Innovative use of Nanotechnology for Sustainable Ultra-High Performance Concrete

by Vic Perry

….with Next Generation Nano-engineered UHPC 2.0™

Our Mission:

To improve society’s quality of life by building more durable and resilient infrastructure with *UHPC 2.0*™ – the infrastructure that provides clean water, food, sanitation, the movement of goods and the accommodation of people.

“ We make a living by what we get, but we make a life by what we give.” Winston Churchill

Outline:

Claiborne Pell Newport Suspension Bridge, RI

- ***UHPC definition***
- ***The nano-physics and chemistry of UHPC 2.0™***
- ***What is Carbon Nano-Fiber & How is it made?***
- ***A project comparison of Embodied CO_2 in a UHPC Bridge***
- ***Q&A***

What is UHPC?

Ultra-high performance concrete (UHPC) — a cementitious composite material with enhanced strength, durability, and ductility compared to high performance concretes.

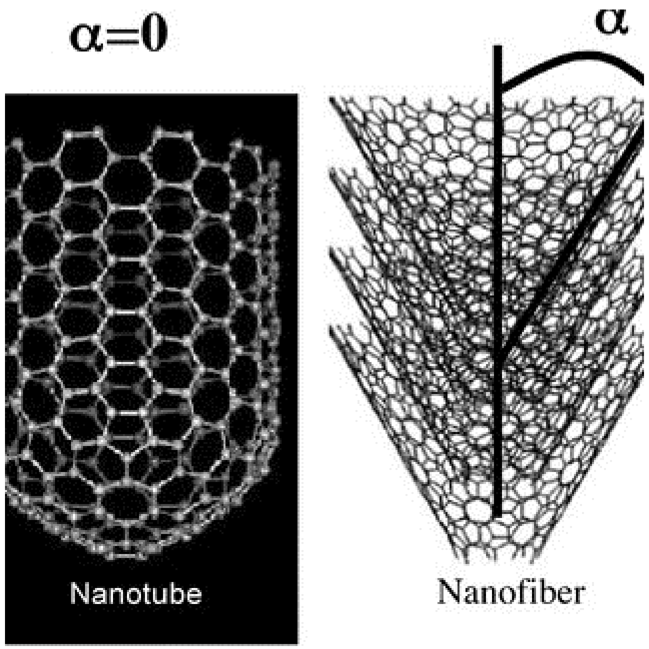
Note: *UHPC may contain fibers for post-cracking ductility, have a specified compressive strength of at least 120 MPa at 28 days, and are formulated with a modified multi-scale particle packing of inorganic materials of less than 0.6 mm diameter (larger sizes may be used).*

Reference: CSA A23.1 Annex U- UHPC

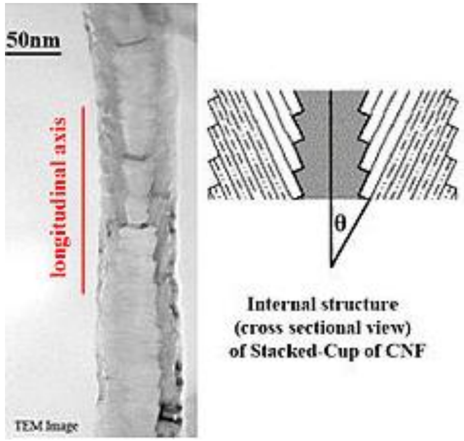
ceEntek's Nano-engineered Next Generation UHPC 2.0™

What is CNF?

Same chemistry – carbon
but different crystal structure.
-A good source of carbon
are Graphite and hydrocarbons like,
Natural Gas



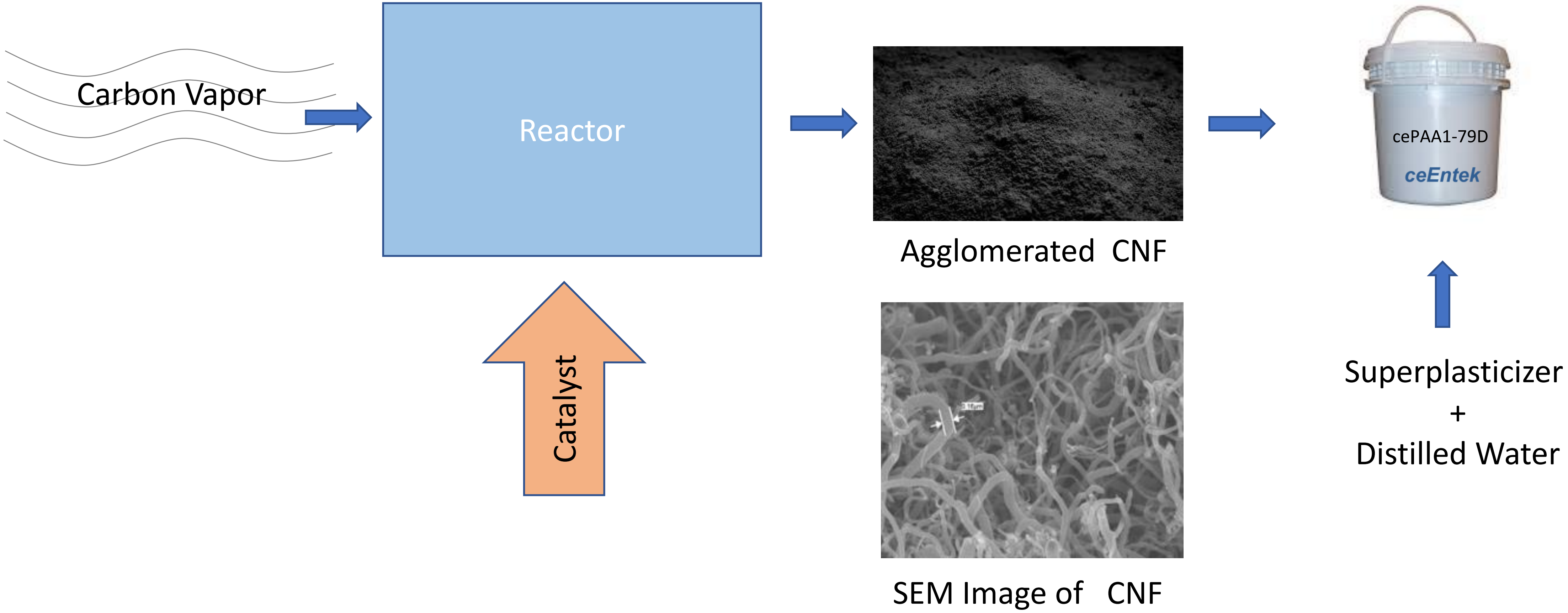
Structural Difference between
Carbon Nanotubes and Carbon Nanofibers
(Carbon atoms in a 2D honeycomb)



Carbon Nanofibers
(using Transmission Electron Microscopy)

How is it Made?

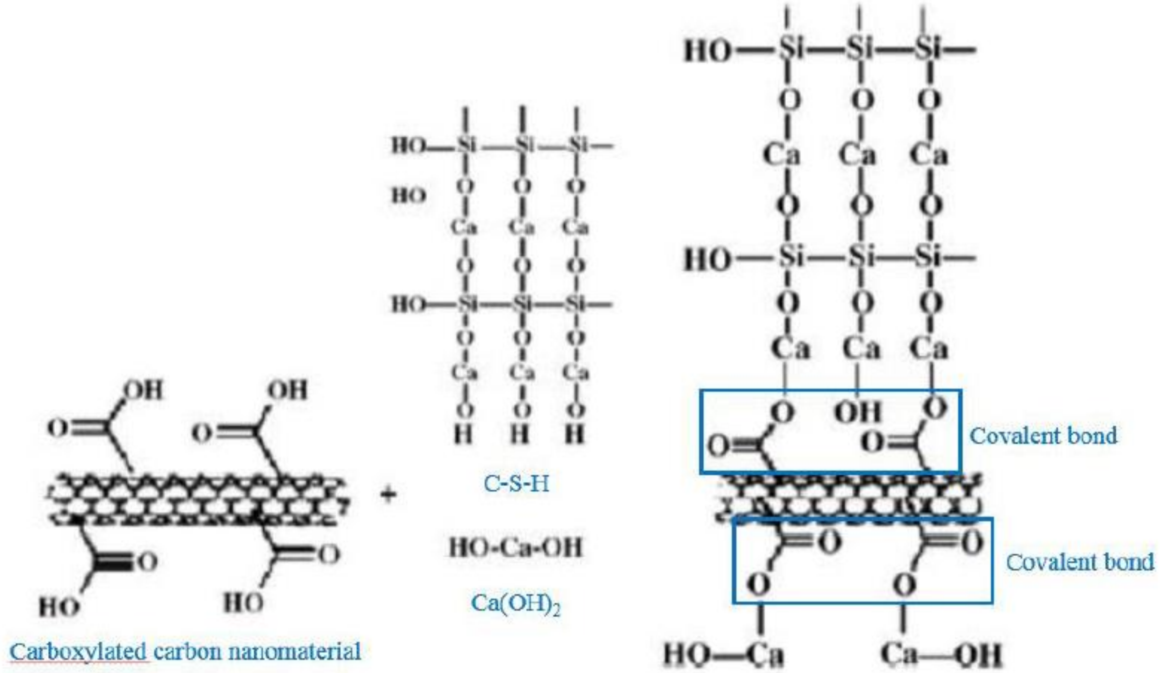
Next Generation Nano-engineered UHPC 2.0™



WHAT DOES CNF DO FOR UHPC – ENHANCES LINKAGE OF THE MATRIX

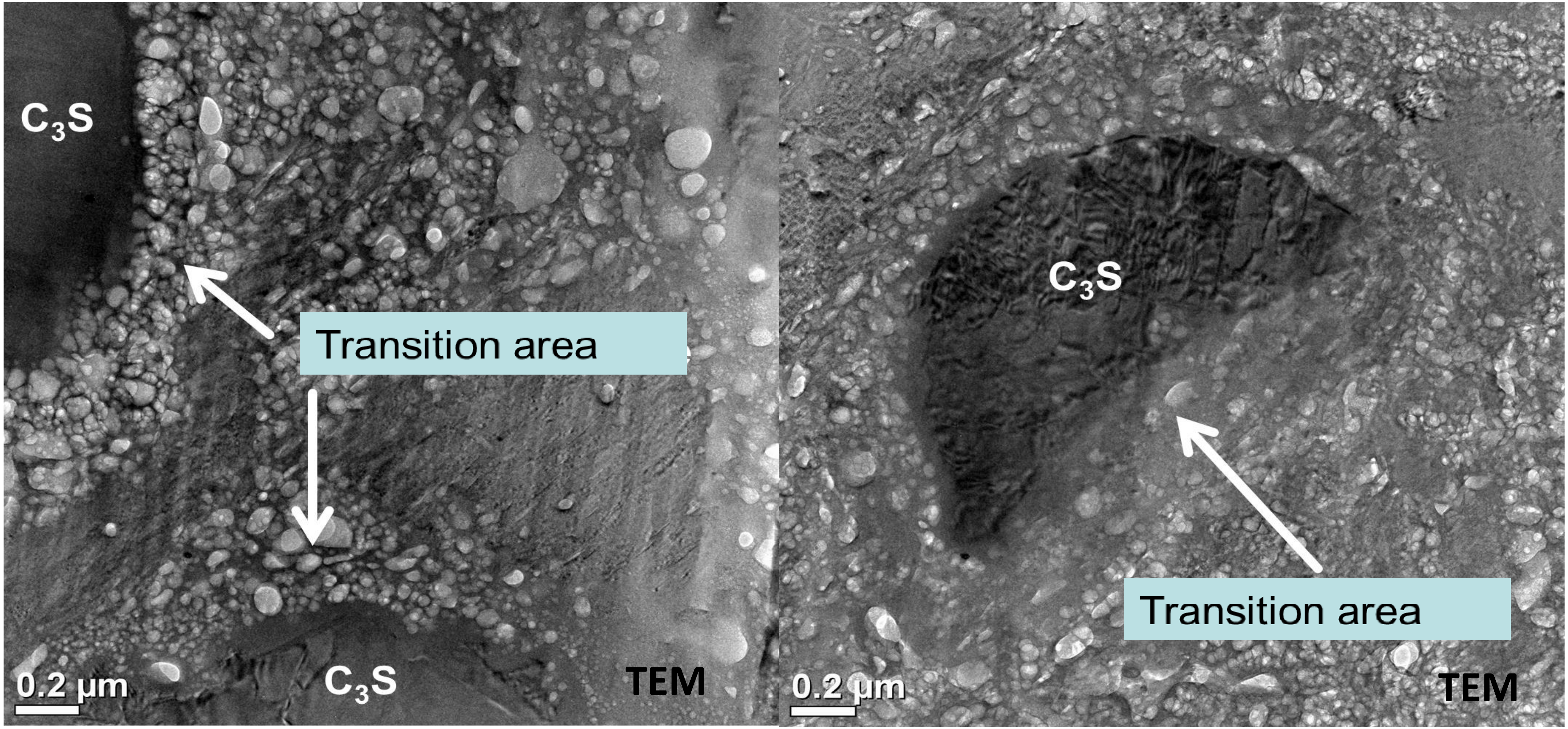
Mechanical behavior and microstructure of cement composites incorporating surface-treated multi-walled carbon nanotubes

Geng Ying Li [a,b,*], Pei Ming Wang [b], Xiaohua Zhao [a]

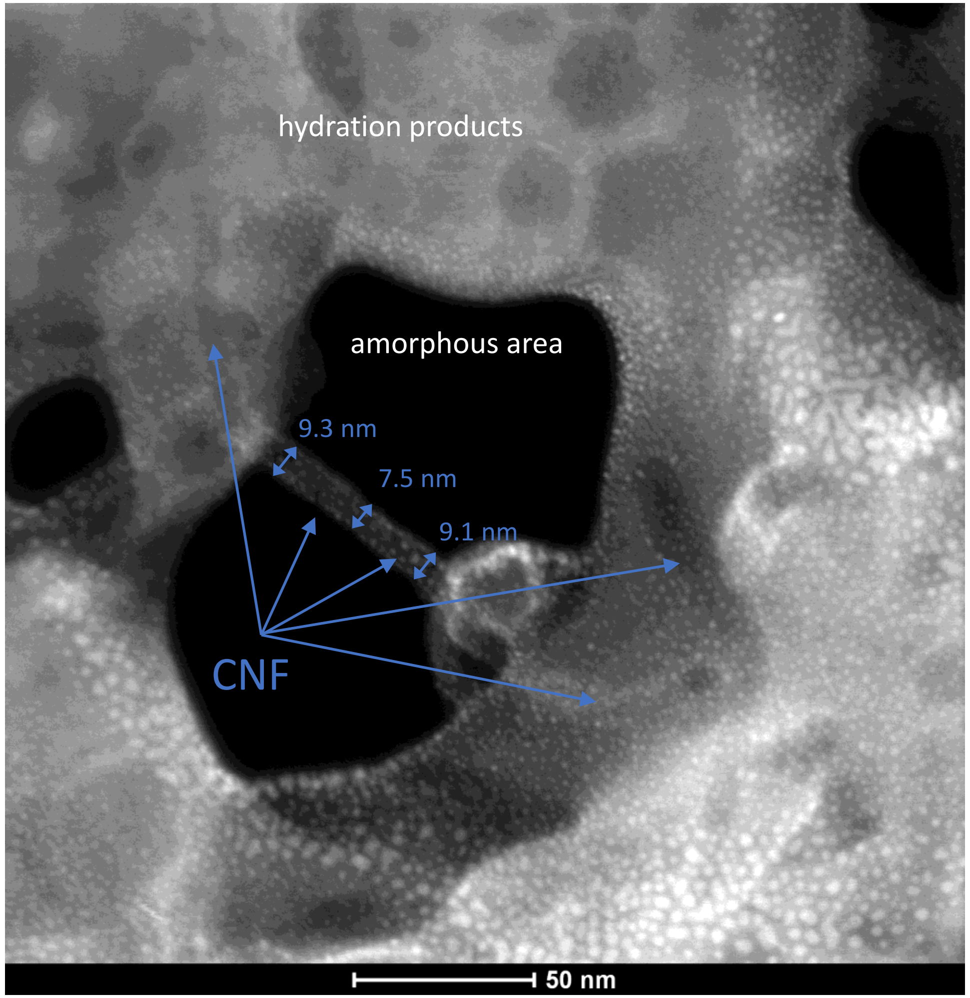


Chemical Bond is a Must!

HOW DOES CNF INFLUENCE ON MICROSTRUCTURE



WHAT DOES CNF DO FOR UHPC - FORCE-LOCKING CONNECTION



High-Angle Annular Dark-field Scanning Transition Electron Microscopy (HAADF-STEM*) image of a CNF spanning a pore. Both ends are chemically connected to the matrix.

The smaller diameter of the CNF in the center of the pore shows that it is under tensile stress.

* highly sensitive to variations in the atomic number (Z-contrast images)

What does CNF do for UHPC?

(Fresh Properties & Early Hydration Phases)

- During the early hydration process, the carbon nano-fibers cross-link with the calcium ions to have a higher water retention capacity, thereby extending the fluid working time;
- The CNF regulates the cement hydration products into regular shaped hydration products creating a final nano-engineered dense (ITZ) compact micro-structure;
- The more uniform hydration reduces differential internal stresses and improves cross linking of the CNF & hydration products thereby providing an increase in early compressive strengths.

A mixture of diluted enhanced CNF paste

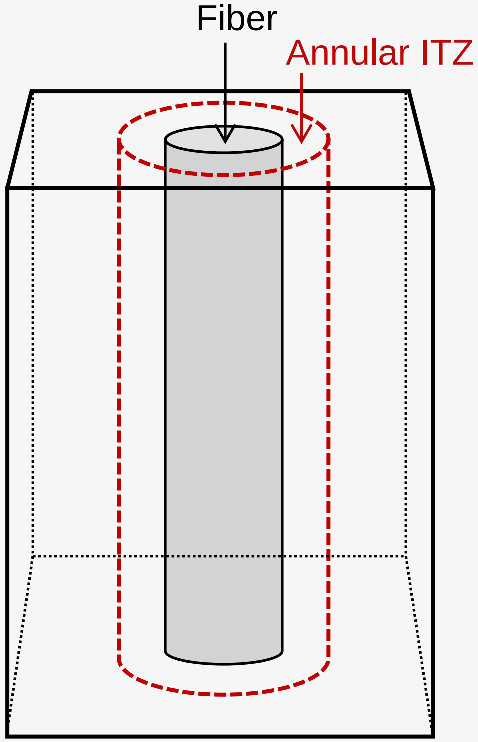
Slump flow of a Thixotropic mix with CNF

What does CNF do for UHPC?

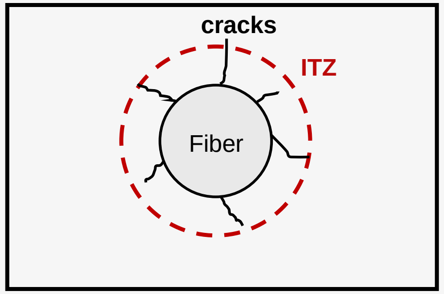
(Hardened Properties)

- It densifies the Interfacial Transition Zone (ITZ) and improves the bond by effectively controlling the early response to cracking - the CNF delays the development of nano-scale cracks that grow into micro-cracks;

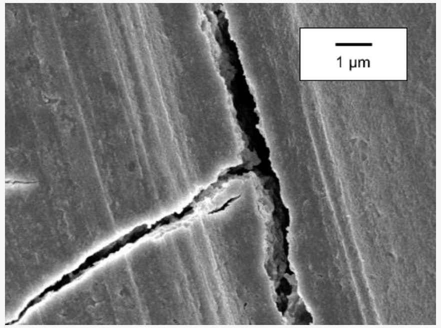
- The CNF densify the ITZ and reduce the wall effect, thus leading to an increases pull-out strength of the steel fibers.



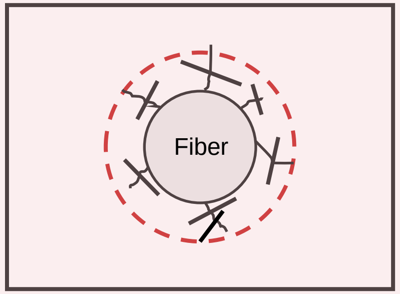
Cement-based matrix



Radial micro-cracks initiation



Radial micro-cracks observed at fiber tunnel

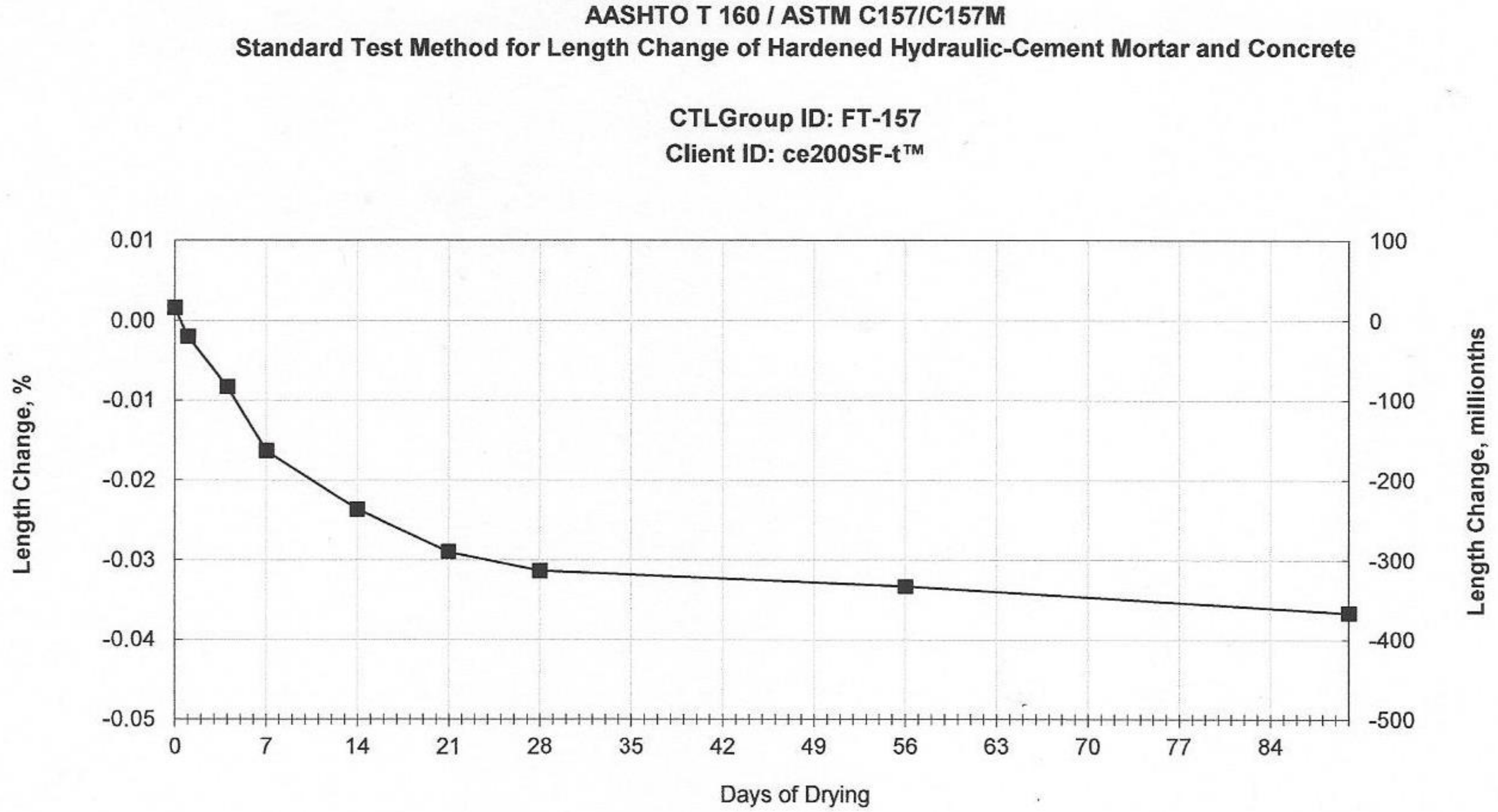


Nanofiber-bridging microcracks

* From Research at NTU by He et al.

What does CNF do for UHPC?

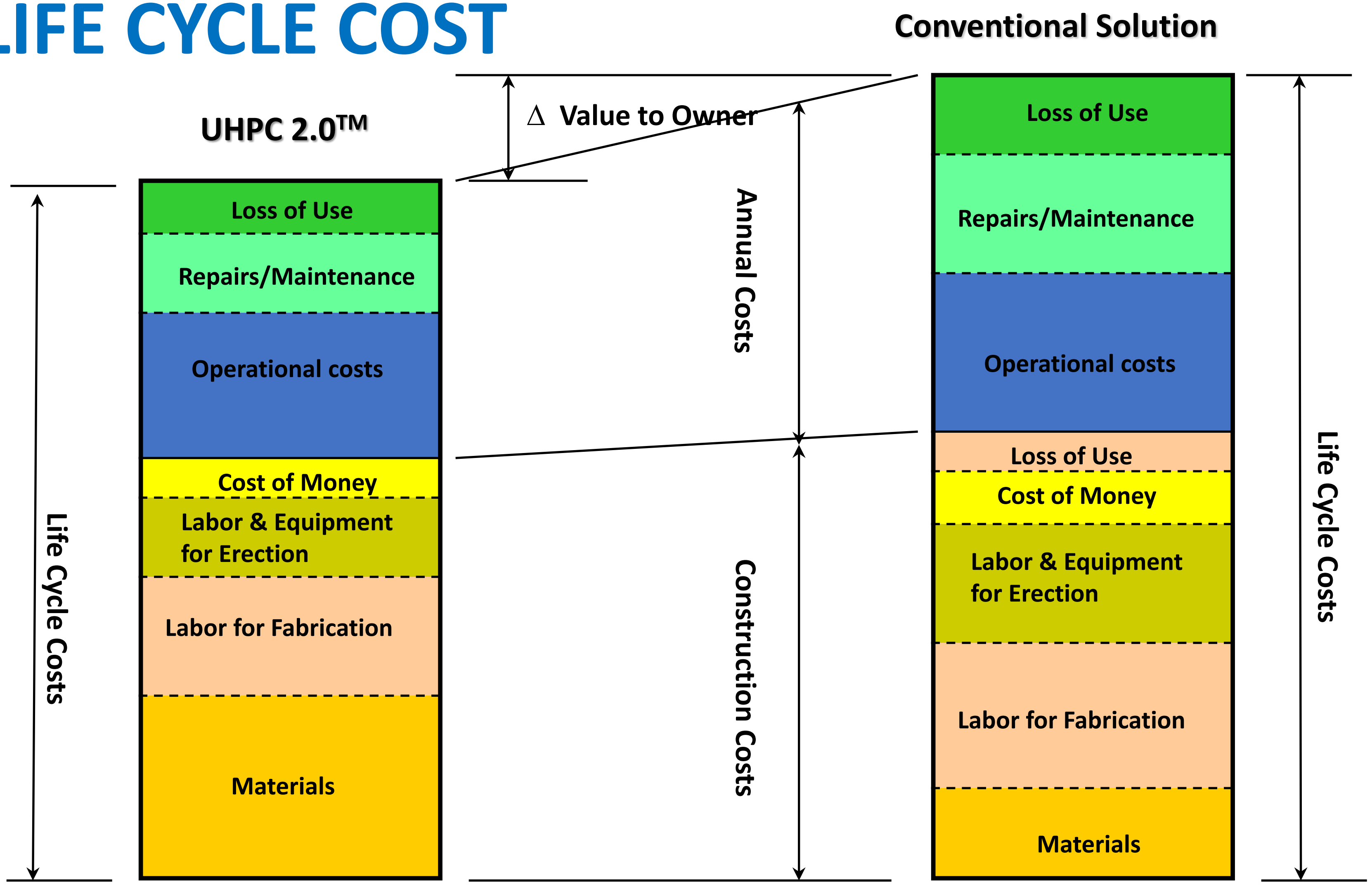
(Reduces Shrinkage)



Example of CO_2 Emissions for a Bridge

Claiborne Pell Newport Suspension Bridge, RI

RELATIVE LIFE CYCLE COST

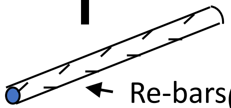


The Concrete Solution

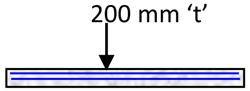
(30 m span)

The Concrete Solution:

+

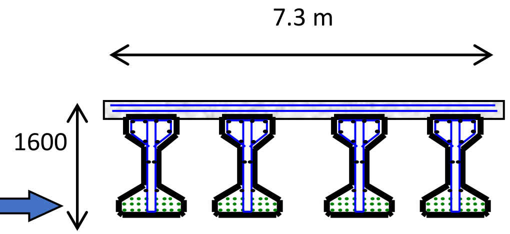


Re-bars*(Epoxy coated)*

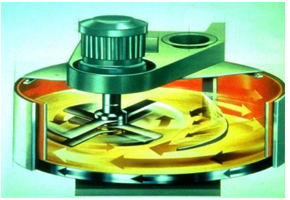


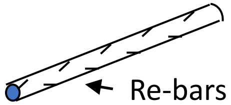
Cast-in-Place Deck

+



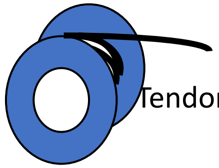
Structural Section of Bridge



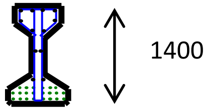


Re-bars

+



Tendons for Pre Stressed

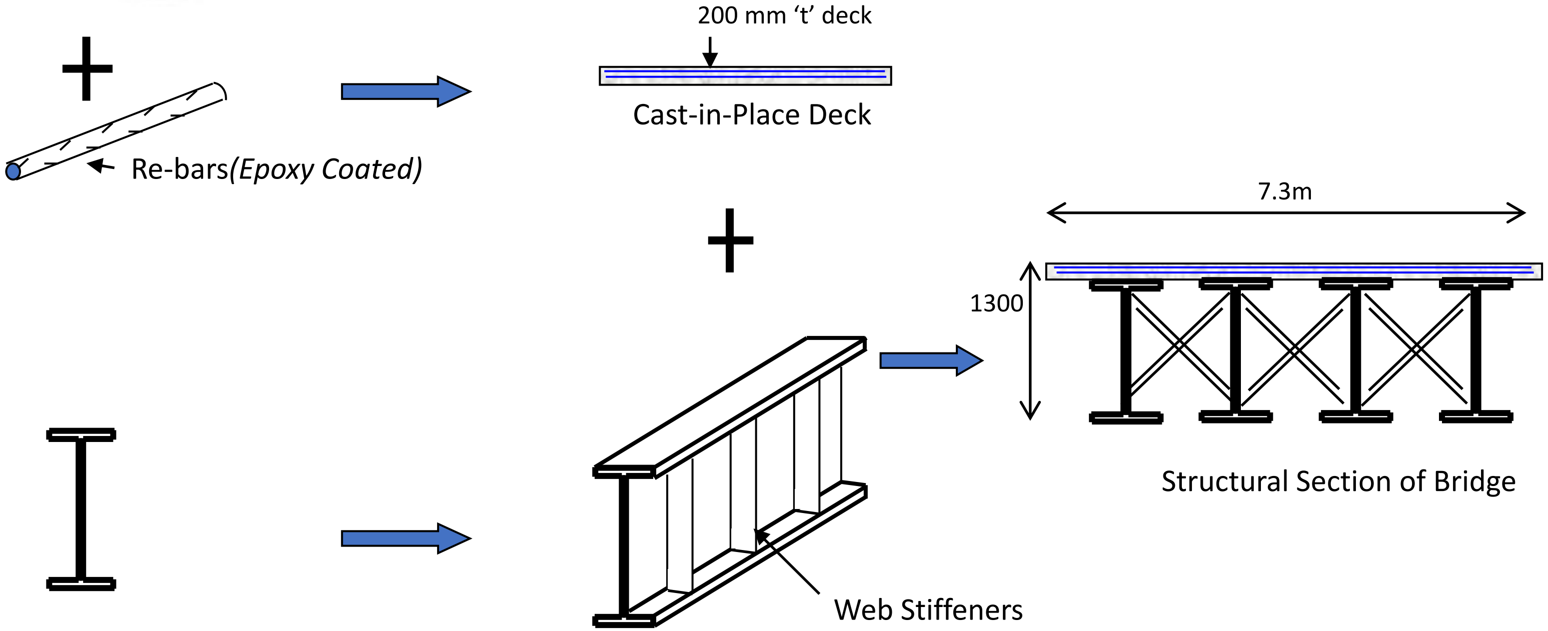


AASHTO TIV Pre-Stressed Bridge Beam

The Steel Solution

(30 m span)

The Steel Solution

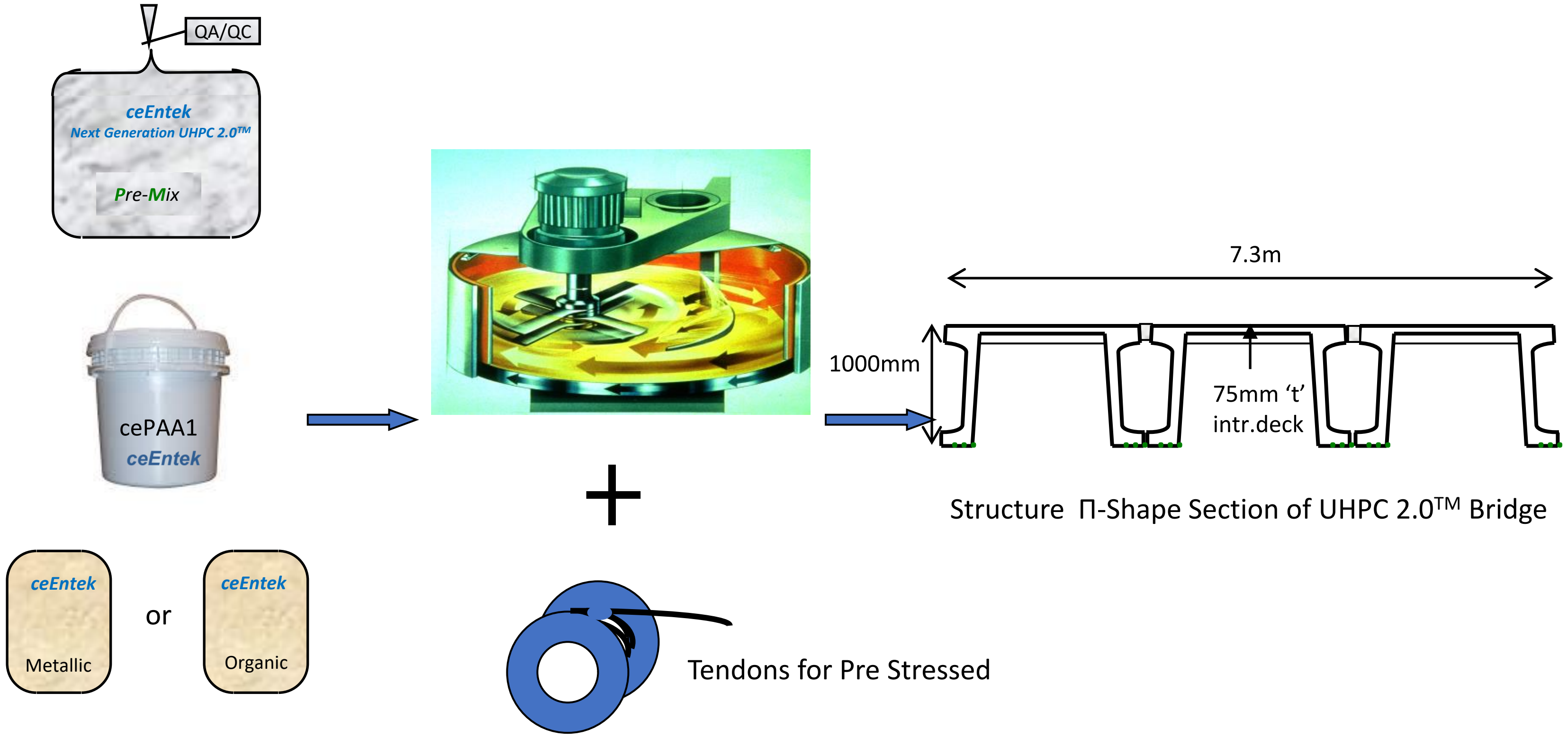


WWF1100 x 291
Steel Girder

The UHPC 2.0™ Solution*

(30 m span)

The UHPC 2.0™ Solution



* Based on MIT optimization Study.

Super- Structure - Quantities of Materials

1) Initial Construction ONLY(NIC: Speed of construction or Life Cycles)

	Steel				*Pre-Cast Concrete*				*UHPC 2.0™*			
	Concrete (m^3)	**Steel** (tonnes)	**UHPC** (m^3)	**Membrane** (m^2)	**Concrete** (m^3)	**Steel** (tonnes)	**UHPC** (m^3)	**Membrane** (m^2)	**Concrete** (m^3)	**Steel** (tonnes)	**UHPC** (m^3)	**Membrane** (m^2)
Deck	**44**	**4.0**	**0**	**219**	**46**	**4.1**	**0**	**219**	**0**	**0**	**0**	**0**
Beams	**0**	**45**	**0**	**0**	**71**	**12**	**0**	**0**	**0**	**9.0***	**35**	**0**
Totals	**44**	**49**	**0**	**219**	**117**	**16.1**	**0**	**219**	**0**	**9.0**	**35**	**0**

Legend:
Steel includes WWF, X-Bracing, Gussets, Stiffeners, Re-bar and Strands & fibers
Concrete includes beams, deck and diaphragms
* Includes steel fibers

Super- Structure - CO_2 Emissions per unit of Materials

Material	*Density (kg/m³)*	*CO_2* (kg /t)*	*CO_2* (kg /m³)*
Concrete	***2300***	***140***	***324***
UHPC 2.0™	***2500***	***250***	***625***
Steel	***7800***	***2200***	***17160***
Asphalt	***2400***	***77***	***184***

*Source - Report to CAC
Prepared by the Athena Sustainable Materials Institute
“Life Cycle Embodied Energy & Global Emissions for Concrete & Asphalt Roadways”

Super- Structure - - Quantities of CO_2 Emissions

1) Initial Construction ONLY(NIC: Speed of construction or Life Cycles)

	Steel				*Pre-Cast Concrete*				***UHPC 2.0™***			
	Concrete *(m³)*	**Steel** *(tonnes)*	**UHPC** *(m³)*	**Membrane** *(m³)*	**Concrete** *(m³)*	**Steel** *(tonnes)*	**UHPC** *(m³)*	**Membrane** *(m³)*	**Concrete** *(m³)*	**Steel** *(tonnes)*	**UHPC** *(m³)*	**Membrane** *(m³)*
Volume of Materials	44	49	0	11	117	16.1	0	11	0	9.0	35	0
CO_2 /volume	324	2200	575	184	324	2200	575	184	324	2200	625	184
CO_2 Sub-Total	14256	107800	0	2024	37908	35420	0	2024	0	19,800	21875	0
Total(kg) =	124,080				75,352				41,675			

Super- Structure - -Quantities of CO_2 Emissions (Con’t)

2) Impact of speed of Construction :

Assumptions:

i) Five days are saved on construction schedule, therefore new alignment in service one week sooner.

ii) Now 10,000 vehicles per day save 2 km of travel for one week.

*iii) CO_2 per vehicle kilometer = 0.25kg**

→ ***Savings = 35000 kg of CO_2***

	Steel	Pre-Cast Concrete	UHPC 2.0™
CO_2 Sub-Total	124,080	75,352	41,675
CO_2 Savings for Schedule	0	0	(35000)
CO_2 Sub-Total	124,080	75,352	6675

** Source - Environment Canada

UHPC 2.0™ reduces CO_2 to < 10% of Conventional!

Super- Structure - Quantities of CO_2 Emissions (Con't)

3) Impact of Maintenance & Operations :

Assumptions:
i) 50 year life.
ii) Replace asphalt membrane 1 time.
iii) Replace entire Concrete deck once in 50 year life.
iv) Extra 2 km of detour travel for one week during 50 year life

→ ***Additional = 60,080 kg of CO_2***

	Steel	Pre-Cast Concrete	UHPC 2.0™
CO_2 Sub-Total	124,080	75,352	6675
Extra CO_2 for O & M	60,080	60,080	(0)
CO_2 Sub-Total	184,160	135,432	6675

UHPC 2.0™ reduces CO_2 to < 5% of Conventional!

ADVANTAGES OF CONSTRUCTING A BRIDGE IN UHPC 2.0™

X-SECTIONAL AREA OF MATERIALS	REDUCED
PASSIVE REINFORCING STEEL	ELIMINATED
FORMWORK	REDUCED
CRANE TIME	REDUCED
CONSTRUCTION TIME	REDUCED
WATERPROOFING FOR PROTECTING R/F	ELIMINATED
CORROSION INHIBITORS / EPOXY RE-BAR	ELIMINATED
FOUNDATIONS	REDUCED
ENVIRONMENTAL IMPACT	REDUCED
OPERATIONAL MAINTENANCE	REDUCED
SEISMIC PERFORMANCE	IMPROVED

THANK YOU!

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