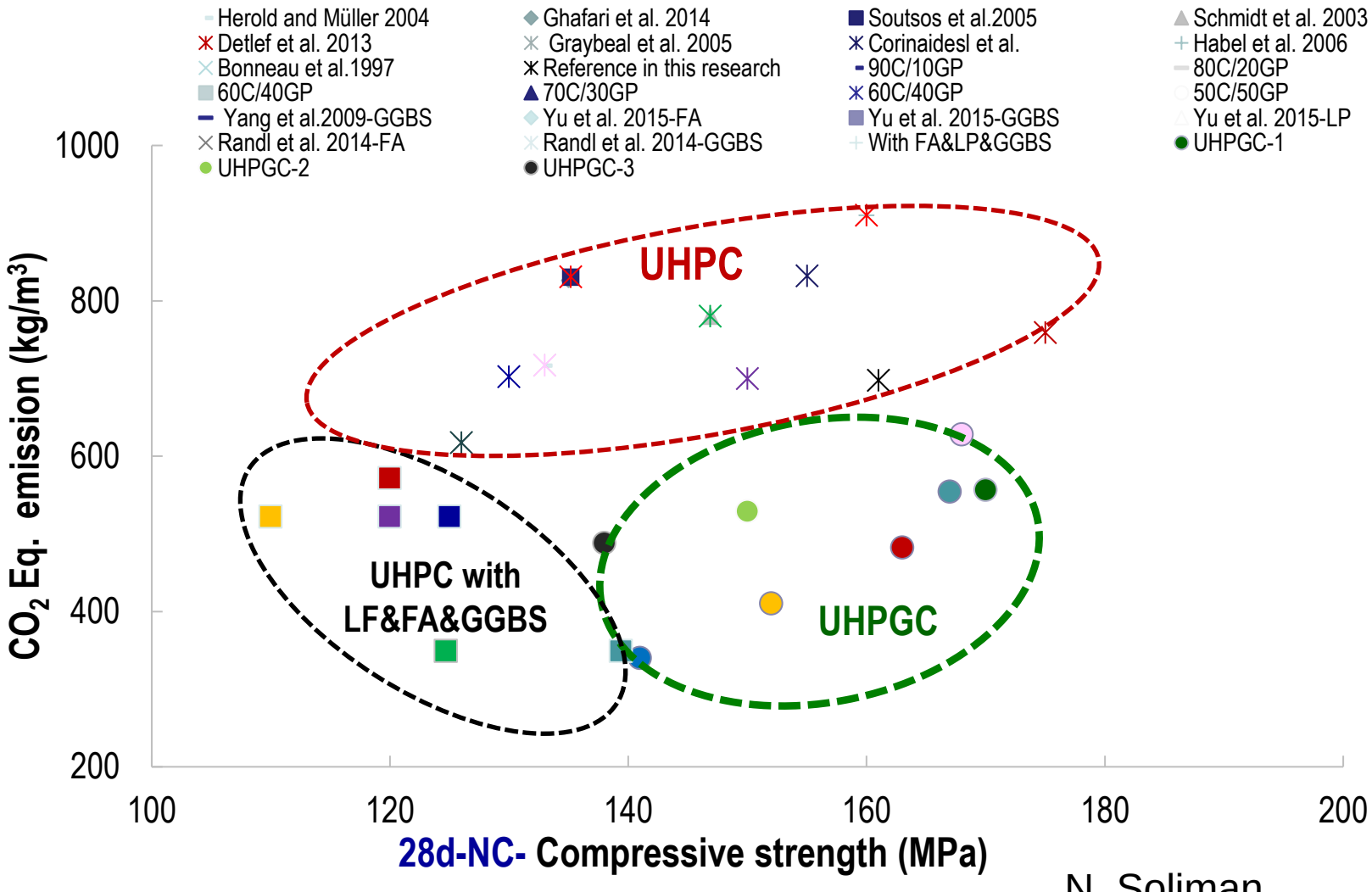
Characteristics	Class A	Class B	Class C	Class D (architecture)
Flowability	Semi-flowable	Flowable	Highly flowable	Highly flowable
Mini-slump flow, mm	> 200	> 230	> 260	> 280
w/b	0.150–0.190	0.190-0.225	0.225-0.250	0.225-0.250
SP (solid content of cement (%)	1-2.5	1-2.5	1-2.5	1-2.5
Steel fiber, %	2	2	2	--
PVA fiber, %	--	--	--	2.5
2-day f'c -Hot curing (90 °C), MPa	> 200	175-200	160-175	--
28-day f'c -Normal curing (20 °C), MPa	> 160	> 140	> 130	> 100
91-day f'c -Normal curing (20 °C), MPa	> 180	> 150	> 140	> 120
Flexural strength, MPa	> 25	> 20	> 15	> 10
Modulus of elasticity, GPa	> 50	> 45	> 40	> 40
Chloride-ion penetration (Coulombs)	Negligible < 20	Negligible < 20	Negligible < 20	Negligible < 20
Freeze and thawing (1000 cycles (%)	100	100	100	100

UHPC *vs.* UHPGC

	Characteristics	UHPC	New UHPGC
Materials Characteristics	Materials	Cement, SF, QP, QS	Cement, SF, GP, GS, FGP
	w/b	0.10 - 0.25	0.10 - 0.25
	SP (solild content of cement %)	1-5	1-2.5
	Density (kg/m^3)	2320 - 2450	2350 - 2500
	Slump flow (mm)	130-250	190 - 300
	Workability	Stiff to flowable concrete	Semi flowable- highly flowable concrete
	Material cost estimation ($/m^3$)	**≈1000**	**≈450 (half price)**
	CO_2 emission (t/m^3)	**≈650**	**≈325 (half emission)**
Mechanical Properties	Compression strength, (MPa)	110 - 230	120 - 240
	Young's Modulus, (GPa)	> 40	> 40
	Flexure strength (MPa)	> 10	> 10
Durability Properties	Abrasion test (50 cycles)	1.3 - 1.7	< 1.3
	freeze-thaw cycles 1000 cycles	100% durable	100% durable
	Chloride penetration (coulombs)	< 100	< 20

Evaluation of CO_2 emission of UHPGC

(cement without transportation)



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Health Impact

Unlike Quartz Powder Glass Powder does not have any risk on human health

SIMDUT 2015

Fiche de Données de Sécurité
Canada – conformément à la Loi sur les produits dangereux (SIMDUT 2015)

Date de révision: Première version
Date: le 21 septembre, 2015

Page: 1/9

Nom commercial: **Verrox**

SECTION 1: Identification

Identificateur de produit: Verrox
Synonymes: Sans objet
Autres moyens d'identification: Sans objet
No. de Fiche: Sans objet
Usage recommandé: Ajout cimentaire
Restrictions d'utilisation: Des utilisations autres que comme recommandé ci-dessus.

Identificateur du fournisseur initial:
Fournisseur: Tricentris, Centre de tri
Adresse: 651 ch. Félix-Touchette
Lachute, QC, J8H 2C5
Téléphone: (450) 562-4488, Heures d'ouverture: 7h à 16h, du lundi au vendredi. (Zone de l'Est)

SECTION 2: Identification des dangers

Classification du produit conformément à la Loi sur les produits dangereux (2015) (Canada)/ Système d'information sur les matières dangereuses utilisées au travail (SIMDUT 2015):

Les dangers physiques
Pas classé comme un danger physique

Les dangers pour la santé

Pas classé comme un danger pour la santé

Les dangers pour l'environnement
Pas déterminé

Mentions d'avertissement: Sans objet

Mention de danger: Sans objet

Field application

Two pedestrian bridges at Sherbrooke University Campus - 2014

UNIVERSITÉ DE SHERBROOKE

NSERC CRSNG

BÉTONS GÉNIAL

Class D

(architecture)

Mix design

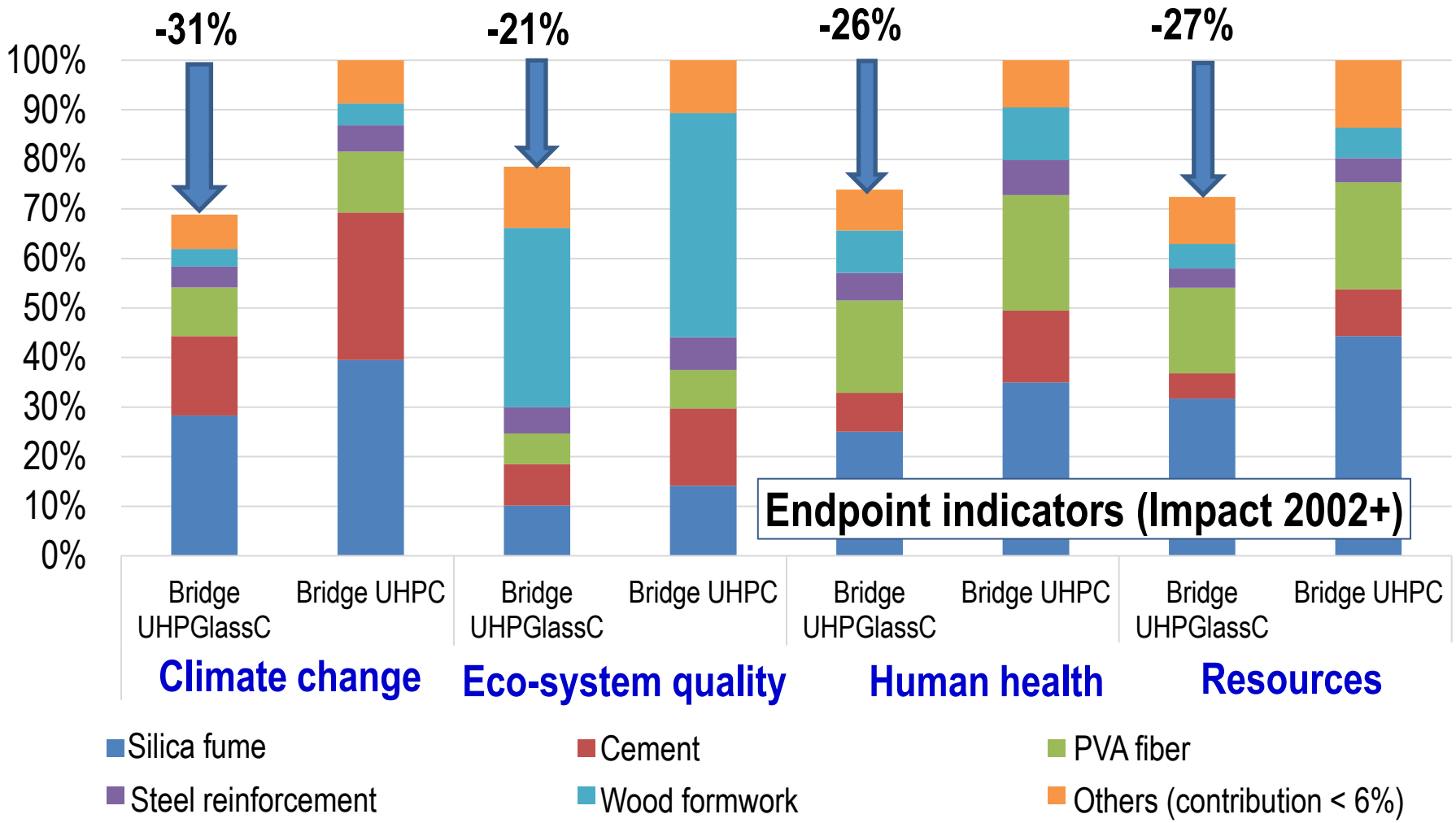
Materials	HS-Cement	Silica fume	Quartz sand	Glass powder	Water	SP	PVA
kg/m^3	555	205	888	410	226	17	32.5 (2.5)

Mechanical properties

Properties	Concrete age, (days)			
	1	7	28	91
Compressive strength (ASTM C 39), MPa	12	52	96	127
Splitting-tensile strength (ASTM C 496), MPa	--	--	10	11
Flexural strength (ASTM C 1018), MPa	--	--	10	12
Modulus of Elasticity (ASTM C 469), GPa	--	--	41	45

Compressive strength 2 days Hot curing 138 MPa

Life-cycle analysis



J Deschamps

Ultra-high performance glass concrete

Manufacturing of 2 pedestrians bridges in the campus of University of Sherbrooke

Nancy Soliman PhD thesis

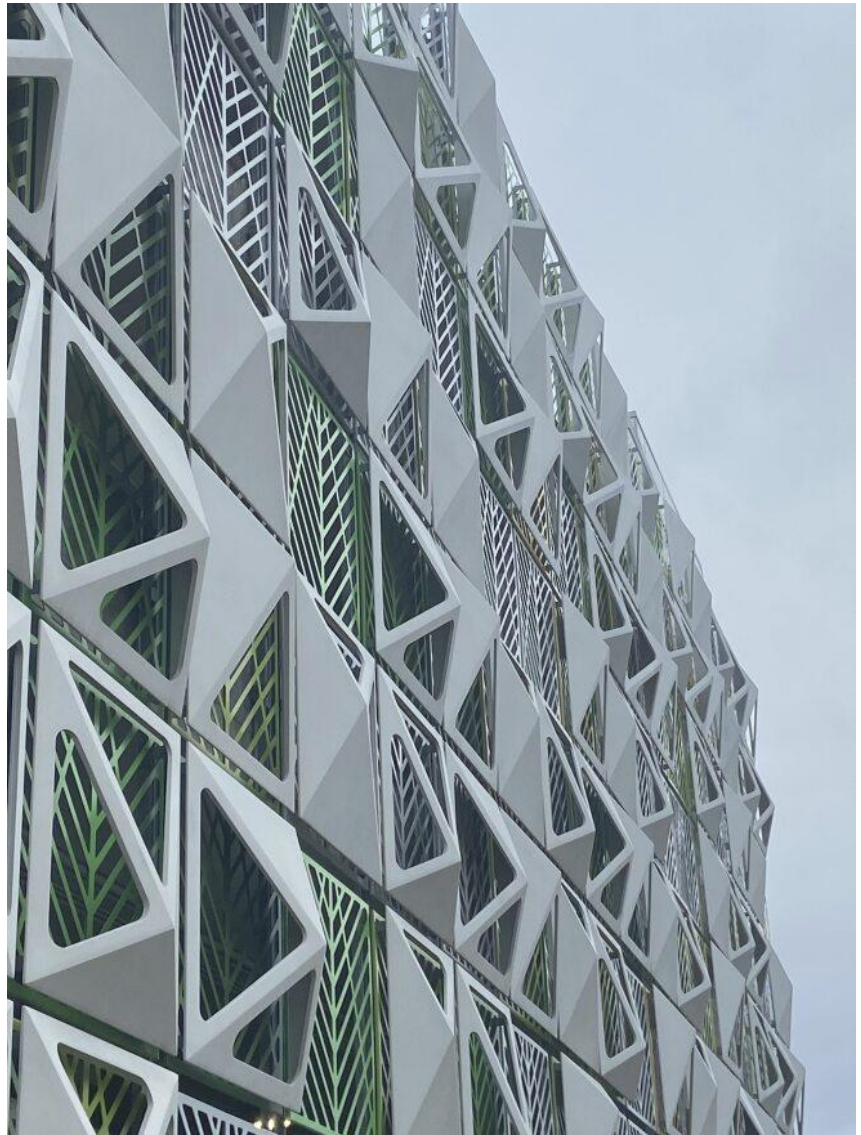
Patent

A. Tagnit Hamou and N. Soliman, Ultra-high performance glass concrete and method for producing same, Patent in USA, Canada, Europe and Brasil

Building

Applications of UHPGC

Building and architectural Applications



Applications of UHPGC

Building and architectural Applications

Emerson college
120 Boylston Street, Boston, 1917

Renovation project on the façade of Emerson College.

The UHPC was chosen:

- Ability to take on any form, such as replicating the intricate carvings at this building
- Fit within the existing wall thickness
- Addition of insulation.

Creation of **3D molds by laser technology**
With UHPC, it was possible to replicate the building, including the stone lions that decorate the façade.

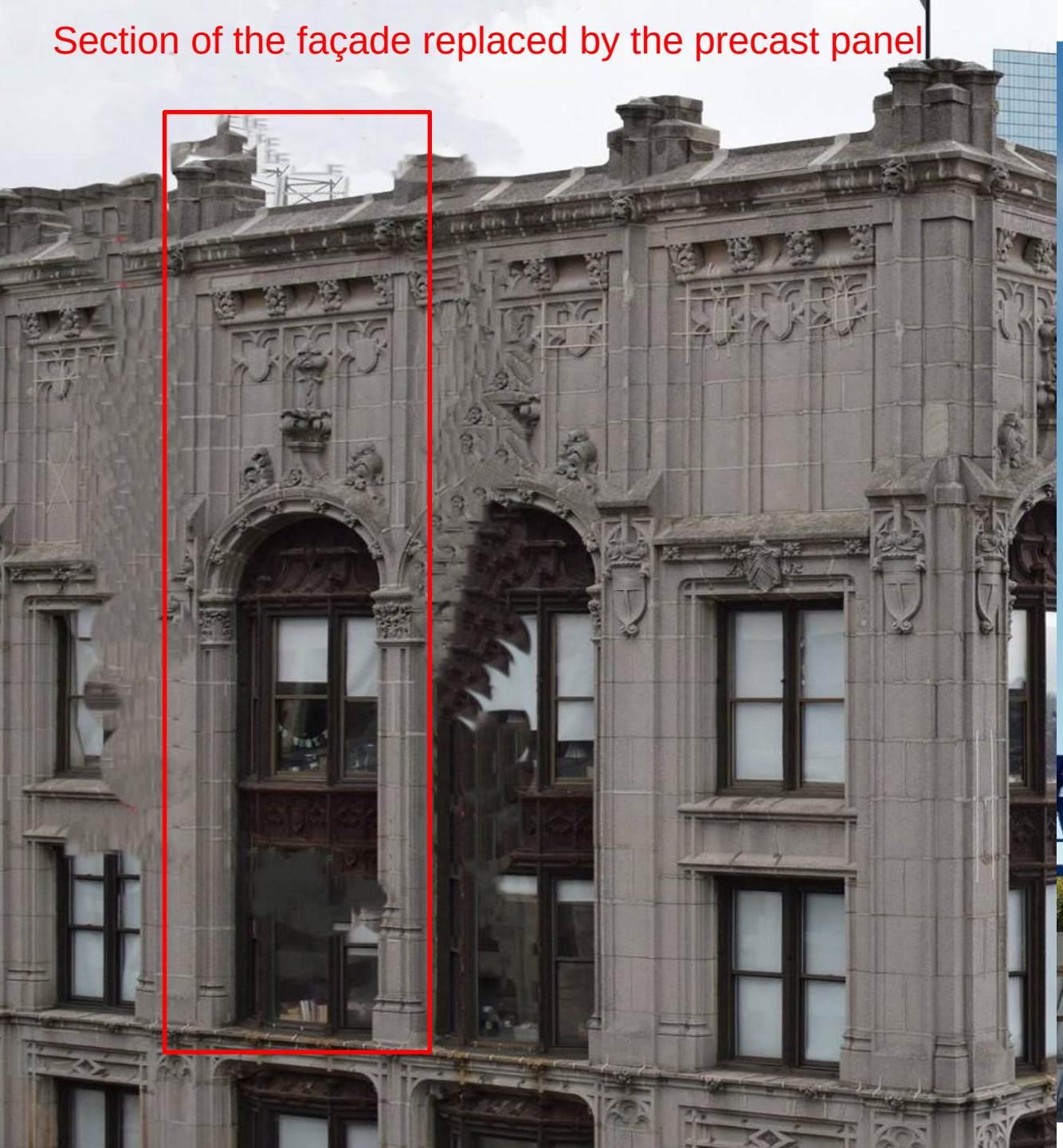
Solution: **Architectural – UHPC**

Architect: Elkus | Manfredi Architects

Contarctor: Suffolk Construction Company

BPDL® BÉTON PRÉFABRIQUÉ

Section of the façade replaced by the precast panel



Total of 1500 panels

BPDL®
BÉTON PRÉFABRIQUÉ

Emerson college, Little Building
120 Boylston Street, Boston, 2019

Conclusion

- UHPGC can be designed using ground glass pozzolan and glass sand of different particle-size distributions

Depending on material content :

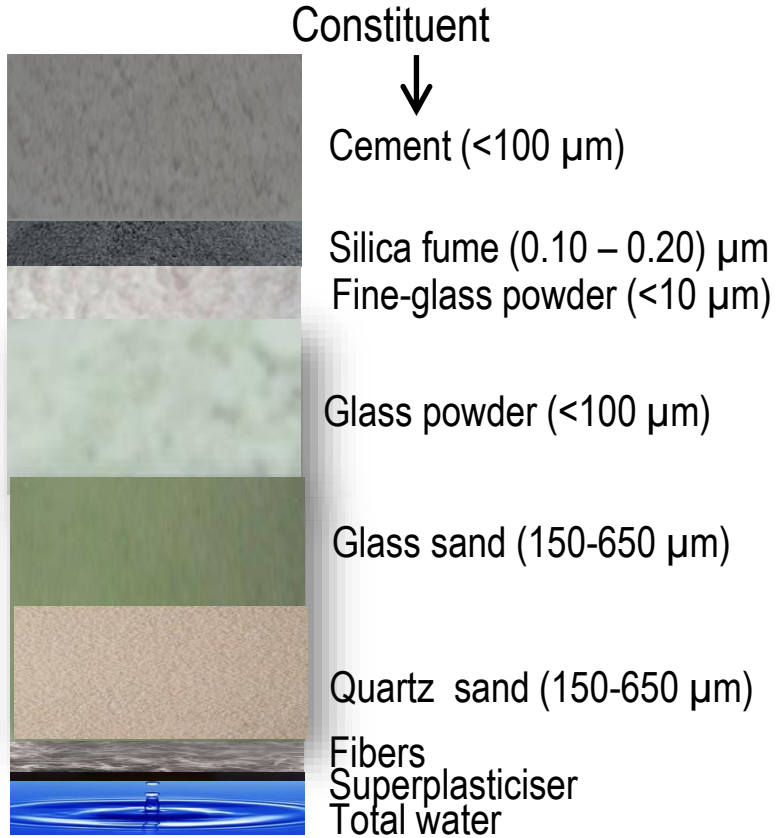
- *Glass powder*
- *Fine glass powder*
- *Glass sand*

Compressive strength :

- *120 to 240 MPa*

Slump:

- *180 to 330 mm*



Architecture Application

Structure Application


Sherbrooke University Campus
Thank You