Gammon

Ultra-high Performance Concrete in Construction

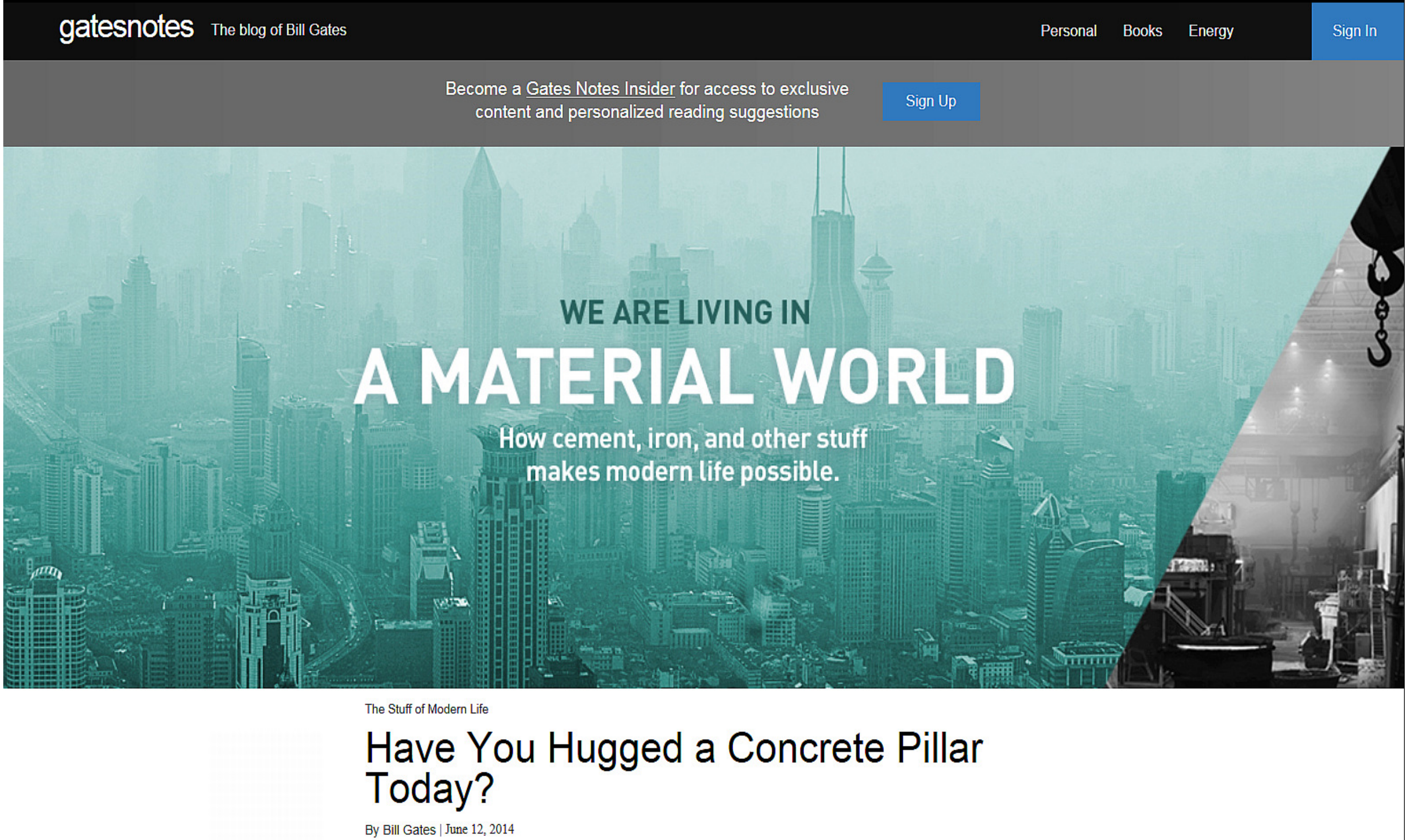
Herbert Zheng

26 April 2017

Contents

A. Ultra-High Performance Concrete (UHPC)

Concrete: the material making the modern world



Source: http://www.gatesnotes.com

Innovations in concrete technology

Eddystone Lighthouse, UK, 1759
(Sources: Geological Society of London)

Stone House, Hong Kong, 1923

ACI Excellence in Concrete Construction, 2015

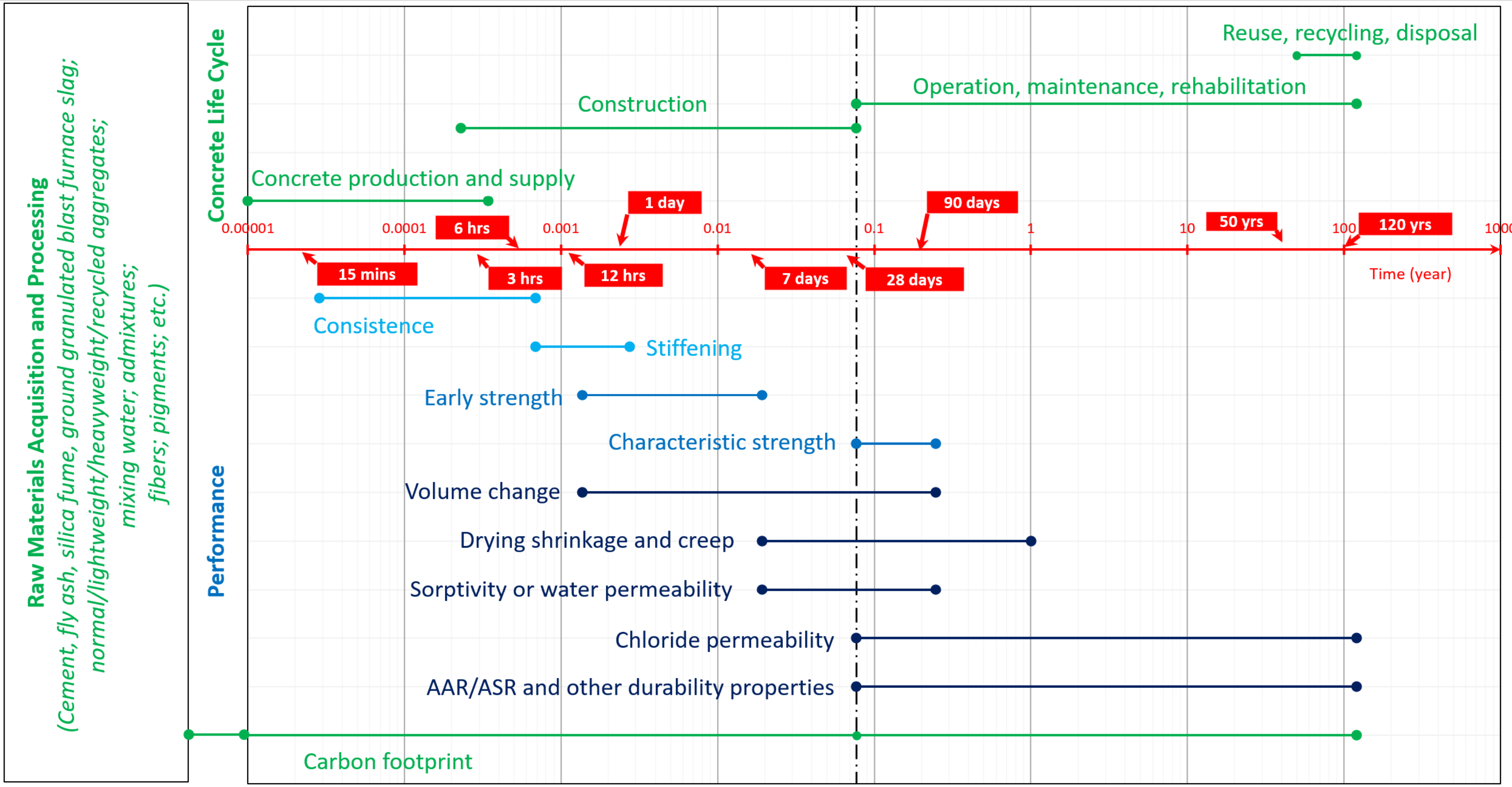
aci

Excellence

in Concrete Construction Awards

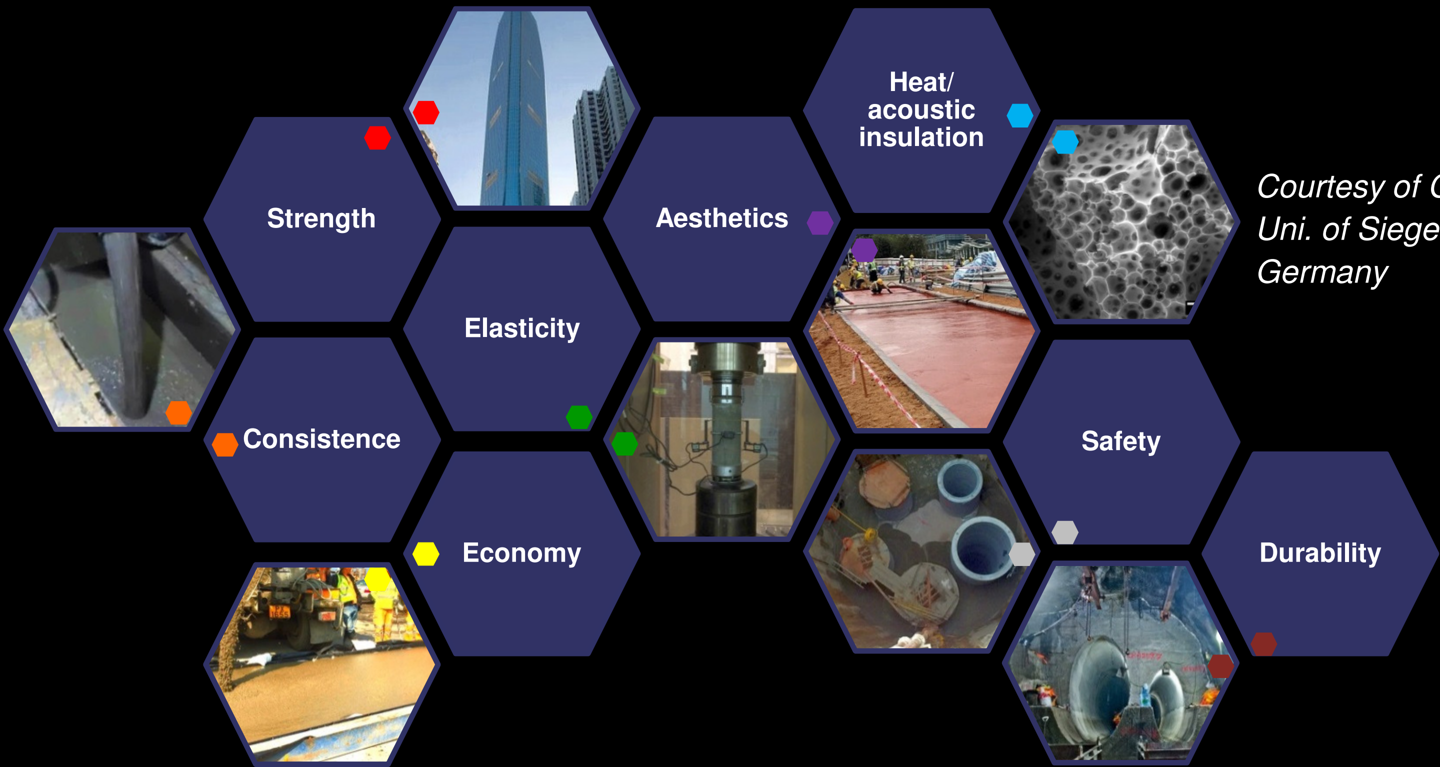
Curtesy by American Concrete Institute

Properties of concrete and its lifespan



High-performance concrete (HPC)

– Tailor-made properties to improve the efficiency in use



Courtesy of C. Krämer, Uni. of Siegen, Germany

Ultra-high performance concrete (UHPC)

- UHPC defined by Federal Highway Administration, U.S. (2011):
  - *cementitious composite material composed of an optimized gradation of granular constituents*
  - *water-to-cementitious materials ratio less than 0.25*
  - *high percentage of discontinuous internal fiber reinforcement*
  - *compressive strength greater than 150 MPa*
  - *sustains post-cracking tensile strength greater than 5 MPa*
  - *discontinuous pore structure that significantly enhancing durability*

- UHPC defined in Europe (2012):
  - *Steel fiber reinforced cementitious composite*
  - *characteristic unconfined compressive strength from 150 ~ 250 MPa*
  - *contains steel fibers to achieve ductile behavior in tension*
  - *possibly overcomes or minimizes the use of active/passive reinforcement*
  - *high binder content which leads to absence of any capillary porosity*
  - *direct tensile strengths generally higher than 7 MPa*

UHPC (continued)

- UHPC defined in China (2016):
  - *cementitious composite material that satisfies compacted packing requirements of granular constituents*
  - *compressive strength between 120~200MPa*
  - *tensile strength between 7~12MPa*
  - *elastic modulus between 40~60GPa*
  - *other fresh/hardened concrete property requirements*

- Other names since 1972:
  - *Macro Defect Free cement (MDF), U.K.,1981*
  - *Densified System containing homogeneously arranged ultra-fine Particles (DSP), Denmark/U.S./Canada, 1980's*
    - *Compact Reinforced Composite (CRC), Denmark, 1987*
    - *Ultra-High Performance Fiber Reinforced Concrete (UHPFRC), U.S., 1987*
    - *Reactive Powder Concrete (RPC), France, 1995*
    - *Special Industrial Concrete (Beton Special Industriel, BSI), Germany, 1990's*
  - *Slurry Infiltrated Fibre Concrete (SIFCON), U.S.,1980's*
  - *Engineered Cementitious Composite (ECC), U.S.,1992*
  - *Ultra-High Strength Concrete/Super-High Strength Concrete*

HPC and UHPC classified by strength

"Concrete meeting <u>special combinations of performance and uniformity requirements</u> that cannot always be achieved routinely using <u>conventional constituents</u> and <u>normal mixing, placing, and curing practices</u>."

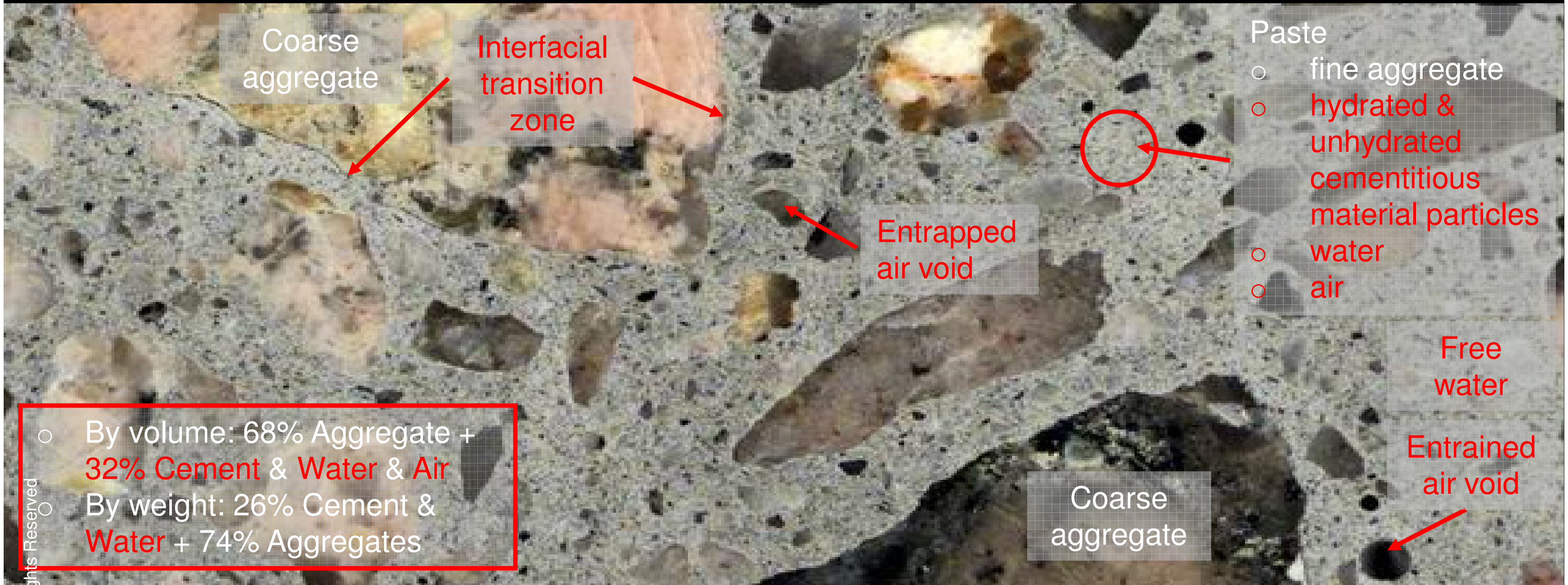
- American Concrete Institute, January 2013

	Normal concrete	High-performance concrete		
		High strength	Very high strength	Ultra-high performance concrete
Grade strength by cube (MPa)	≤ 50	55 - 80	85 - 120	> 120
Water/cement ratio	≥ 0.45	0.30 - 0.45	0.25 - 0.30	0.15 - 0.25
Chemical admixtures	Not required	Superplasticizer	Superplasticizer	Superplasticizer
Mineral admixtures	Not required	PFA/GGBS	Silica fume	Silica fume/Nano material
Chloride permeability (Coulombs)	> 2,000	500 – 2,000	100 – 500	≤ 100
Tensile strength (MPa)	Not required	Not required	Not required	≥7
Sustained tensile strength (MPa)	Not required	Not required	Not required	≥5

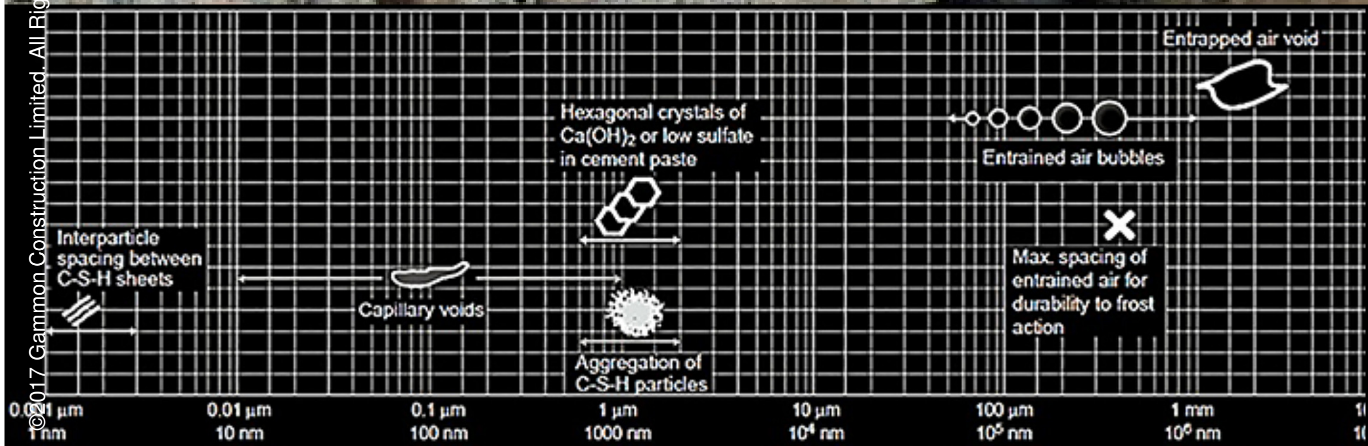
Modified from Büyüköztürk, O. and Lau, D. High Performance Concrete: Fundamentals and Application, Massachusetts Institute of Technology, Cambridge, Massachusetts, U.S., 2002.

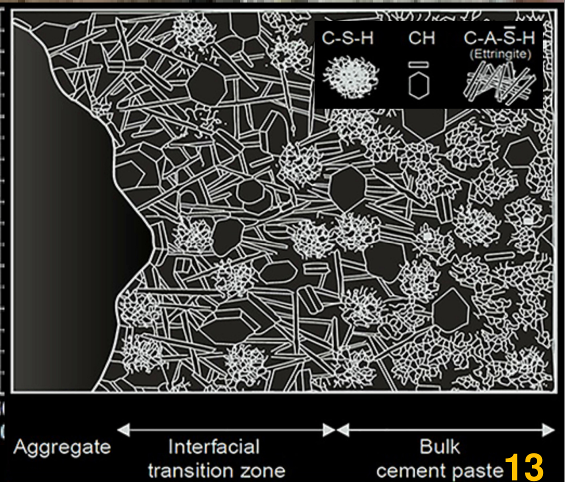
B. Microstructure, Compositions and Properties

Microstructure of concrete



- By volume: 68% Aggregate + 32% Cement & Water & Air
- By weight: 26% Cement & Water + 74% Aggregates





Source: P.K. Mehta and P. J. Monteiro. Concrete: Microstructure, Properties and Materials (3rd Ed.), McGraw-Hill, London, UK, 2006.

Typical UHPC solution

Raw material for premix:
- Cement, sand, secondary cementitious materials, nano-carbon tubes (or other ingredients kept secret), etc.

Fibers:
- *Metallic*
- *Organic*
- *Glass*
- *Polymer*

+

Pre-blended UHPC dry mix:


+

Admixtures
- *Super-plasticizer*
- *Accelerat-ors*
- *Anti-shrinkage admixtures*

Ready-mixed UHPC for placing



Source: Ductal® Solutions, Thorp UK, September 12th, 2016

Mix proportions

Weight composition of UHPC with compressive strength of 200 MPa

	Sauzeat *et al*	Aitcin and Richard
Cement	1	1
Water	0.28	0.15
Superplasticizer	0.06	0.044
Silica fume	0.33	0.25
Fine sand	1.43	1.1
Quartz flour	0.3	N.A

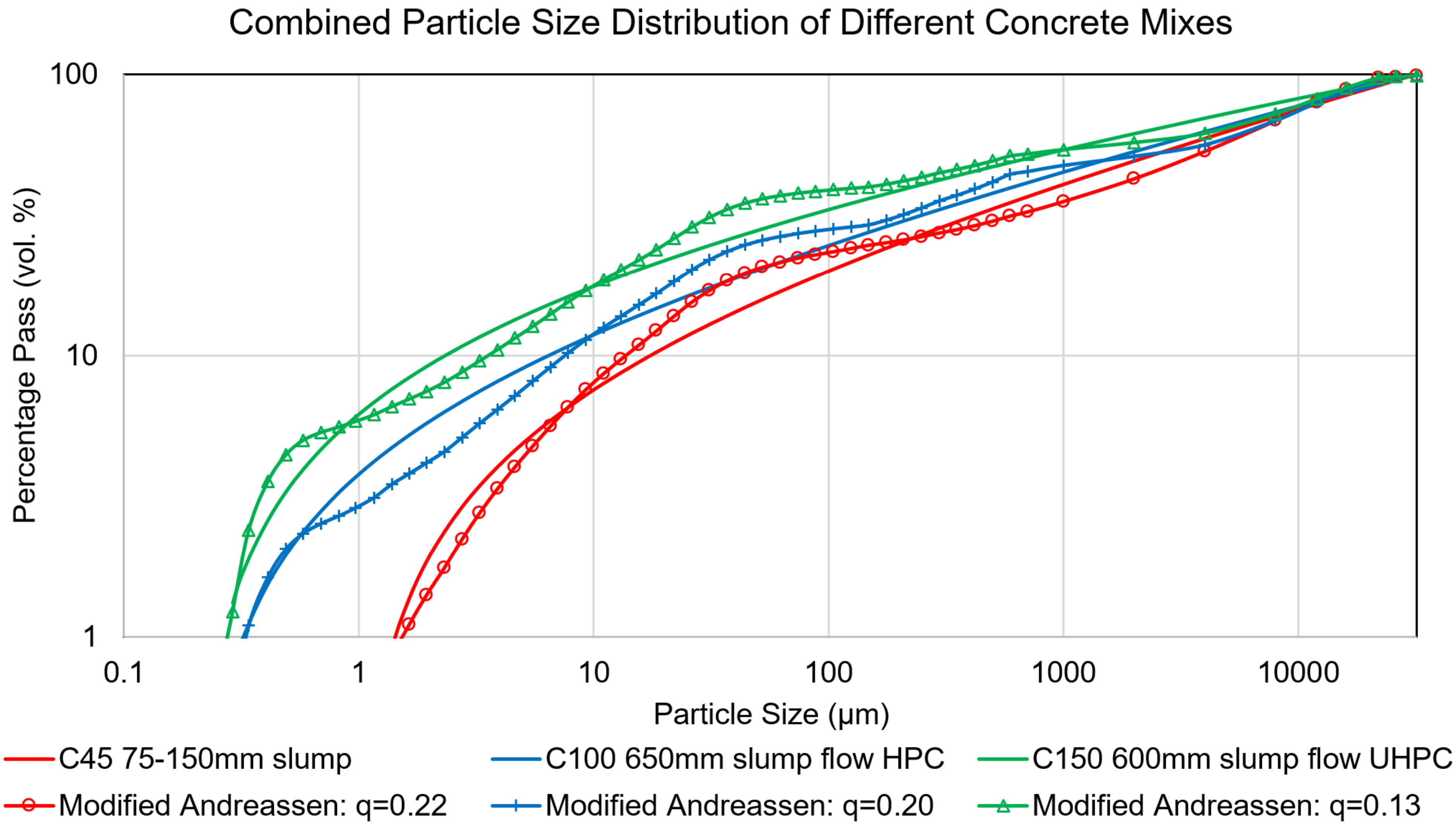
Source: Büyüköztürk, O. and Lau, D. High Performance Concrete: Fundamentals and Application, Massachusetts Institute of Technology, Cambridge, Massachusetts, U.S., 2002.

- ✓ Less use of concrete
- ✓ Slimmer and lighter structures
- ✓ Faster construction program
- ✓ Lower life-cycle cost

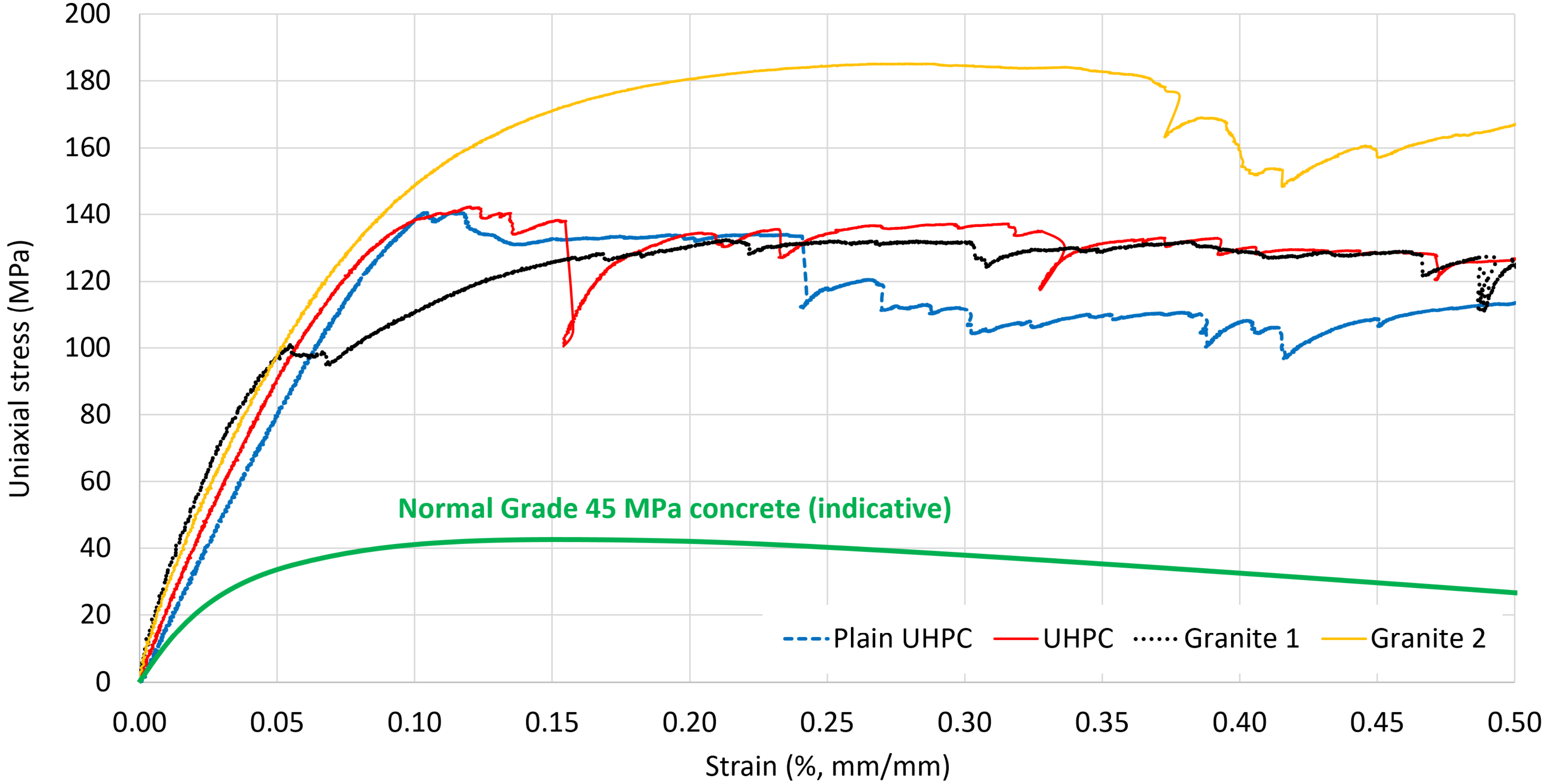
General material properties

Properties	Plain UHPC	UHPC	Ductal®	Dura®
Density, D (kg/m^3)	2620	2650	2300±100	2425±25
Strength, f (MPa)				
- $f_{cu,\ c,\ 100mm}$	159	170	144	160-180
- $f_{cy,\ c,\ \phi 100x200mm}$	133	147	120	-
- $f_{cy,\ split\ tensile,\ \phi 150x300mm}$	10	7	-	-
- $f_{p,\ flexural, 100x100x500mm}$	-	-	15	20-30
- $f_{p,\ tensile,\ 100x100x500mm}$	-	-	7	-
Elastic modulus, E_c (GPa)	55	55	45	45-50
Chloride permeability (10^{-12}m^2/s)	-	-	0.02	0.06
Rapid chloride permeability (C)	22	96	-	<100

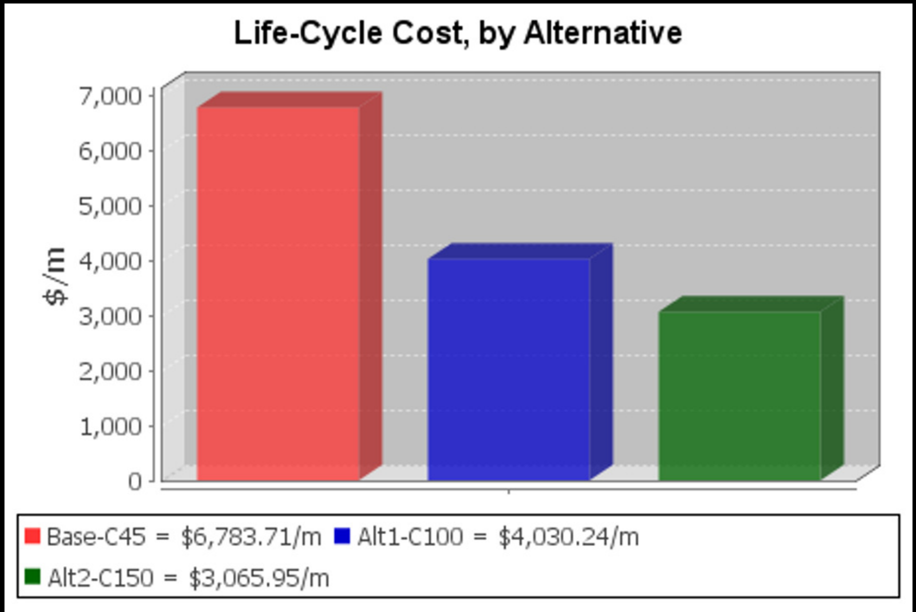
Specific strength vs packing density

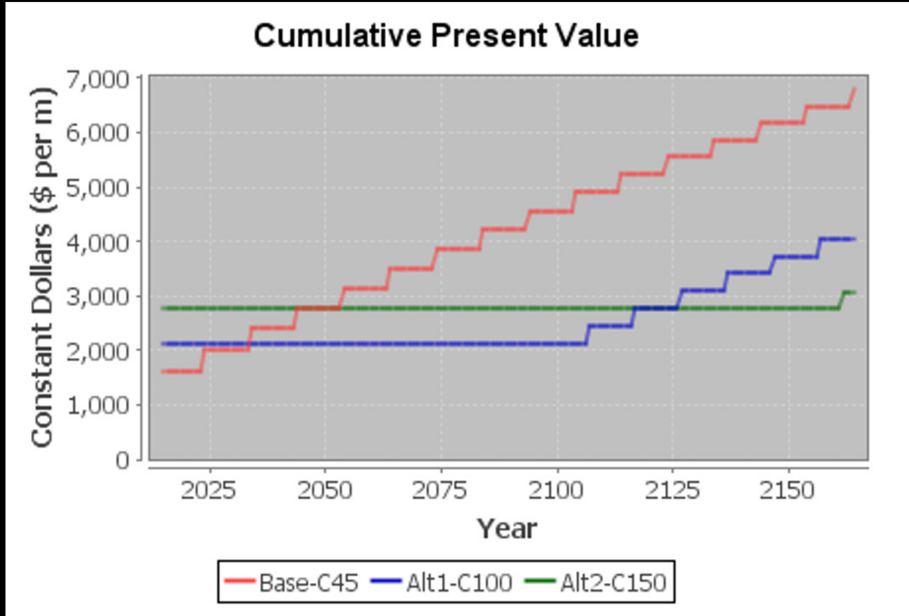


Stress-strain relationship



Durability and life-cycle cost

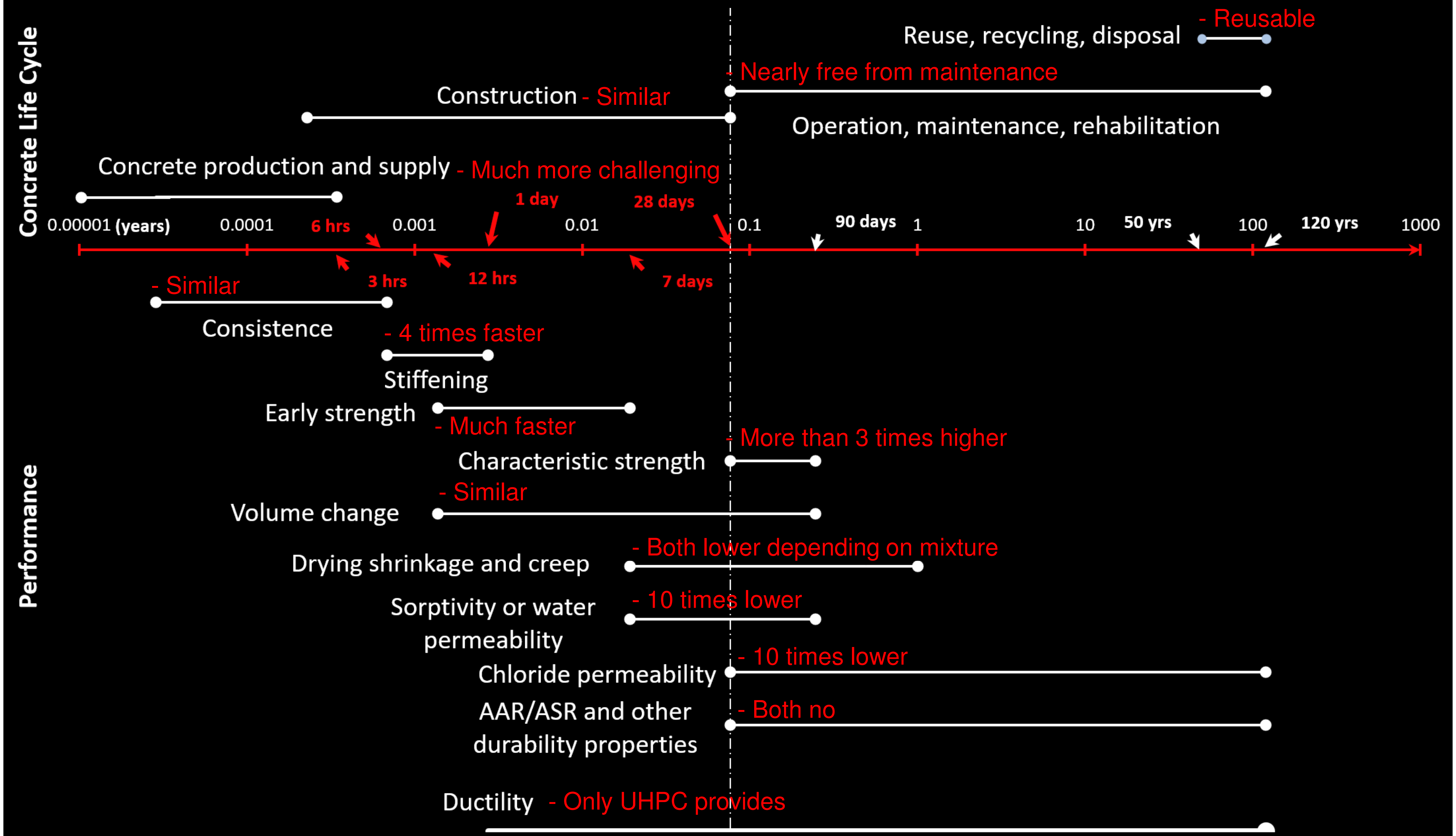




Alt name	D28	m	Ct	Init.	Prop.	Service life
Base-C45	8.39E-12 m*m/sec	0.4	0.05 % wt. conc.	3.4 yrs	6 yrs	**9.4 yrs**
Alt1-C100	7.39E-13 m*m/sec	0.4	0.05 % wt. conc.	86.1 yrs	6 yrs	**92.1 yrs**
Alt2-C150	3.06E-13 m*m/sec	0.32	0.05 % wt. conc.	141.2 yrs	6 yrs	**147.2 yrs**

Note: 1. The structural element and exposure condition under investigation 1x1x10m pier located in marine tidal zone.
2. Rapid chloride penetration test results of grade 45, 100 and 150MPa concrete are 1,250, 134 and 22 coulombs, respectively.

Lifespan of UHPC vs normal HPC



Note: The comparison is based on a typical UHPC against common local grade 45MPa marine concrete.

UHPC conferences and products

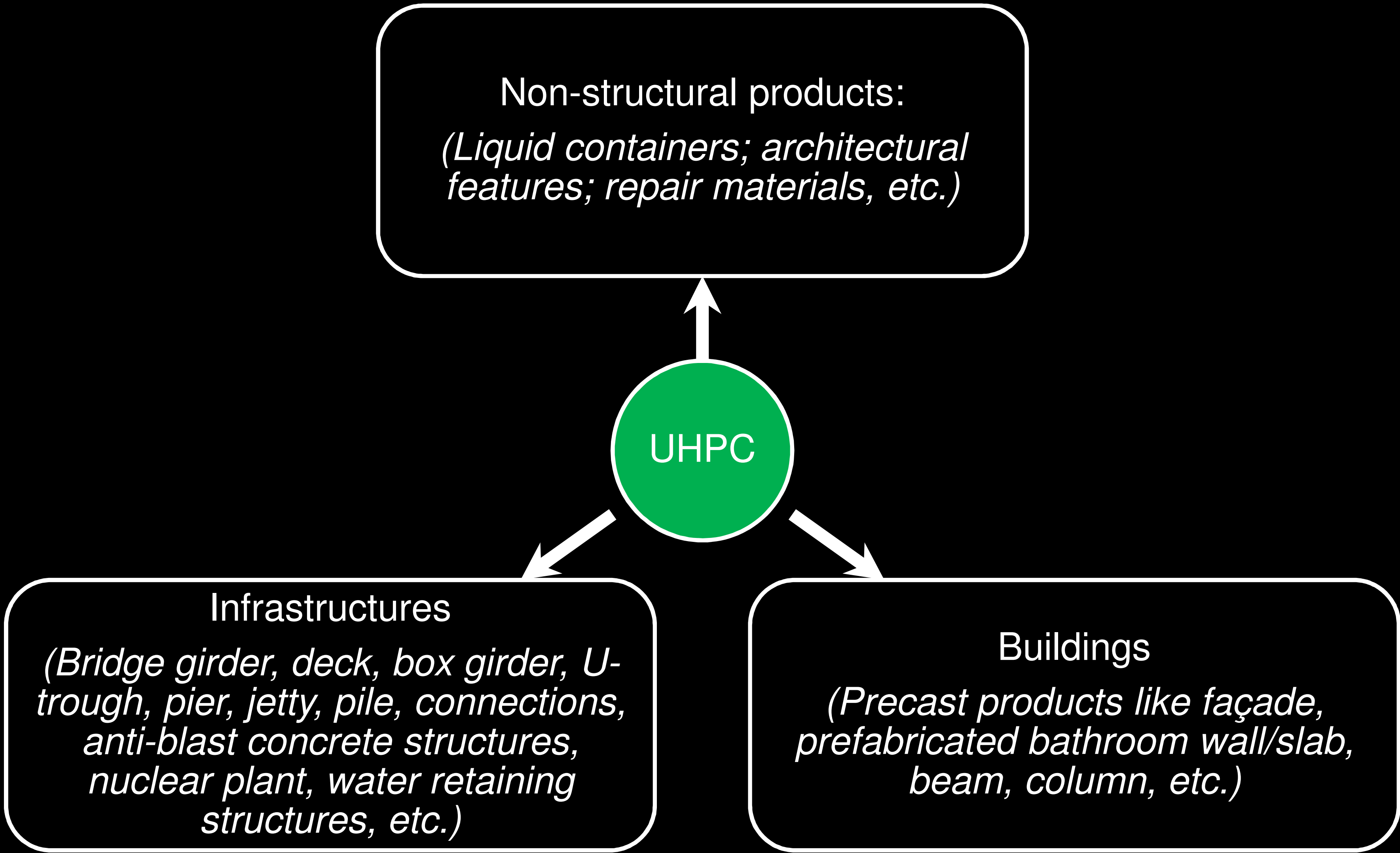
- International Symposium on UHPC and Nanotechnology for High Performance Construction Materials (HiPerMat) at Uni. of Kassel, Germany

- Engineering Research and Development Center, US Army Corps of Engineers
  - *Cementitious material*
  - *Compressive strength > 138MPa*
  - *No coarse aggregates*

- Commercial products:
  - *Ductal®, France*
    - *Reactive Powder Concrete (RPC) by Lafarge*
    - *Generic brand designation RPC200, RPC400, etc.*
  - *Densit® and Hi-Con®, Denmark*
    - *Compact Reinforced Composite (CRC)*
  - *Hunan University & Hunan Mingxiang Science and Technology Ltd., China*
    - *RPC, Compressive strength 120 - 200MPa*
  - *DURA®, Malaysia: RCP*
  - *ceEntek, Singapore: RCP with nano materials*

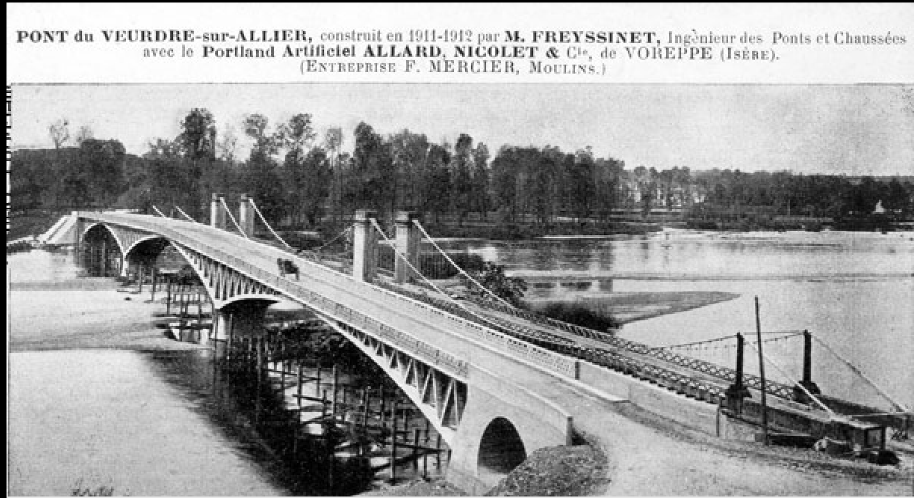
C. Construction Applications

Construction application of UHPC

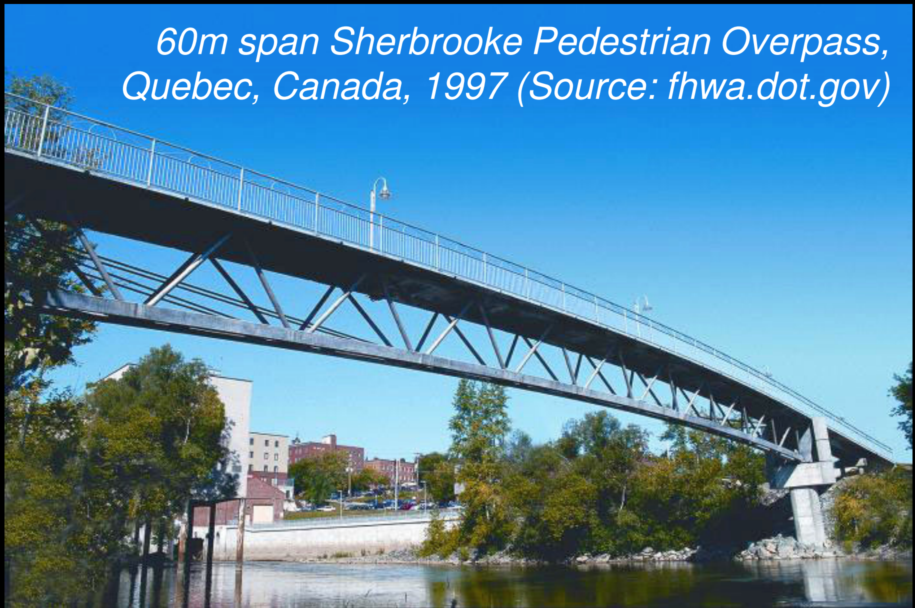


Innovations in concrete bridge construction

14m span Pont de Chazelet, France, 1875 (Source: Se connaitre)



Max 72m span Pont du Veurdre, France, 1911-1944 (Source: Association Eugene Freyssinet)



60m span Sherbrooke Pedestrian Overpass, Quebec, Canada, 1997 (Source: fhwa.dot.gov)

120m span Footbridge of Peace, Seoul, South Korea, 2002 (Source: fhwa.dot.gov)

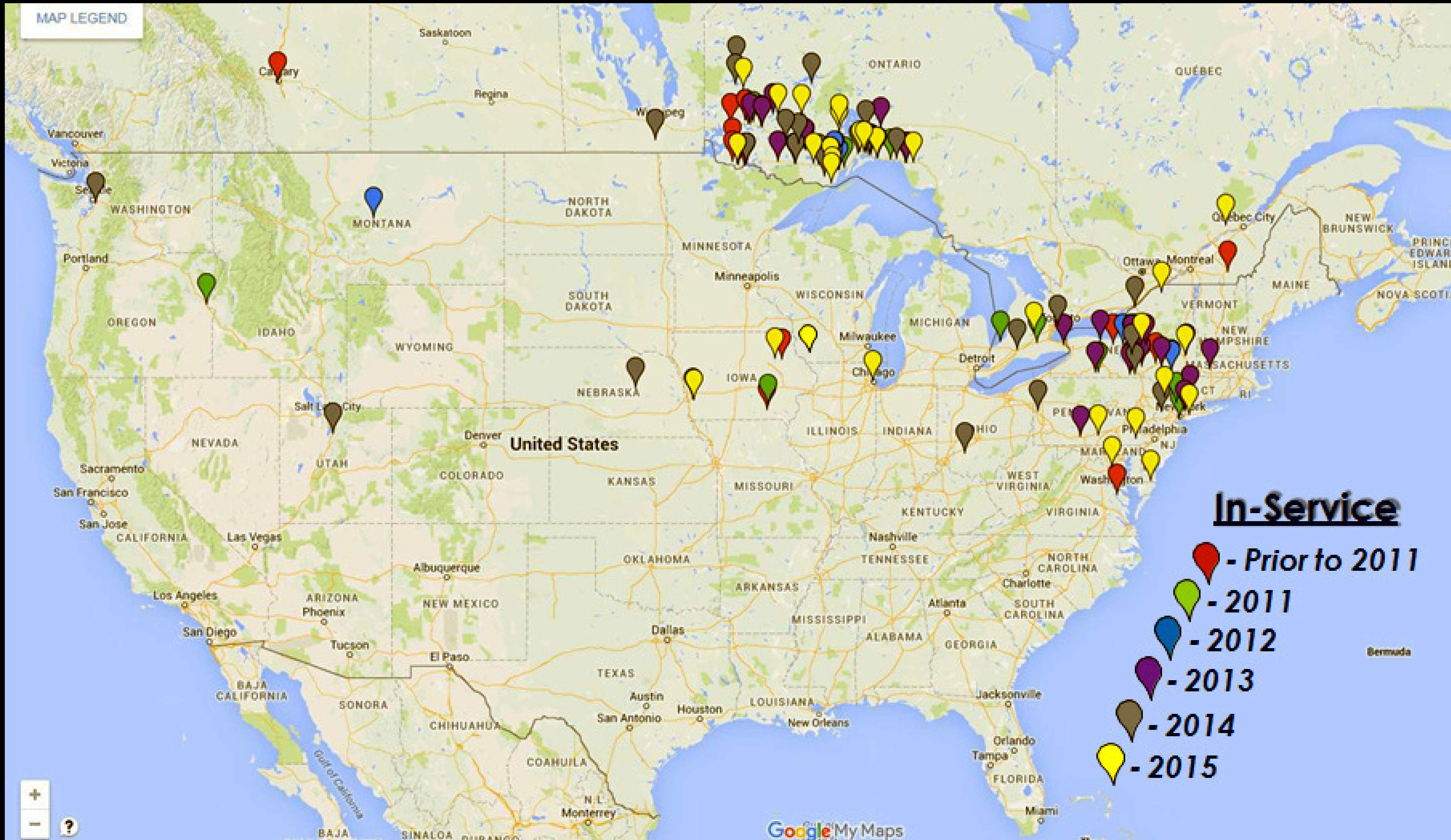
The 1st UHPC bridge in China

- 6.6m wide, 70.8m long in three spans (27.6, 36.8 & 6.4m) and 5.4m high
- Slab thickness 0.2m
- Depth-span ratio 1/28

- Unit weight of main beam: 0.855t/m^2
- Max compressive strength 200MPa
- Precast bridge
- Fabricated in 10 hours on 8 Jan 2016

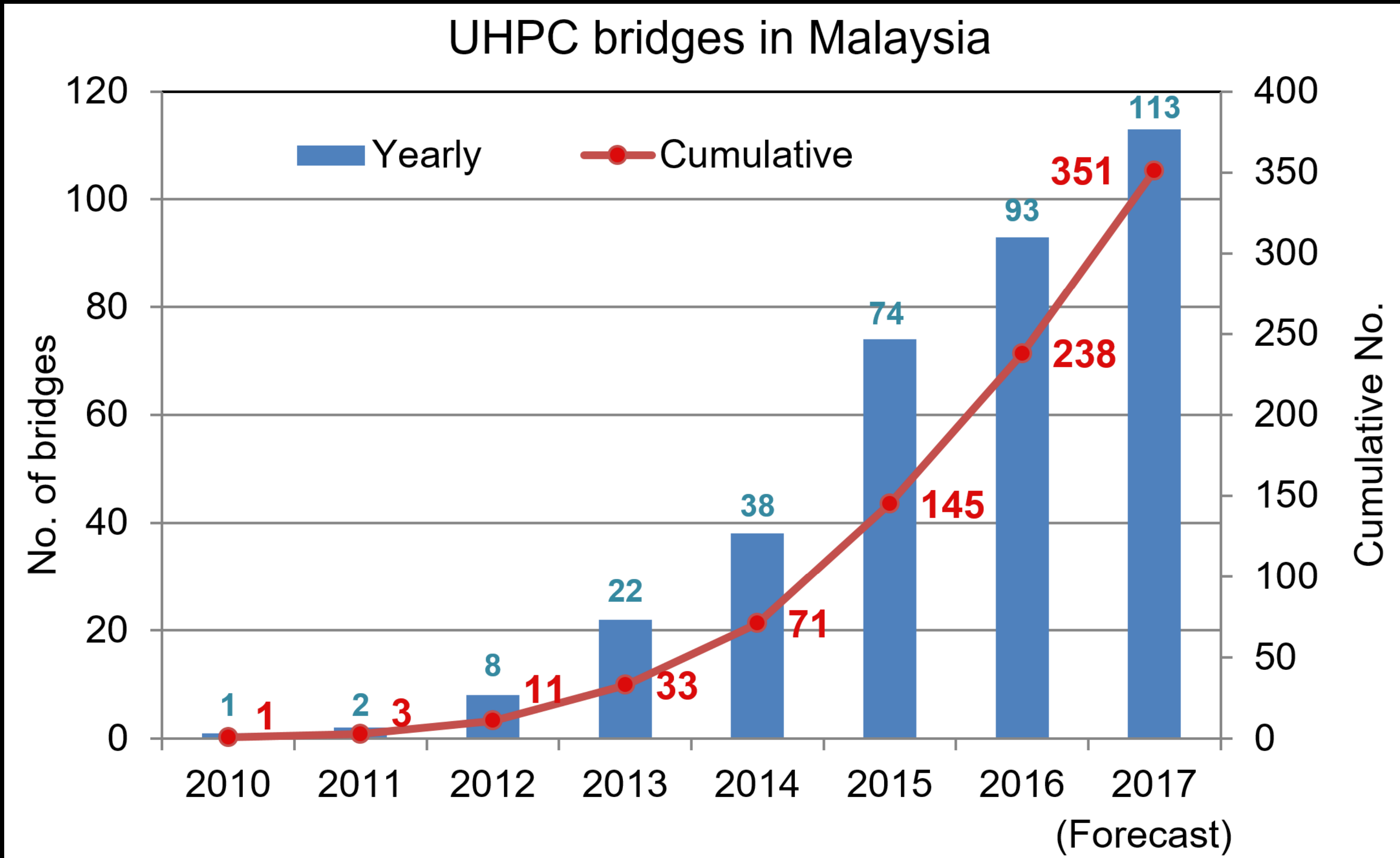
Source: http://news.sciencenet.cn/htmlnews/2016/9/355715.shtm

UHPC bridges in North America



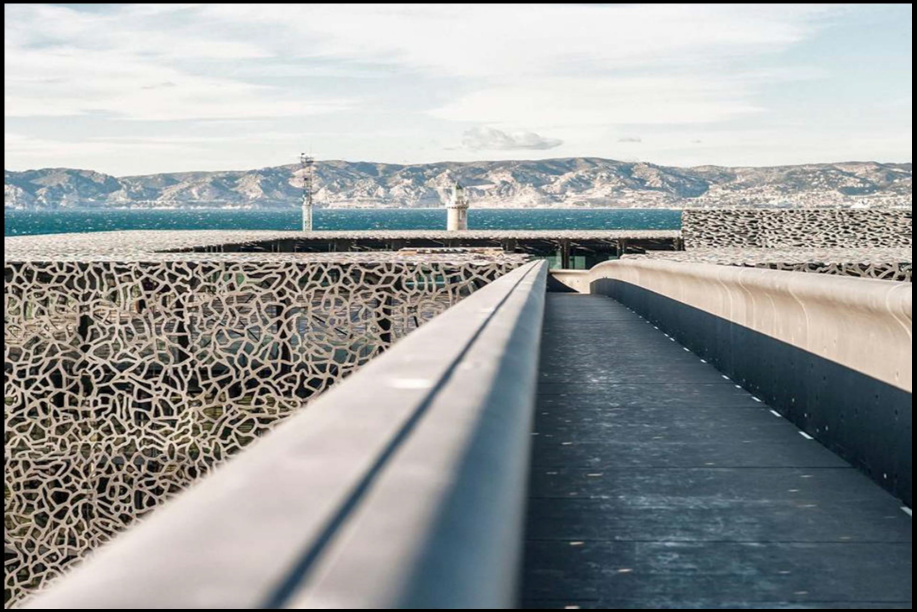
Source: Z. Haber. Ultra high performance concrete (UHPC), FDOT Design Training Expo, Daytona Beach, FL, U.S. (Jun 2016)

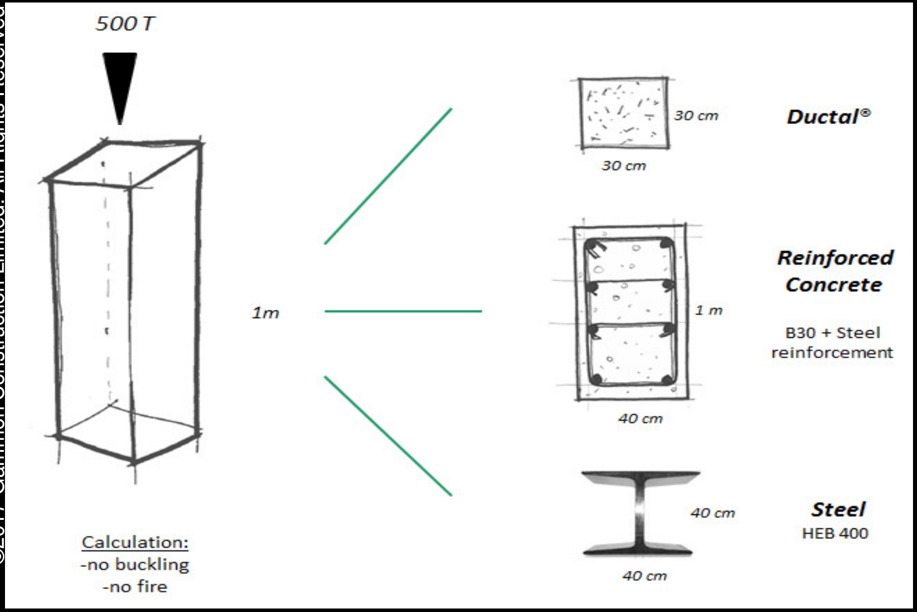
UHPC bridges in Malaysia



Data from Y. L. Voo. Ultra high performance concrete technology for present and future, ACI Singapore Chapter Building Construction Authority Joint Seminar "Concrete for Sustainability, Productivity and the Future", Singapore, (Mar. 2017)

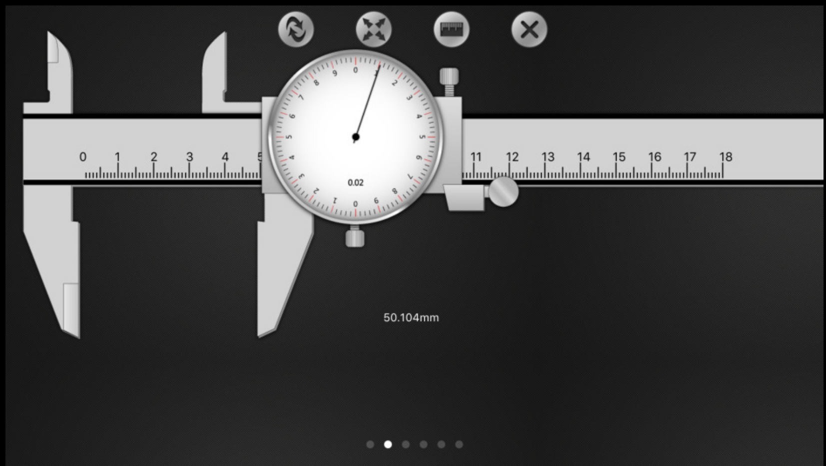
Museum of European and Mediterranean Civilizations and Ductal® UHPC





Source: Ductal® Solutions, Thorp UK, September 12th, 2016

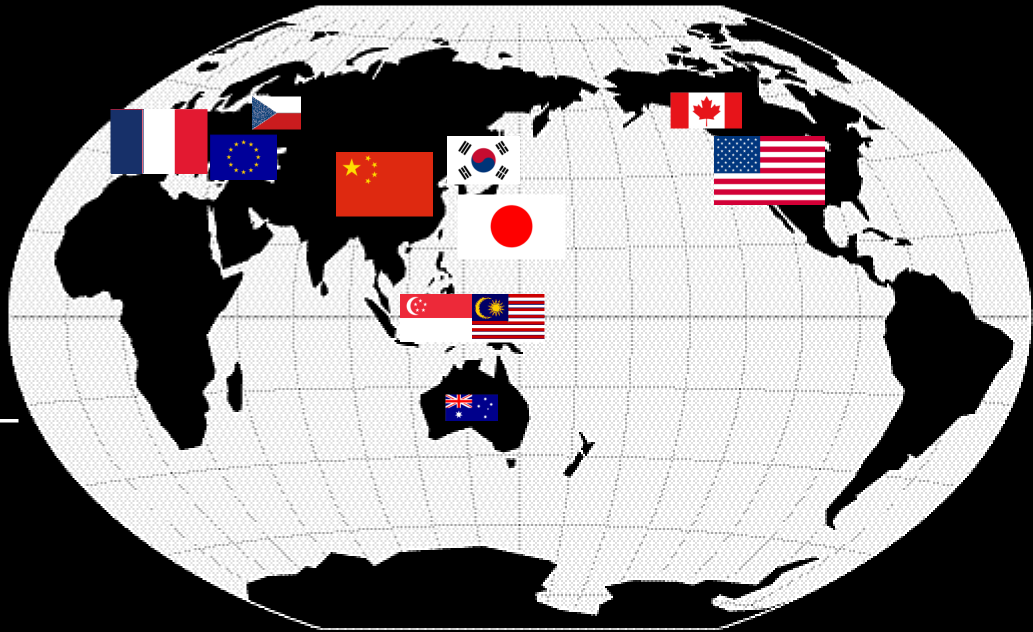
Prefabricated bathroom unit



Various applications

Upper left photo: Brian H. Green. Ultra high performance concrete (UHPC): What it is, its history and why we care? (Sep 2011)
Lower left and right photo: Ductal® Solutions, Thorp UK, September 12th, 2016

Current status



- Association Francaise de Genie Civil. Ultra-high performance fibre reinforced – reinforced concrete – Interim Recommendations, France (2002).
- Japan Society of Civil Engineers. Recommendations for design and construction of ultra-high performance fibre-reinforced concrete structures (Draft), Japan (2006).
- Tsinghua University. National standard reactive powder concrete (Draft), China (2013).
- U.S. Department of Transportation, Federal Highway Administration. TechNote Design and Construction of Field-cast UHPC Connections, U.S. (2014).
- China Concrete & Cement-based Products Association. Ultra-high performance concrete specification: materials and tests, China (2016).

Common challenges in UHPC construction

- Academic: lack of local scientific research and development
- Technological:
  - *Lack of code of practice for structural use of UHPC*
  - *Relatively short history of worldwide field application*
  - *Lack of data about UHPC made from locally available raw materials*
- Economic:
  - *Lack of localized justification on economic benefits*
  - *High investment in manufacturing facility*
  - *High material cost*
  - *High cost for verification/demonstration trials*
- Social:
  - *Lack of demands for advanced concrete technology*
  - *Lack of financial and regulatory authority's support to pilot application*
  - *Lack of common understanding, knowledge and experiences in local engineering society*

D. Summary

Summary

- UHPC has been developed for more than 40 years and used in north America, Europe, Japan, China.
- Due to proved benefits, applications of UHPC in building or infrastructure projects are accelerating in recent years. In the near future, the use of UHPC in both precast and cast in-situ will keep increasing.
- Existing research data reveals that properly designed and manufactured UHPC can achieve a compressive strength well above 150MPa and such potential could notably minimize or eliminate the use of steel reinforcement, further helping achieve a more sustainable built environment.
- In Hong Kong, research and pilot project implementation is needed to harvest the sustainable, economic and social benefits of UHPC.

Thank You

http://www.gammonconstruction.com