Irish Concrete Society

Lunchtime Seminar Series

29th September 2020

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INNOVATION

Practical Applications of Recent Irish Research in Concrete Technology

Talk 2:
UHPC - a New Frontier in Concrete Design

UHPC – A New Frontier in Concrete Design

William Wilson

Presentation Layout

- What is Ultra High Strength/Performance Concrete?
  - Development & History
  - Mix Designs
  - Typical Applications

- My Ultra High Strength/Performance Concrete Research
  - Aim of my Research
  - Mix Design Development & Characteristic Strength Testing
  - Structural Testing using Experimental & Numerical Methods

- Future of Ultra High Strength/Performance Concrete
  - Recent Advances
  - Future in Ireland

What is Ultra High Strength/Performance Concrete (UHSC/UHPC)?

What is UHSC/UHPC?

- Developed in France in the mid 1990s
- Designed to Exceed the Performance of Standard & High Performance Concretes
- Coarse Aggregate Removed and Replaced with Ultra Fine Particles.
- Common Practice to Add Fibres
  - (Steel/Synthetic/Blend)
  - Ultra High Performance Fibre Reinforced Concrete (UHPFRC).

Pergamon
Cement and Concrete Research, Vol. 25, No. 7, pp. 1501-1511, 1995

0008-8846/95 $9.50+.00

0008-8846(95)00144-1

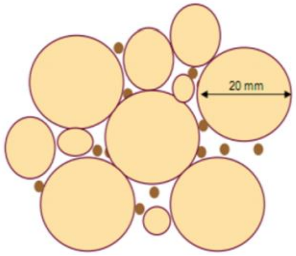
COMPOSITION OF REACTIVE POWDER CONCRETES

Pierre Richard, Marcel Cheyrezy
Scientific Division BOUYGUES, 78061 St Quentin en Yvelines, France

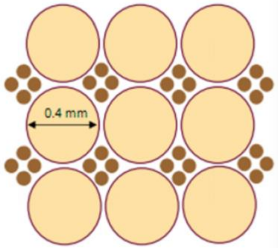
(Refereed)
(Received January 5; in final form April 12, 1995)

ABSTRACT

Development of an ultra-high strength ductile concrete designated RPC (Reactive Powder Concrete), was made possible by the application of a certain number of basic principles relating to the composition, mixing and post-set heat curing of the concrete.
RPC 200, which can be used under job site conditions similar to those for conventional high performance concretes, can be used in the construction of prestressed structures incorporating no passive reinforcement.



Conventional + HPC



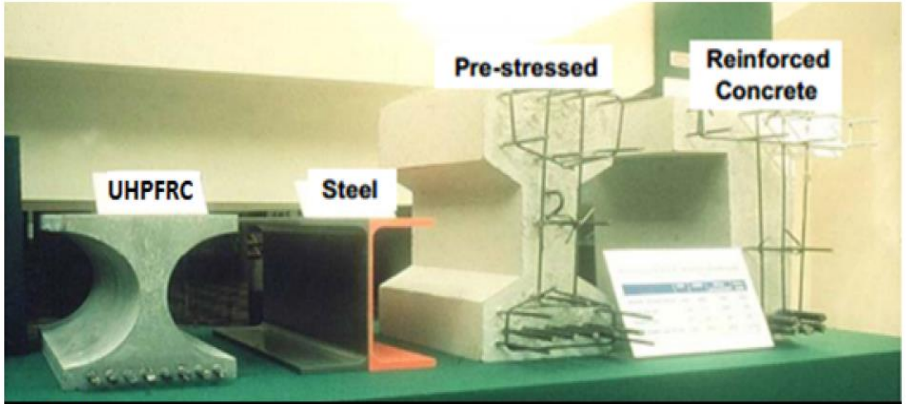
UHPC

UHPC Compression Failure

UHPFRC Compression Failure

Typical Strength of UHSC/UHPC

Strength Property	Conventional Concrete	HPC	UHSC/UHPC	UHPFRC
Compressive Strength (MPa)	20 – 60	60 – 100	100 - 170	130 - 230
Tensile Strength (MPa)	2 – 5	3 – 6	5 – 10	7 – 20
Flexural Strength (MPa)	3 - 5	9 - 18	10 - 40	20 - 60
Elastic Modulus (GPa)	20 - 40	35 - 45	40 -50	45 - 55



Section Parameters	UHPFRC	Steel	Pre-stressed concrete	Reinforced concrete
Section Depth	360mm	360mm	700mm	700mm
Weight	130kg/m	110kg/m	470kg/m	530kg/m

Longer Spans & Shallower Elements

Typical Applications

- Bridge design – Beam & Deck Construction
- Offshore & Wind Energy
- Blast Resistance
- Wear Protection
- Concrete Repair/Shotcreting
- Architecture
  - Facades
  - Furniture
  - Stair Cases

Typical UHSC/UHPC Mix Designs

Material/ Component (kg/m³)	Conventional Concrete	HPC	UHSC/UHPC
Cement	< 400	400 - 600	600 - 1000
Silica Fume (MicroSilica)	-	30 - 60	50 - 300
Quartz Flour/Glass Powder	-	-	100 - 250
Coarse Aggregate	950 - 1100	800 - 1000	-
Fine Aggregate	≈ 800	600 - 800	-
Fine Sand (<0.5mm)	-	-	1000 - 1200
Water	170 - 210	100 - 170	110 - 200
Admixture	0 – 4 (0-1%)	5 – 8 (0.5 – 2%)	10 – 70 (2% - 6%)
Fibres (By Volume)	0 – 0.5%	0 – 1%	0 – 4%
Maximum Aggregate Size	10 – 20mm	8 – 14mm	0.1 – 3mm
Water/Cement (Water/Binder)	0.40 – 0.70	0.25 – 0.40	0.14 – 0.27

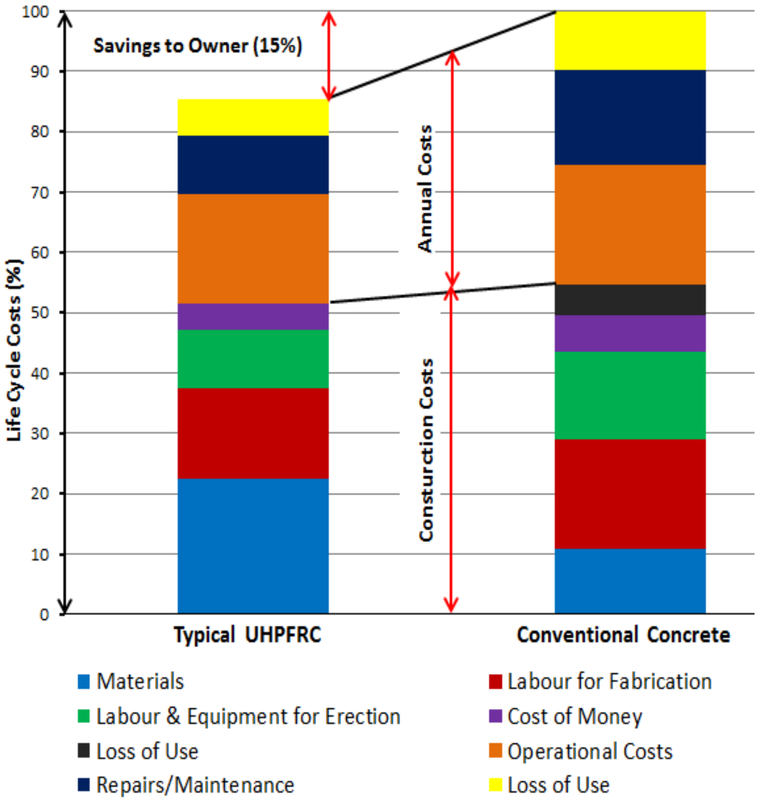
Advantages & Disadvantages of UHPC

Advantages

- Thinner & Lighter Structures
- Reduced Quantities of Steel Reinforcement
- Increased Durability

Disadvantages

- Shortage of Design Codes & Recommendations
- Rise in Initial Cost of Mix per Cubic Metre
- Availability of Mix Constituents



My UHPC/UHPFRC Research

Rationale for my Research

- Lack of Materials in Ireland for Typical UHPC Mixes
  - Development of a New UHPC Mix(s)
- Lack of Understanding into the Behaviour of UHPC
  - Conduct Experimental Strength Tests
  - Develop Novel Testing Methods
- Lack of Design Codes
  - Conduct Small-Scale Structural Experimental Tests
  - Validate Numerical Modelling Methods using the Experimental Results
- Lack of Knowledge of UHPC in Ireland
  - Demonstrate it is Possible

Material/ Component (kg/m^3)	UHSC/UHPC
Cement	600 - 1000
Silica Fume (MicroSilica)	50 - 300
Quartz Flour/Glass Powder	100 - 250
Fine Sand (<0.5mm)	1000 - 1200
Water	110 - 200
Admixture	10 - 70
Fibres (By Volume)	0 – 4%

Mix Development

- Typical UHPC Mix from Literature as a Starting Point
  - Removed Materials that were not Feasible
  - Replaced with Materials with Comparable Properties/PSDs
  - Particle Packing Model used to Refine Mixes

- Materials Utilised
  - CEM I
  - MicroSilica
  - Sand – Fine Sand & Medium Concrete Sand
  - Admixture – Superplasticiser & Accelerator
  - Micro Steel Fibres – 13mm Length






Mix Series	Mix A – Fine Sand	Mix B – Concrete Sand
Total Powder	1013	822
Water/Binder	0.18	0.20
Steel Fibres (%)	0, 1, 2, 3, 4	0, 2

Mixing & Curing Procedure

- Creteangle Multiflow 56L pan mixer
  - Mixing time
    - UHPC ≈ 18 minutes
    - UHPFRC ≈ 22 minutes
  - Vibrating table 1 minute
  - Covered with damp cloth & polythene sheets
  - Demoulding at 24 hours

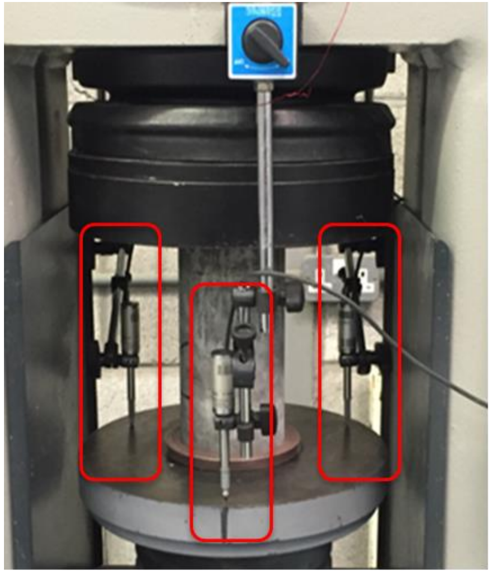
- Curing
  - Method A - Water Tank at 20ºC
  - Method B – Steam Curing 48 Hours & Water Tank at 20ºC

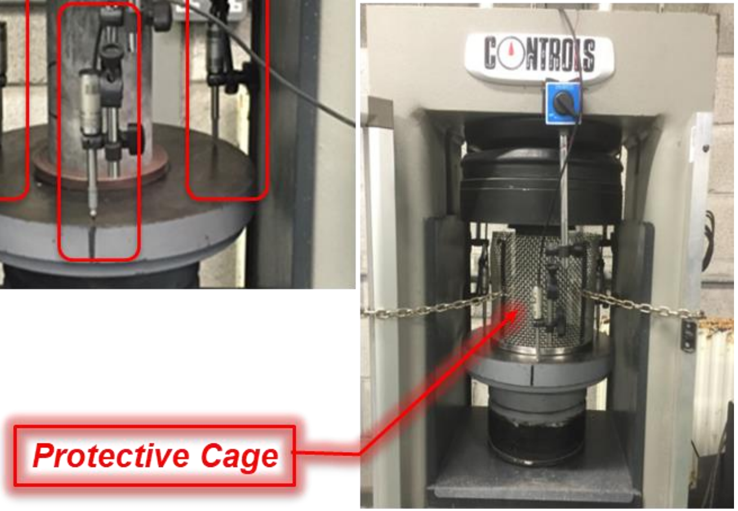
- At least 3 specimens for each test type

Characteristic Strength Testing - Compression

- Cube Tests - Strength Only
  - 100mm Sides
  - Force loading (0.5MPa/s)

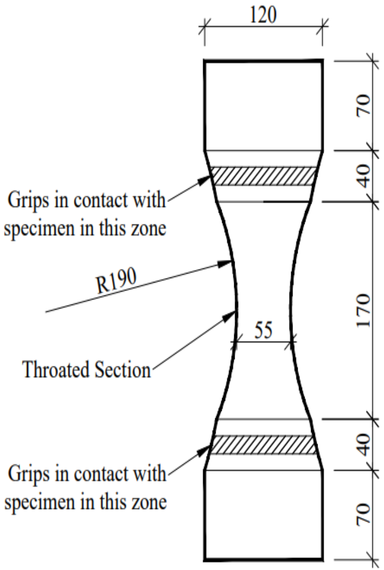
- Cylinder Tests - Strength & Behaviour
  - 100mm dia & 200mm height
  - Force Loading (0.5MPa/s) up to 85% Peak Load
  - Displacement Loading (1µm/s) to Failure
  - Stress-Strain Data & Elastic Modulus Data
  - LVDTS at equal spaces

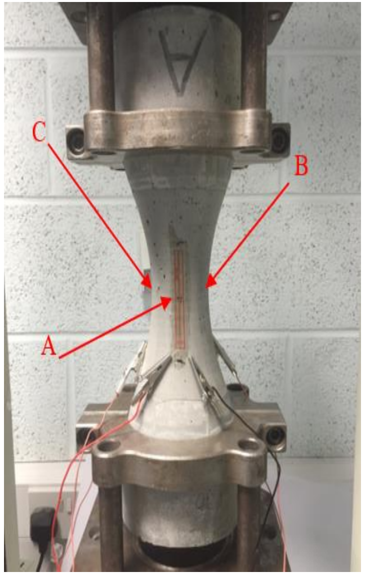


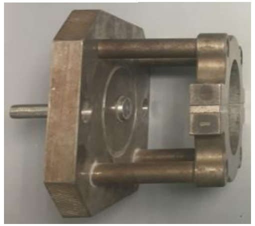


Characteristic Strength Testing – Tensile

- New Test Specimen Developed
- Throated/Dogbone Specimen
  - Circular Cross Section
  - Diameter Reduced from 120mm to 55mm
- Direct Contact between Grips & Specimen
- Grip shaped to create Friction
- Displacement Loading – 0.4mm/min
- Three Strain Gauges used to Measure Strain at Specimen Throat
  - Identical Readings => Uni-Axial Behaviour

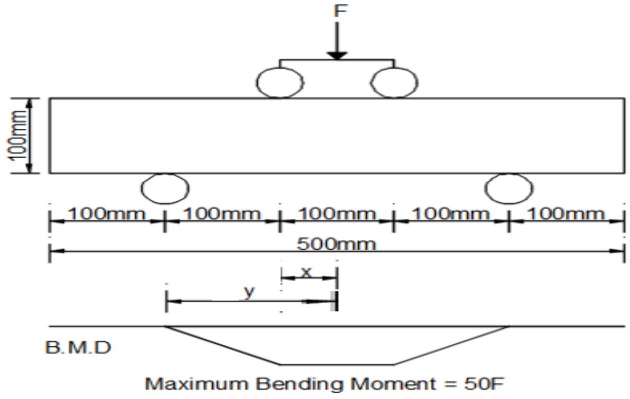


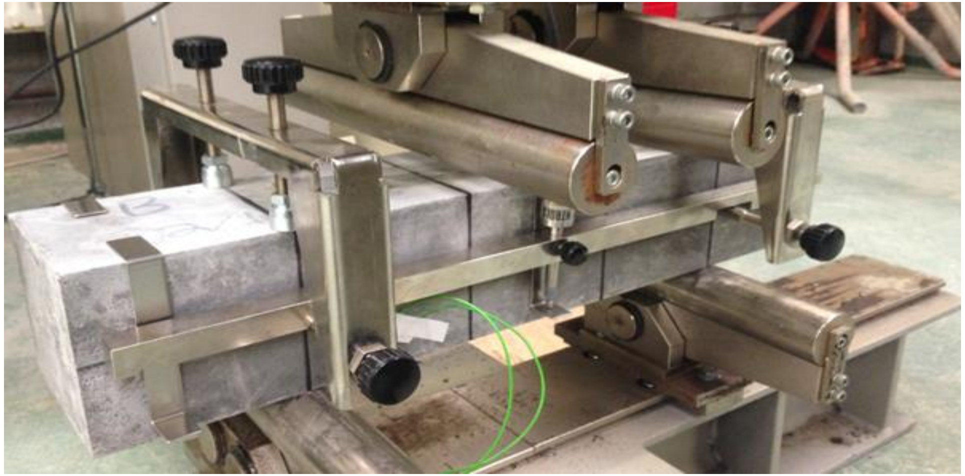




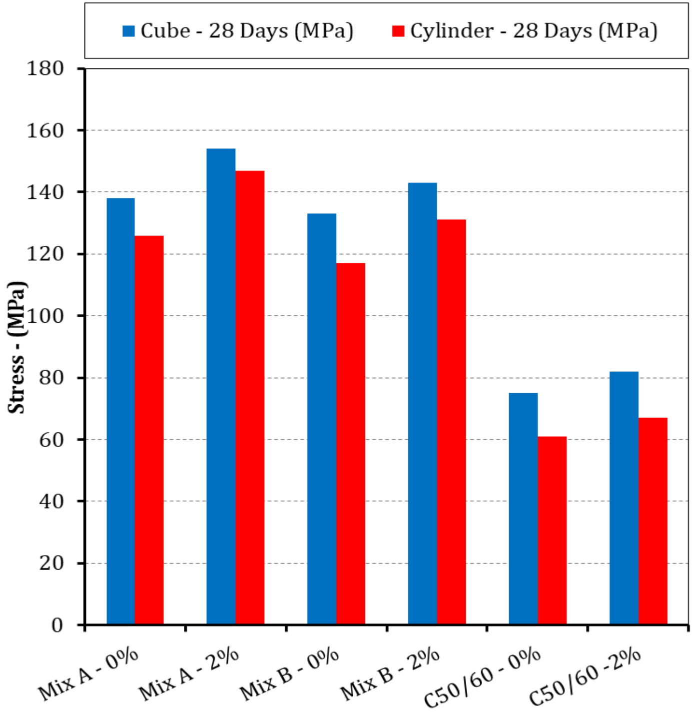
Characteristic Strength Testing – Flexural

- Four-Point Bending/In-Direct Tensile Test
  - h x w x l =100mm x 100mm x 300mm
  - Displacement loading using LVDTs
  - Test speed varied from 2µm/s to 8µm/s

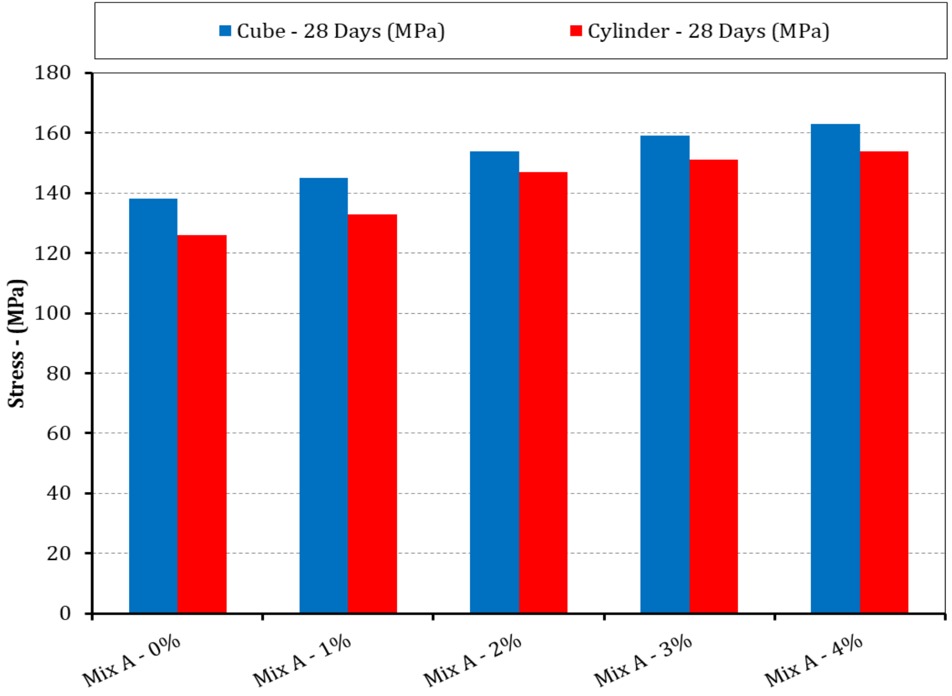




Characteristic Strength Results - Compression

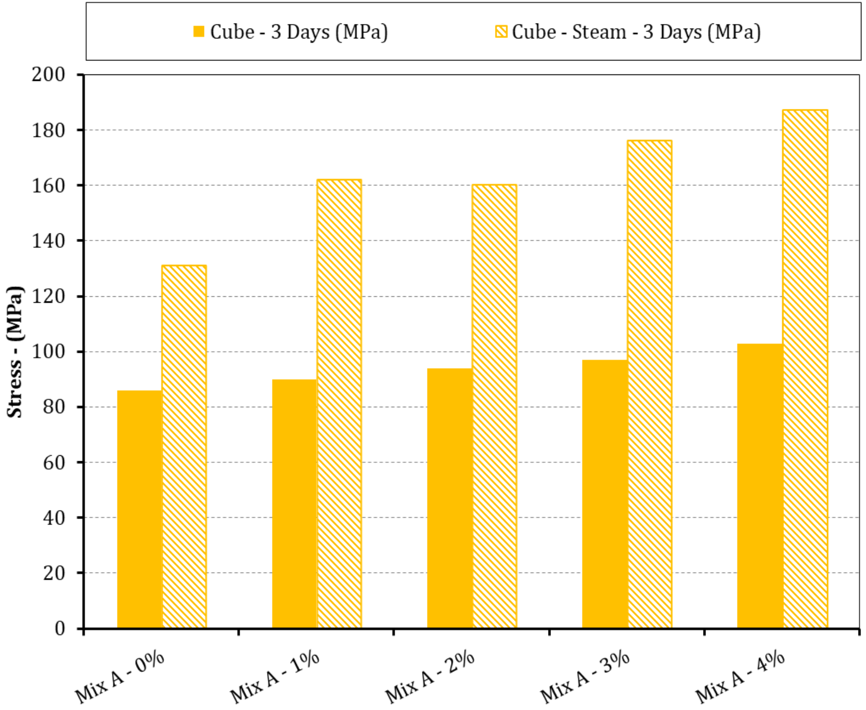


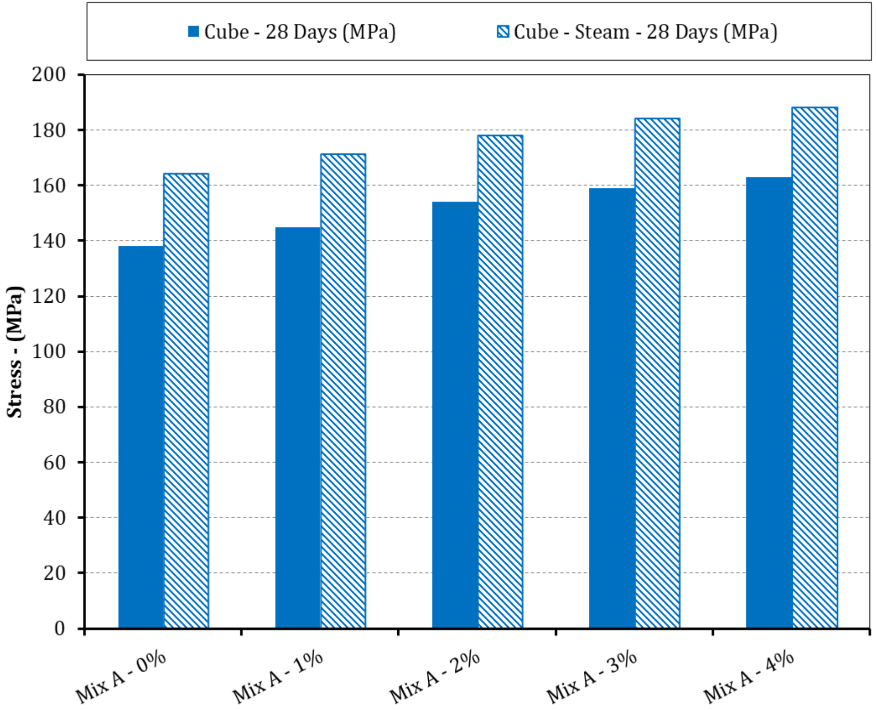
Change of Mix Design



Change of Fibre Dosage – Mix A

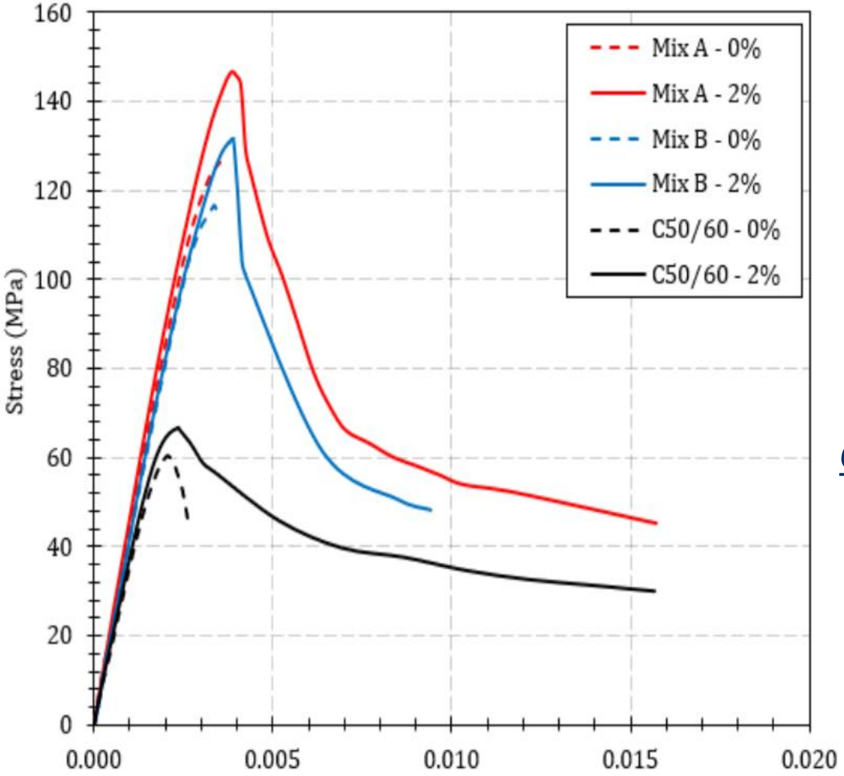
Characteristic Strength Results - Compression





Effect of Early Age Steam Curing – Mix A

Characteristic Strength Results - Compression

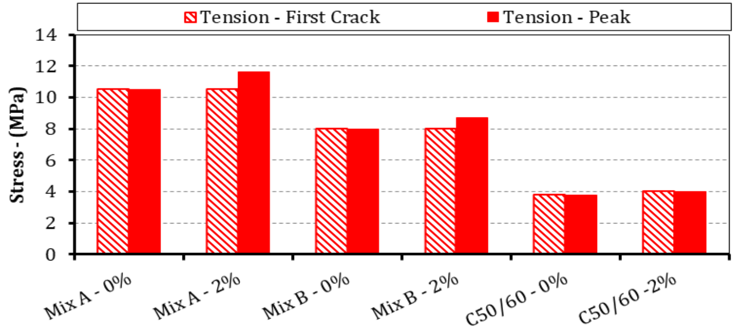


Mix A – 0% **Mix A – 2%**

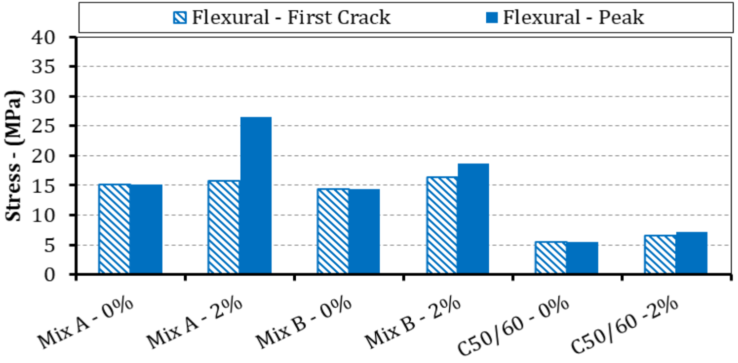
C50/60 – 0% **C50/60 – 2%**

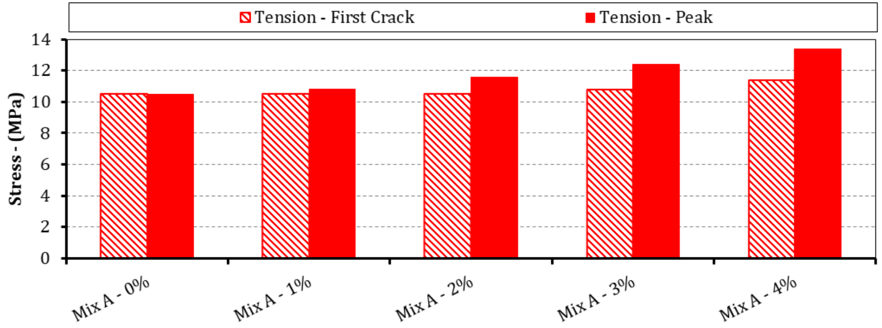
Mix B – 0% **Mix B – 2%**

Characteristic Strength Results - Tensile

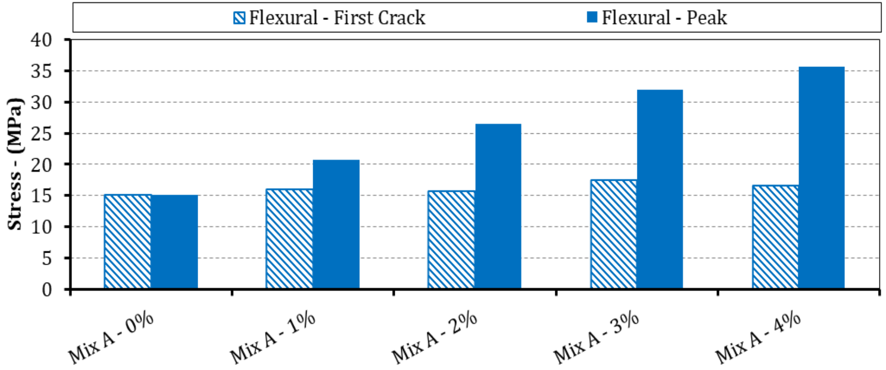


Change of Mix Design



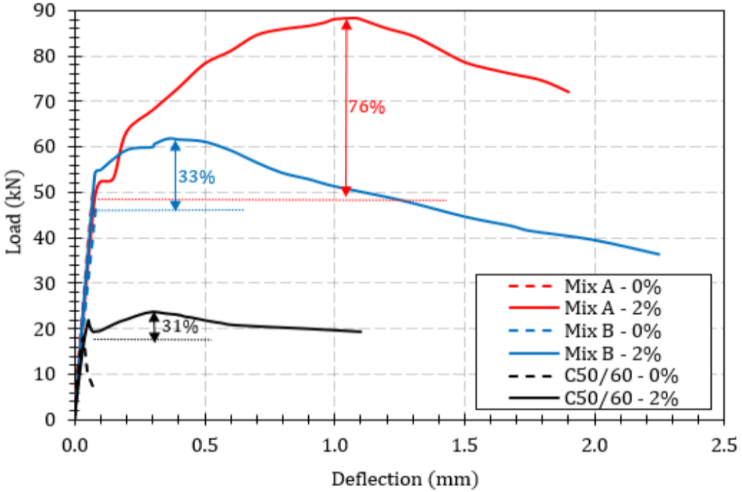


Change of Fibre Dosage – Mix A



Characteristic Strength Results - Tensile

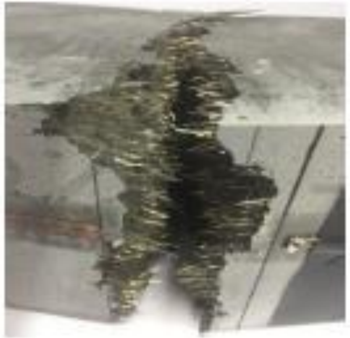
- Fibre Orientation Determines Post First Crack Strength
- Fibres in UHPC Align with the Direction of Flow of Concrete





C50/60 – 2% ***Mix B – 2%*** ***Mix A – 2%***





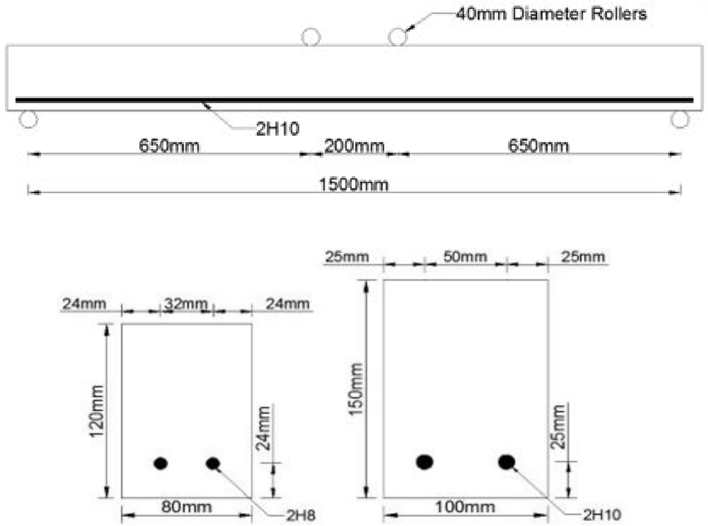
Small Scale Structural Testing - Beams

- Beams Tested using Four Point Bending

- Flexural Frame – 100kN Capacity
- Beams had a Clear Span of 1500mm
- Height to Width Ratio of 1.5

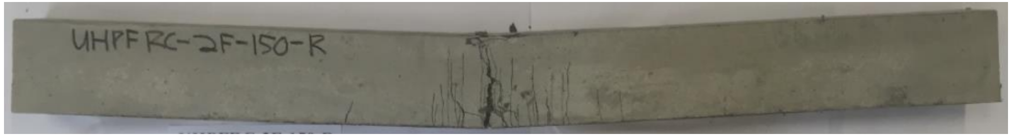
- 16 Beams Tested:
  - 12 UHPC/UHPFRC Beams – Mix A
    - 2 Beam Heights – 120mm & 150mm
    - 3 Fibre Reinforcement Ratios – 0, 1 & 2%
    - 2 Secondary Reinforcement Ratios 0 & 1.3%
  - 4 C50/60 Beams – 0% Fibres, 1.3% Reinforcement
    - Designed Using EC2 to Fail in Flexure

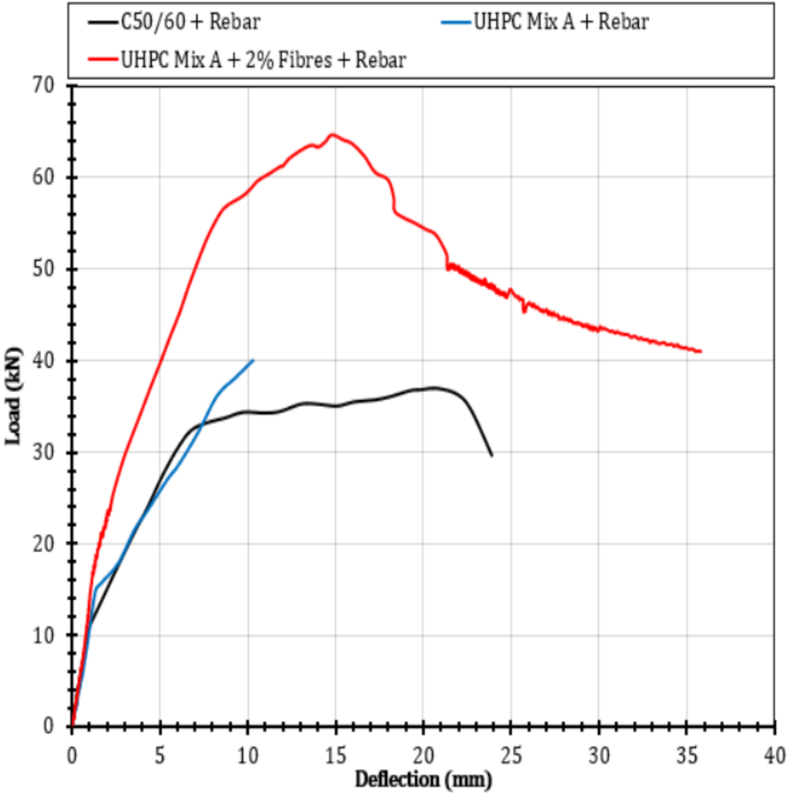
- Tested using Displacement Loading



Structural Testing – Beam Significant Results

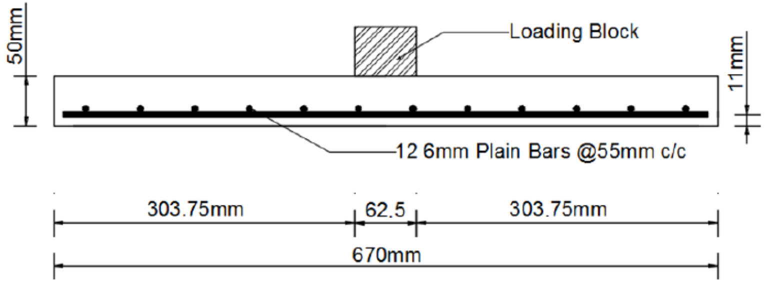
150mm Deep Beams	Peak Load (kN)	Failure Mode
C50/60 + Rebar	37	Flexure
UHPC Mix A + Rebar	40	Shear
UHPC Mix A + 2% Fibres + Rebar	65	Flexure





Small Scale Structural Testing - Slabs

- Slabs Tested in Punching Shear
  - Flexural Frame – 100kN Capacity
- Simply Supported at the Point of Contra-Flexure
  - Encompass the hogging moment
- 9 Slabs Tested- UHPC/UHPFRC Mix A
  - 2 Slab Heights – 30mm & 50mm
  - 3 Fibre Reinforcement Ratios – 0, 1 & 2%
  - 2 Secondary Reinforcement Ratios 0 & 1.4% (50mm Slabs Only)
- Tested using Displacement Loading



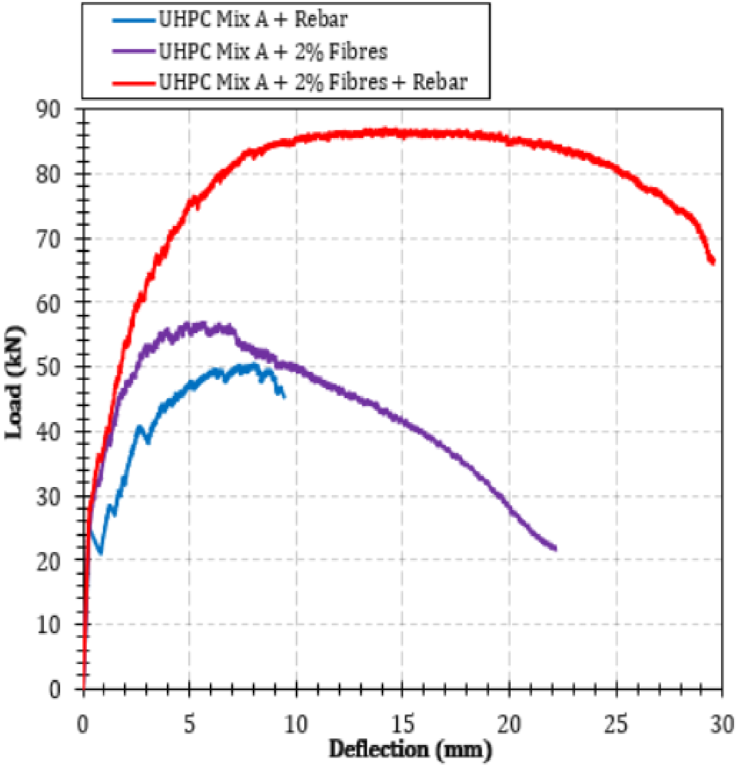
Structural Testing – Slab Significant Results

50mm Deep Slabs	Peak Load (kN)	Failure Mode
UHPC Mix A + Rebar	50	Shear
UHPC Mix A + 2 % Fibres	57	Flexure-Shear
UHPC Mix A + 2 % Fibres + Rebar	87	Flexure

Rebar

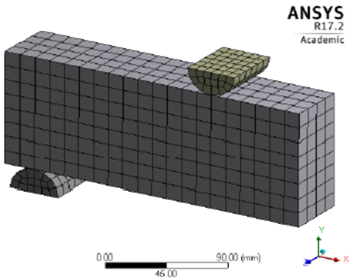
2% Fibres

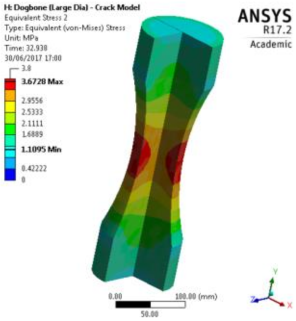
2% Fibres + Rebar

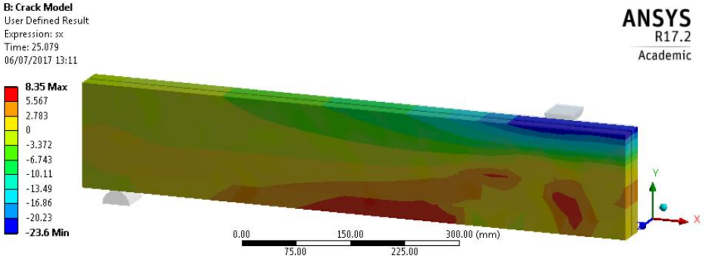


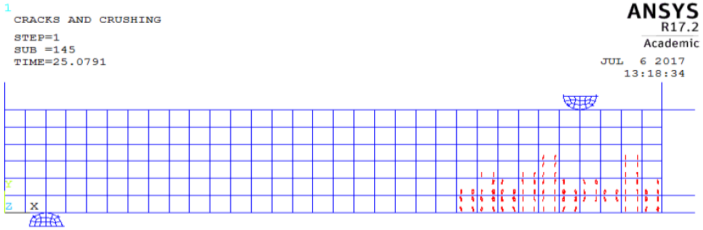
Computer Modelling & Concrete Design

- Used in Concrete Design since 1960's
- Wide Variety of Uses:
  - Check Load Carrying Capacity
  - Predict Failure Mechanisms
  - Predict Deflections & Crack Locations
- Advantages:
  - Cost-Effective
  - Easy to Change Variables, i.e. Beam Depth, Reinforcement Ratio, Fibre Dosage, etc
- Disadvantages:
  - Limited Studies Available on UHPC

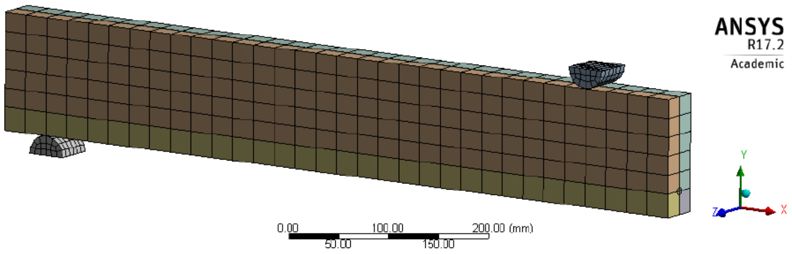




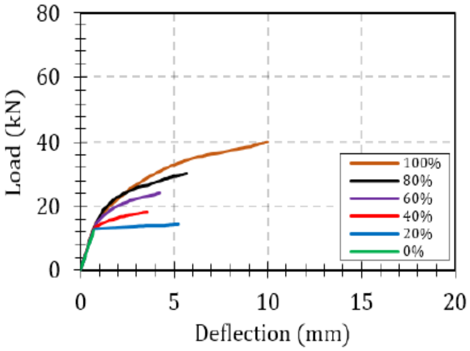


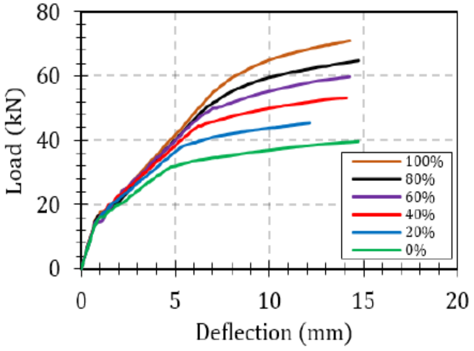


Computer Modelling Practical Applications

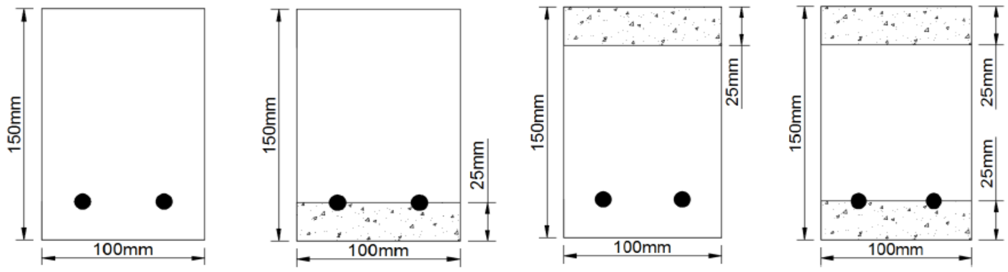


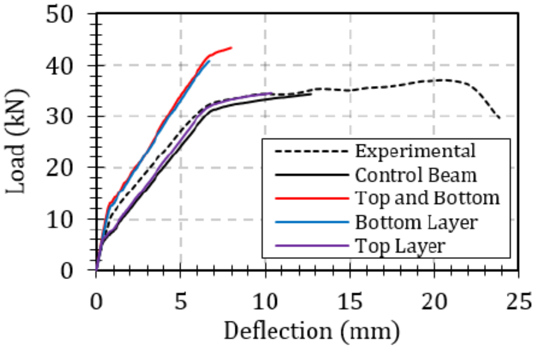
Beam Quarter-Model





Modelling the Effect of Fibre Orientation





Modelling the Effect of Using UHPC for Retrofitting

The Future of UHPC

Recent Advances in UHPC Mix Design

- Supplementary/Replacement Cementitious Materials
  - GGBS/Fly Ash
  - Geopolymers

- The Use of NanoSilica

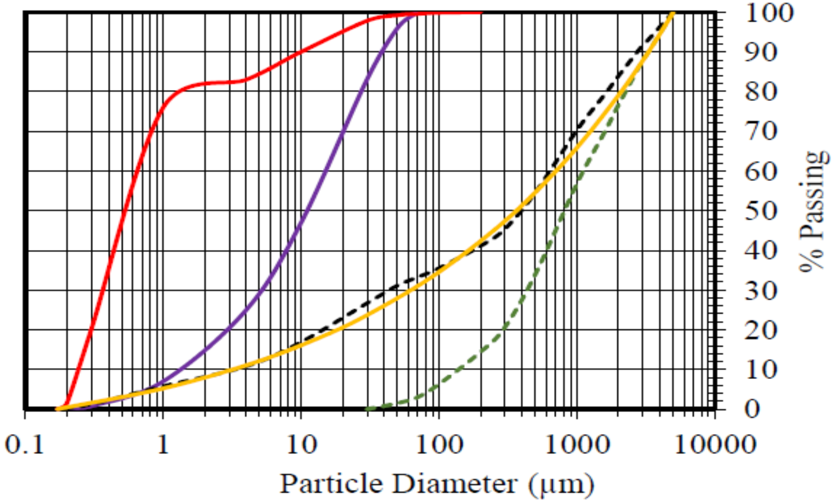
- Fibres for Specific Purpose
  - Polyproplene/HPP/Glass/Steel
  - Blended Fibres – Micro/Macro

- Composite Members
  - UHPC/RC & UHPC/Steel




Sustainability Improvements

- Reduced Binder Contents
  - Mix Design Improvements
  - Use of Particle Packing Theory
- Localisation of Mix Design
  - Studies Conducted in Fanshawe College
  - Validated Irish Mixes Using Canadian Material
- Life Cycle Analysis
  - High Cost per Cubic Metre – FAKE NEWS!
  - Lower Total Volume
  - Recyclable – Reuse!



Mix	Total Binder (kg/m3)	Compressive Stress Cylinder (MPa)
Mix A – Fine Sand 0.5mm	1013	121
Mix B – Concrete Sand 3mm	822	115
Mix C – Concrete Sand 5mm	667	117

Constraints to Using UHPC

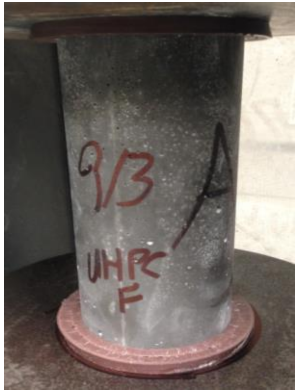
- Lack of Design Codes

- Long Lead Times
  - Laboratory and Plant Trials
  - Plant Modifications May Be Necessary
  - Silo/Bin/Admixture/Fibre Availability
  - Longer Mixing Times

- Placement & Finishing
  - Low w/c => Viscous Mixture
  - Trials to Determine Best Practice

- Curing Method
  - Elevated/Steam Curing Limitations



Future of UHPC in Ireland

- **Precast Construction**
  - Bridge Design
  - Offshore & Wind Energy
  - Architectural Features

- **Ready Mix Concrete**
  - Retrofitting/Strengthening Existing Structures
  - Connections for Precast Elements
  - Industrial Floors
  - Architectural Features

Cements of yesterday and today Concrete of tomorrow

Cement and Concrete Research Journal

Pierre-Claude Aïtcin (2000)

"Contractors and owners have to realise that what is important is not the cost of 1 m^3 of concrete but rather the cost of 1 MPa or 1 year of life cycle of a structure "

Thank You

For further information, please contact:

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