Durability of Special Concretes

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Special concretes

Concrete made for special purposes of application with specific property enhancement

CONVENTIONAL CONCRETE
Code specified *prescription* for mix design

SPECIAL CONCRETE
Engineered mix design with relevant *performance* criteria

What makes concrete *Special*?

INGREDIENTS	TARGET PROPERTIES	APPLICATION
• Use of SCMs and UFMAs • Chemical admixtures • Fibres • Restricted max. size of Aggregates • Quality/Type of Aggregates	• Early strength development • High/Ultra high strength • Enhanced flexural properties • Higher Stiffness – E value • Greater workability • Superior Durability	• Mass concrete • ***Tall buildings*** • *Thin sections* • Marine and underwater • Power plants • Hot and cold climate concrete • Long span bridges • Dams and water storage structures

Why Special concretes ?

Increasing High Rise Buildings (HRBs) and Urban Infrastructures

Increasing market demand for High strength concrete (>60MPa) grades.

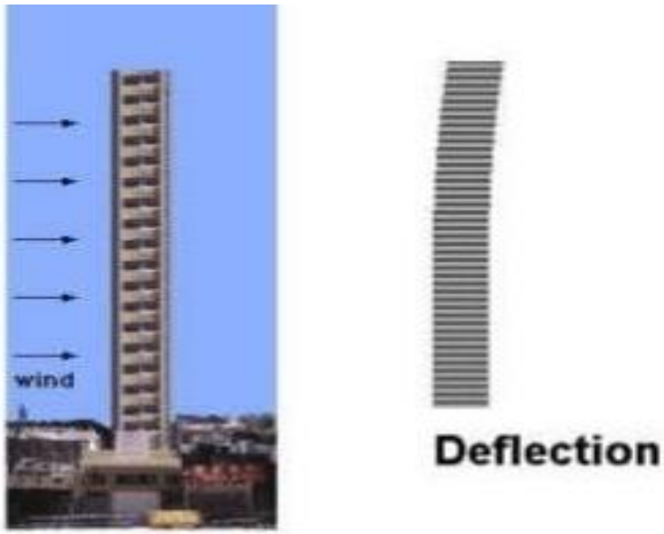
Dependency on concrete of Medium strength (30 to 50 MPa) and unjustified consumption of valuable fresh natural resources..

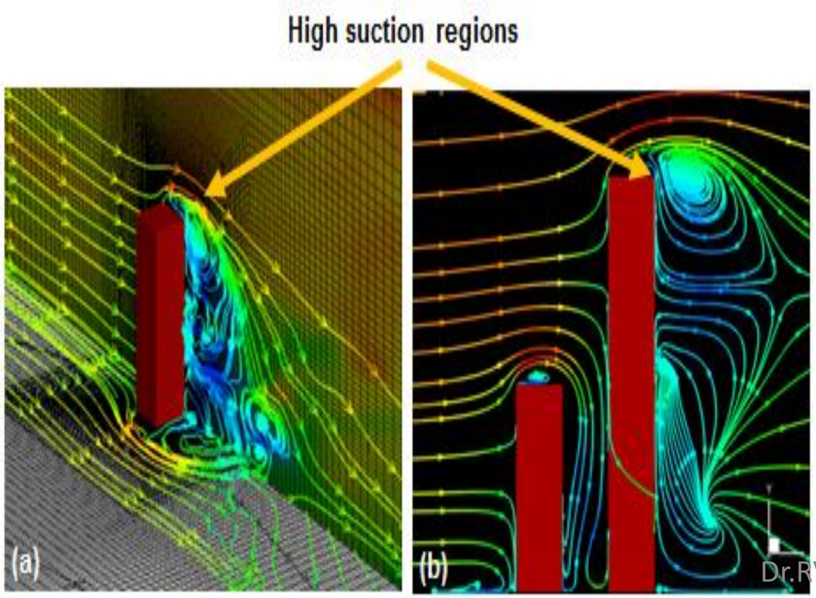
Demand for ***performance specific concrete*** from different aspects of construction.

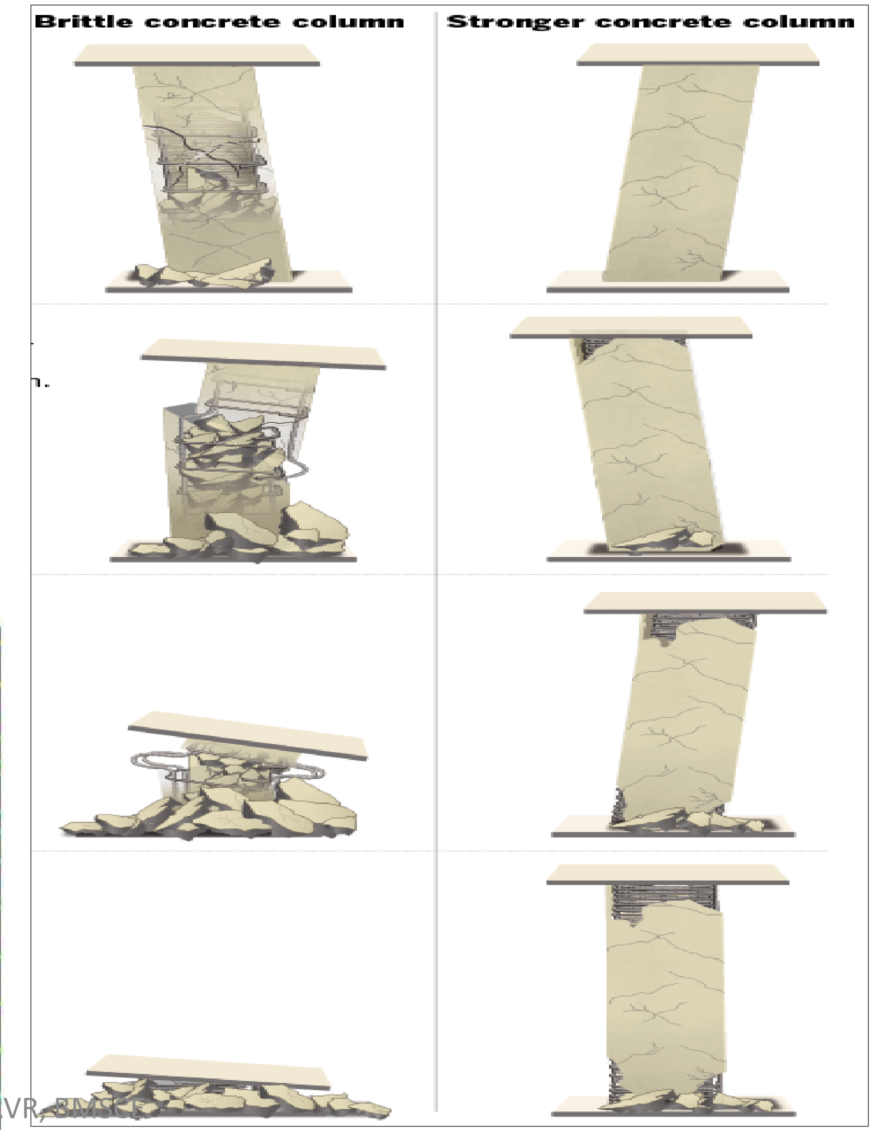
High Performance Concrete

-SCC- High strength concrete- UHPC/Micro-concrete-

Importance of concrete with enhanced MOE and Flexural Toughness

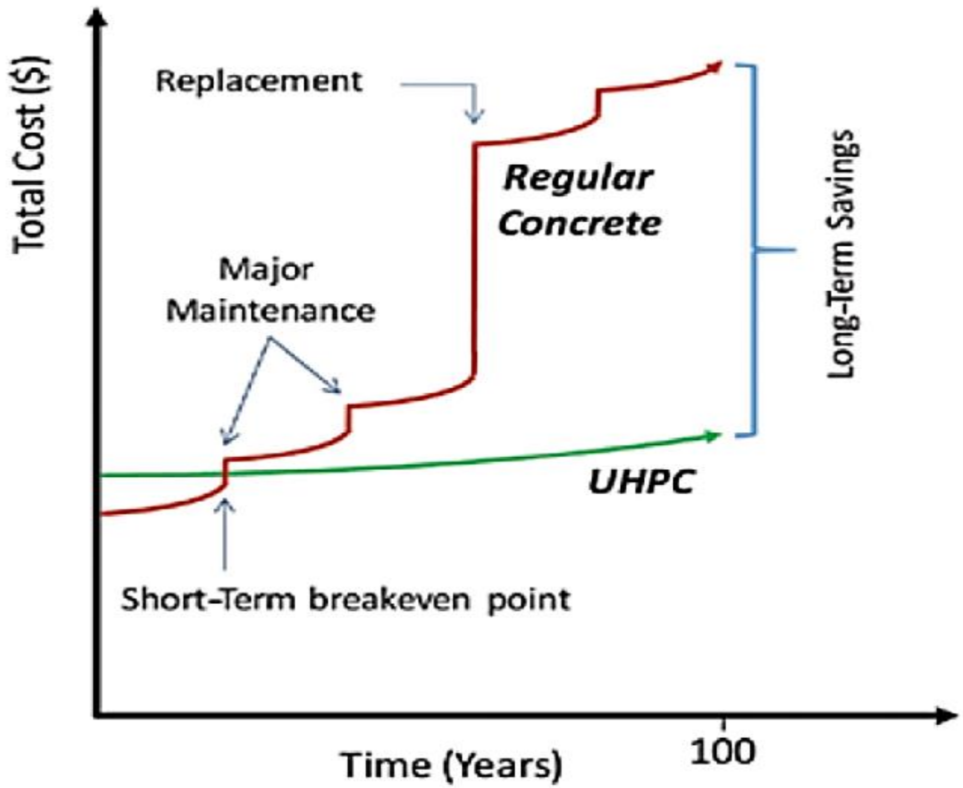






Application benefits of Durable concrete

- Special concrete (HSC/HPC/UHPC) with its enhanced Durability is likely to result in *less maintenance* and *longer service life.*
- Considering the life-cycle costing, the long-term economic benefits are likely to offset the premium costs for initial construction.



*Sherif El-Tawil et al., ACI 2020

IS 16700: 2017

- ***IS 16700:2017- Criteria for Structural Safety in tall buildings outlines concern over the limitations of special concrete with strength >70 MPa.***
- ***Material selection, Brittleness, Autogenous shrinkage, Creep and Durability evaluation is stressed to be of importance.***

b) The minimum grade of concrete shall be M 30. In view of the twin advantages of high-strength concrete in reducing the section sizes and percentage of steel reinforcement in structural elements, such concrete with grades ranging from M 45 to M 70 shall be used, wherever essential. When higher grades are required, the designer shall ensure through testing that such concretes shall have a minimum crushing strain in compression of 0.0020. Grades higher than M 70 (up to M 90) shall be used with utmost caution under the guidance and supervision of a recognized subject expert in concrete technology with specified values for parameters of modulus of elasticity, shrinkage, creep and durability.

f) High strength concretes are quite sensitive to changes in properties of ingredients, variations in mix proportions and testing procedures. Hence, special efforts shall be taken to enforce strict quality assurance (QA) and quality control (QC) during production and testing of such concrete. The contractor/RMC

Durability indices for Special concretes

IS 16700: 2017

- Rapid Chloride Permeability Test (RCPT)
- Water Permeability
- *Shrinkage*

k) Concrete used in tall building construction shall be durable. For ensuring long-term durability, concrete shall satisfy the following test criteria:

1) Rapid chloride ion permeability test in,
   i) *Foundations* — Not more than 1 000 Coulomb.
   ii) *Superstructure* — Not more than 1 500 Coulomb.
2) Water penetration test in,
   i) *Foundations* — 15 mm *Max*.
   ii) *Superstructure* — 20 mm *Max*.

Shrinkage and its relevance in Special concrete

- The rate of volume change in concrete is a complex phenomenon with important influence on the resulting performance, especially durability of concrete.
- From a practical viewpoint, the importance of shrinkage in concrete relates mainly to cracking potential.
- Autogenous shrinkage and Drying shrinkage rates influence on durability aspects.

Shrinkage stress related cracking potential of concrete

ASTM C-1581 classification

TABLE X1.1 Potential for Cracking Classification

Net Time-to-Cracking, t_{cr}, days	Average Stress Rate, S (MPa/day)	Average Stress Rate, S (psi/day)	Potential for Cracking
$0 < t_{cr} \leq 7$	$S \geq 0.34$	$S \geq 50$	High
$7 < t_{cr} \leq 14$	$0.17 \leq S < 0.34$	$25 \leq S < 50$	Moderate-High
$14\ t_{cr} \leq 28$	$0.10 \leq S < 0.17$	$15 \leq S < 25$	Moderate-Low
$t_{cr} > 28$	$S < 0.10$	$S < 15$	Low

Shrinkage specific parameters for Concrete

IS 1343:1980

Grade of Concrete	*Autogenous Shrinkage* ($\varepsilon_{ca} \times 10^6$)
M 30	35
M 35	45
M 45	65
M 50	75
M 60	95

f_{ck} MPa	*Unrestrained Drying Shrinkage Values* ($\varepsilon_{cd} \times 10^6$) *for Concrete with Portland Cement, for Relative Humidity*	
	50 Percent	80 Percent
(1)	(2)	(3)
25	535	300
50	420	240
75	330	190

NOTE — The values for the other designated grades may be obtained by interpolation.

Role of SCMs in Durability of Special Concrete

- Supplementary Cementitious Materials (SCMs) are essential part of durable Special concrete now.
- Modern Processing techniques have made way for new variants of SCMs and better-quality Micro fine Mineral admixtures (MMAs) and Nano mineral admixtures (NMAs)

Common Mineral admixtures used in HSC
[Source: National Ready Mixed Concrete Association (NRMCA)]

SCMs
Fly ash, GGBS

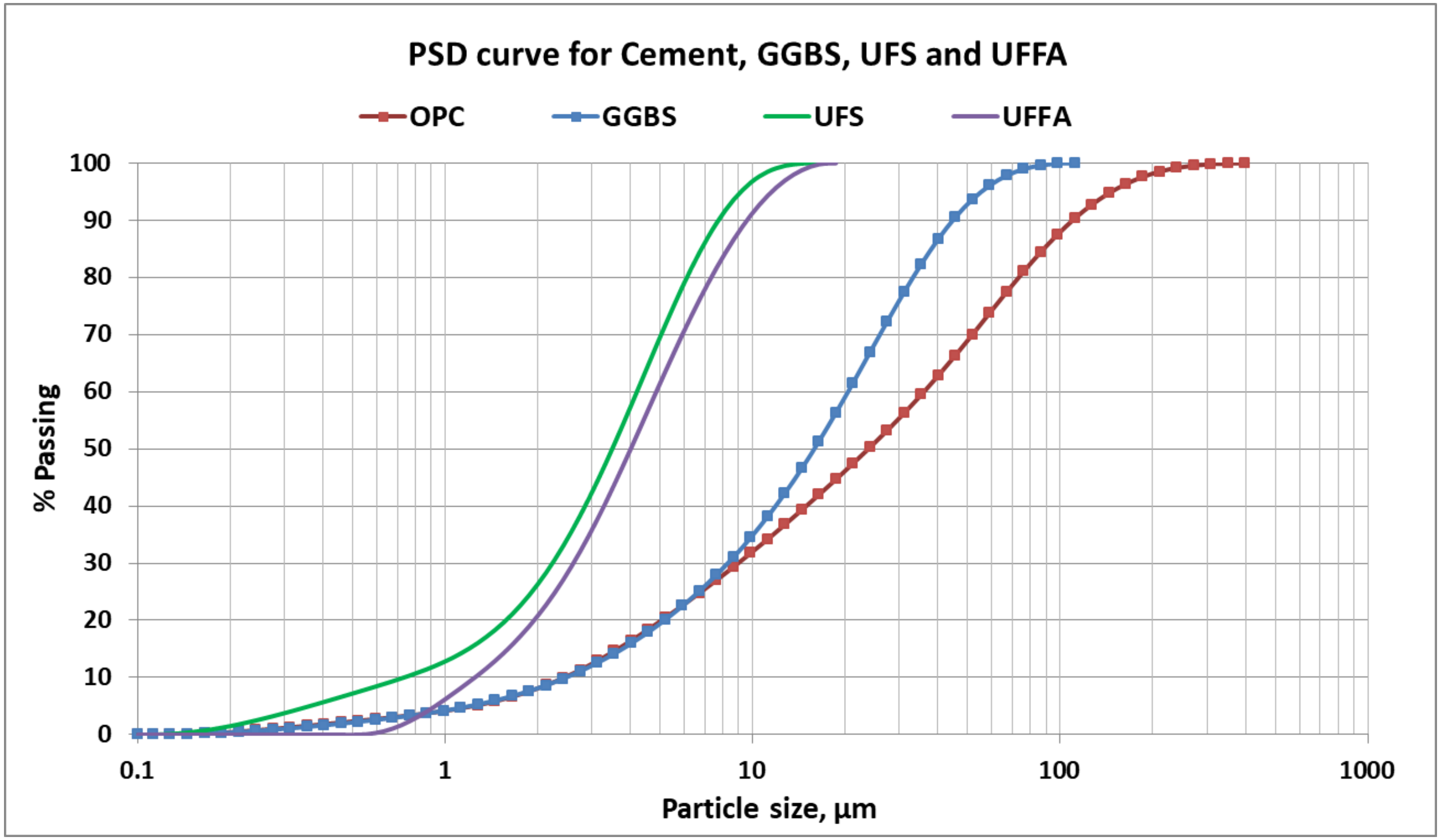
→ Further processing →

Micro mineral Admixtures
Ultrafine Fly ash,
Ultrafine Slag,
Silica fume etc.

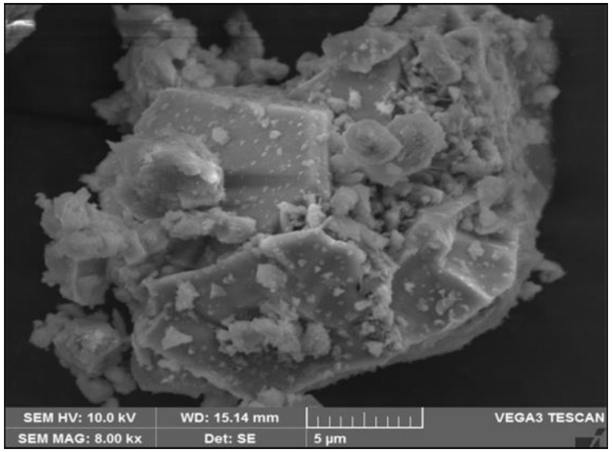
For additional performance improvement →

Nano mineral Admixtures
Ultrafine Silica
Wallostonite
Carbon tubes

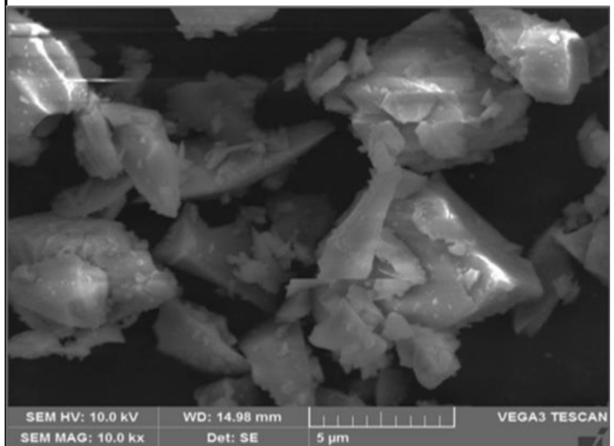
- Particle size distribution of SCMs for Improved packing efficiency of Binder system.
- Finer particles occupying voids left by larger particles.



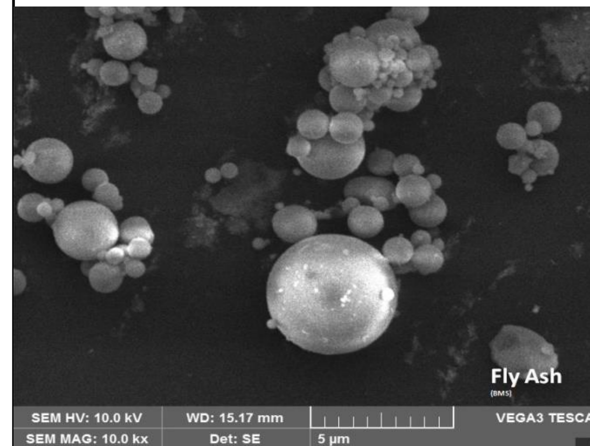
- Particle Morphology of finer SCMs to assist pore refinement of hydrated system



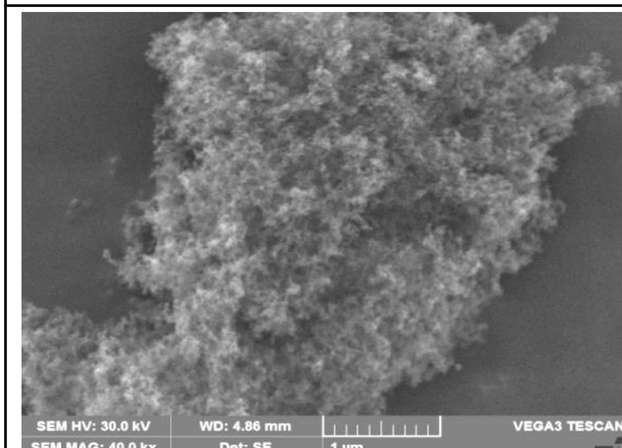
OPC



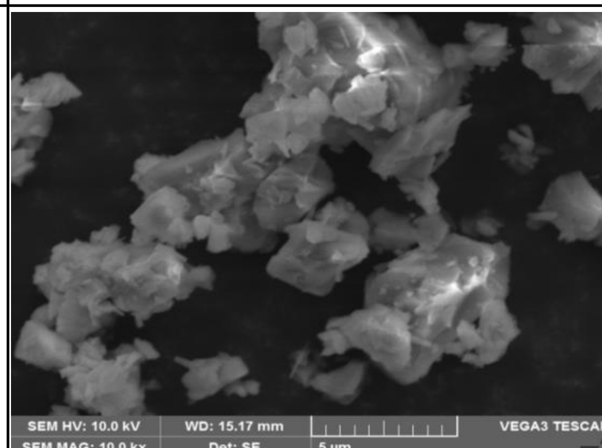
GGBS



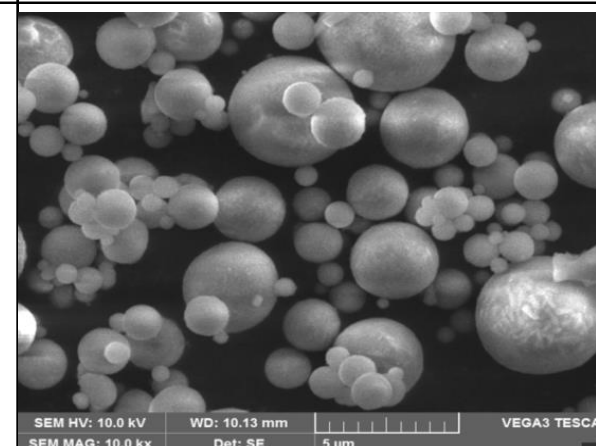
Fly ash



Ultrafine Silica



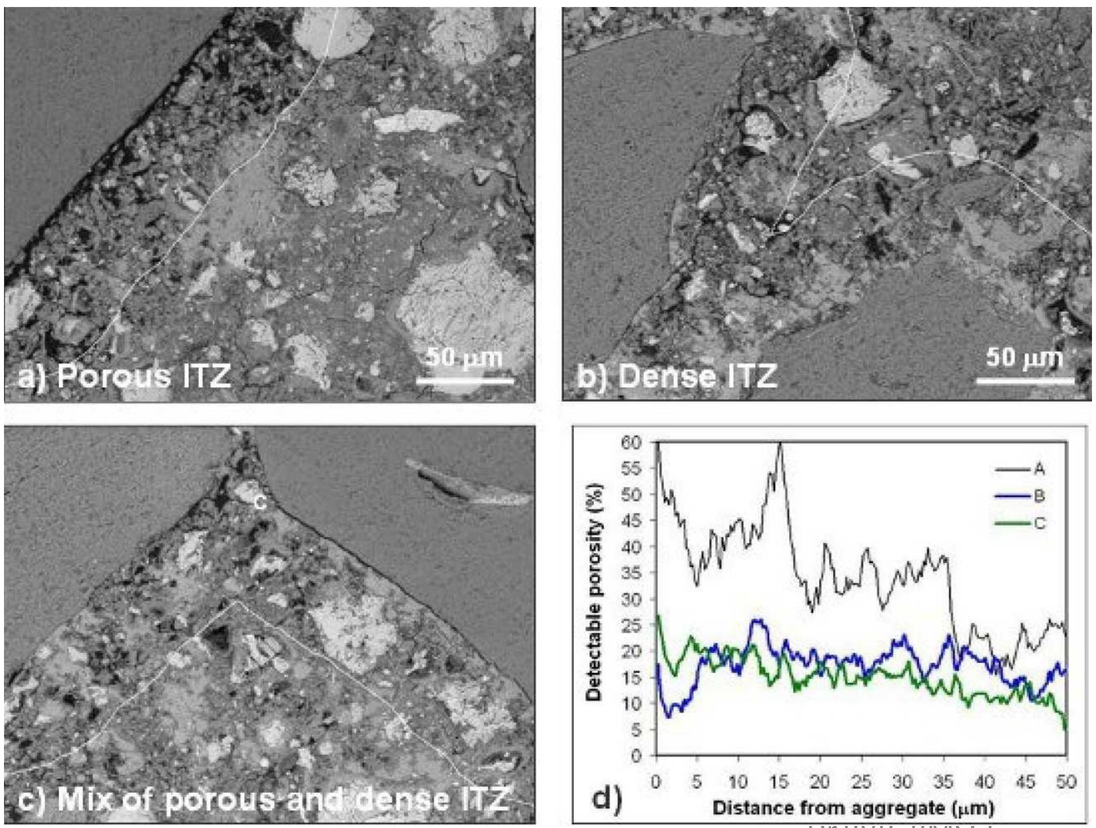
Ultrafine Slag

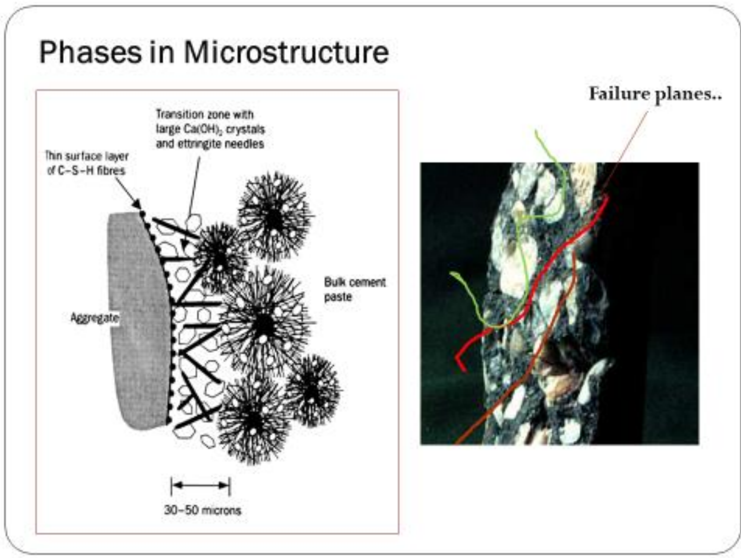


Ultrafine Fly ash

Influence of micro-cracking and Interfacial Transition Zone on transport properties

- The microcracks and continuity of porous phases have a significant influence on permeability, which increases the transport property of concrete by up to a factor of 30.





*H.S. Wong et al., Imperial College, London, 2009

Durability frame work:
ICI handbook on Concrete Durability

For proper selection of the type of SCM or a combination of different SCMs and the % replacement of ordinary Portland cement by SCM(s), it is suggested that initial lab trials are essential to assess both the compressive strengths and durability parameters at different ages.

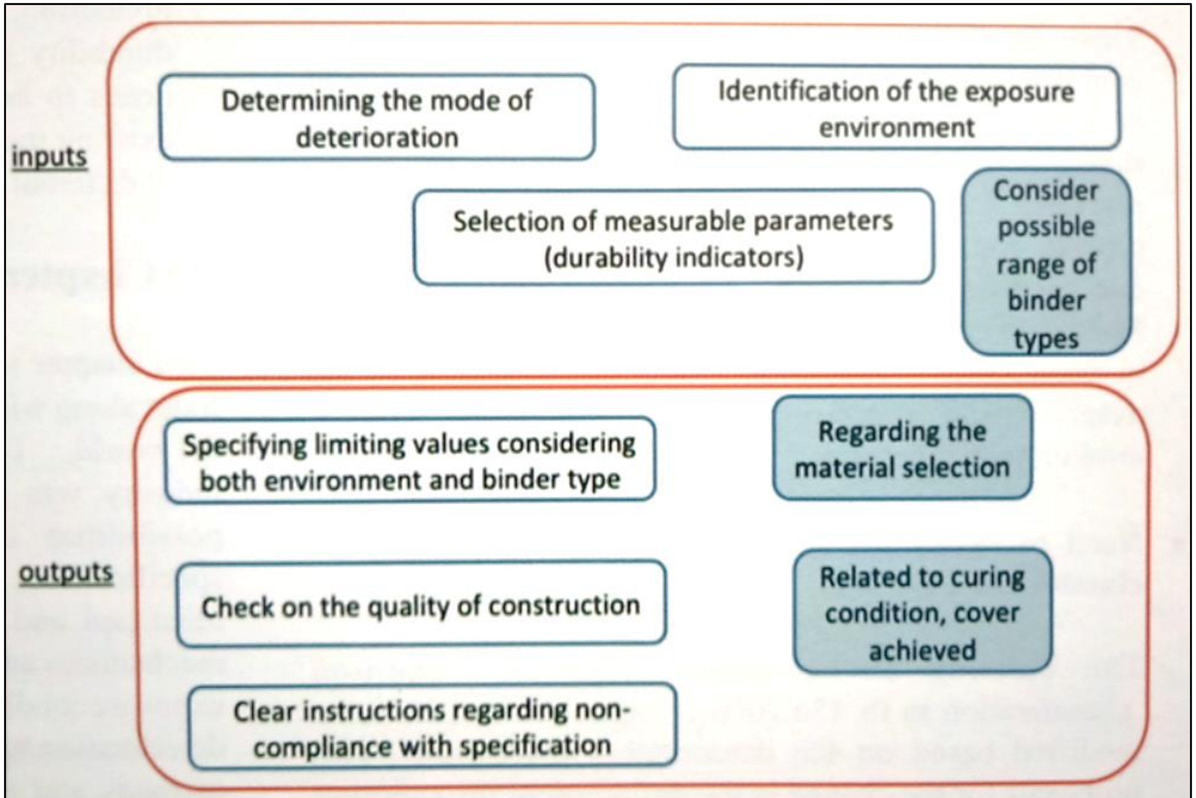


Fig. 2.1 Process of developing performance specification [15]

Mix design approach for Special concrete

- **Self compacting High strength concrete;**

28 day target strength in range of 80 to 100 MPa., in line with IS 16700 specifications.

- Two set of control mixes with Only OPC as binder and GGBS as primary SCM to replace OPC.
  - Target Performance: 28 day strength and Durability

- Ternary blend system with UFS and UFFA: (2 to 12%wt. use)
  - Target Performance: **High early strength, 60MPa (within 7 days)**.

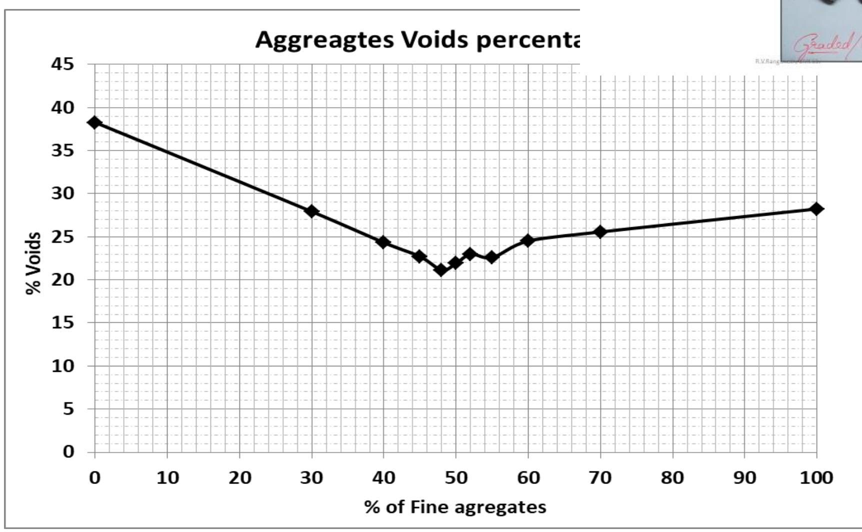
  Application areas: Tall buildings, Pre cast industry.

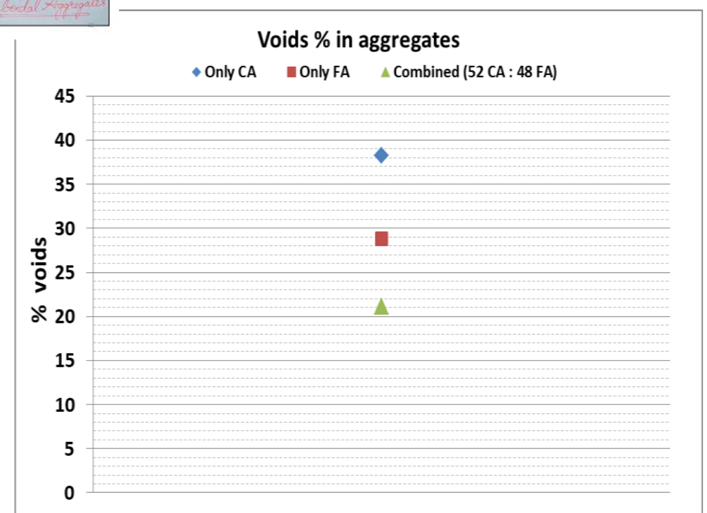
- Quaternary blend with Ultra fine silica (0.5 to 2 %wt. of OPC)
  - Target Performance: **High early strength, 30MPa (within 24 hours)**.

Mix design approach for HSC

- Aggregate packing approach

Aggregate shape, an important contributor





- Paste volume optimization- by multi mineral blend cementitious system

Details of Primary concrete mixes

Mix ID	Paste Volume (Vp)	Aggregate volume (Vag)	Vag/Vp	OPC in kg/m³	w/c	Water in kg/m³	SP, %wt of OPC
PM1	0.30	0.70	2.33	529	0.25	132	0.7
PM2	0.32	0.68	2.12	563	0.25	141	0.7
PM3	0.34	0.66	1.93	600	0.25	150	0.7
PM4	0.36	0.64	1.77	634	0.25	158	0.7
PM5	0.37	0.63	1.70	652	0.25	163	0.7
PM6	0.38	0.62	1.63	670	0.25	167	0.7
PM7	0.39	0.61	1.56	686	0.25	171	0.7
PM8	0.40	0.60	1.50	705	0.25	176	0.7
PM9	0.42	0.58	1.38	740	0.25	185	0.7
PM10	0.44	0.56	1.27	775	0.25	194	0.7

10 mixes following incremental Paste volume with OPC as binder in the set proportion of Aggregate combination.

Optimal mix and range of paste volume selected by evaluating satisfactory target strength parameter by 28 days.

Details of Binary mixes

Mix	OPC kg/m^3	GGBS kg/m^3	Total binder	w/b	Water kg/m^3	Vp	Vag	SP, %wt. of b	% OPC	%GGBS
C1G1	350	266	616	0.25	154	0.36	0.64	0.7	56.8	43.2
C1G2	350	282	632	0.25	158	0.37	0.63	0.7	55.4	44.6
C1G3	350	299	649	0.25	162	0.38	0.62	0.7	53.9	46.1
C1G4	350	315	665	0.25	166	0.39	0.61	0.7	52.6	47.4
C1G5	350	332	682	0.25	170	0.40	0.59	0.7	51.3	48.7
C2G1	400	219	619	0.25	154	0.36	0.64	0.7	64.6	35.4
C2G2	400	235	635	0.25	159	0.37	0.63	0.7	63.0	37.0
C2G3	400	252	652	0.25	163	0.38	0.62	0.7	61.3	38.7
C2G4	400	268	668	0.25	167	0.39	0.61	0.7	59.9	40.1
C2G5	400	285	685	0.25	171	0.40	0.59	0.7	58.4	41.6
C3G1	450	172	622	0.25	155	0.36	0.64	0.7	72.3	27.7
C3G2	450	188	638	0.25	159	0.37	0.63	0.7	70.5	29.5
C3G3	450	205	655	0.25	163	0.38	0.62	0.7	68.7	31.3
C3G4	450	222	672	0.25	168	0.39	0.61	0.7	67.0	33.0
C3G5	450	238	688	0.25	172	0.40	0.60	0.7	65.4	34.6

15 mixes- at constant w/b ratio and varying proportion of OPC to GGBS for required Paste volume;

OPC restricted at 3 quantities 350, 400 and 450 kg/m^3

Optimal mix, for ternary blending, selected by evaluating satisfactory target strength parameter by 28 days.

-- Minimum of 400kg/m^3 necessary for HSC > 80 Mpa --

Comparison of Primary and Binary optimal mixes for Specific High performance Criterions.

Mix PM6 and Mix C2G2 were selected based on the compressive strength observations for evaluating other selected HPC characteristics.

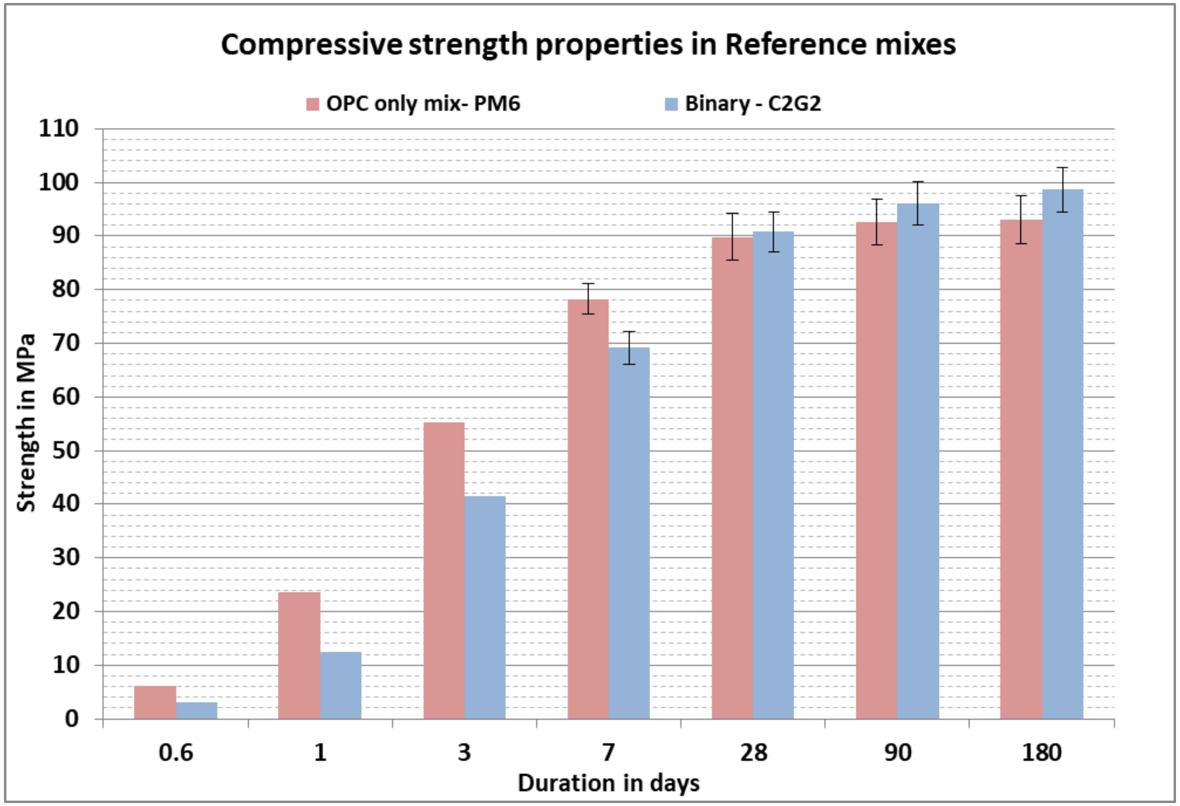
PM6

OPC alone as binder
W/b= 0.25
Optimal paste volume= 0.37
Total binder= 650 kg/m^3

C2G2

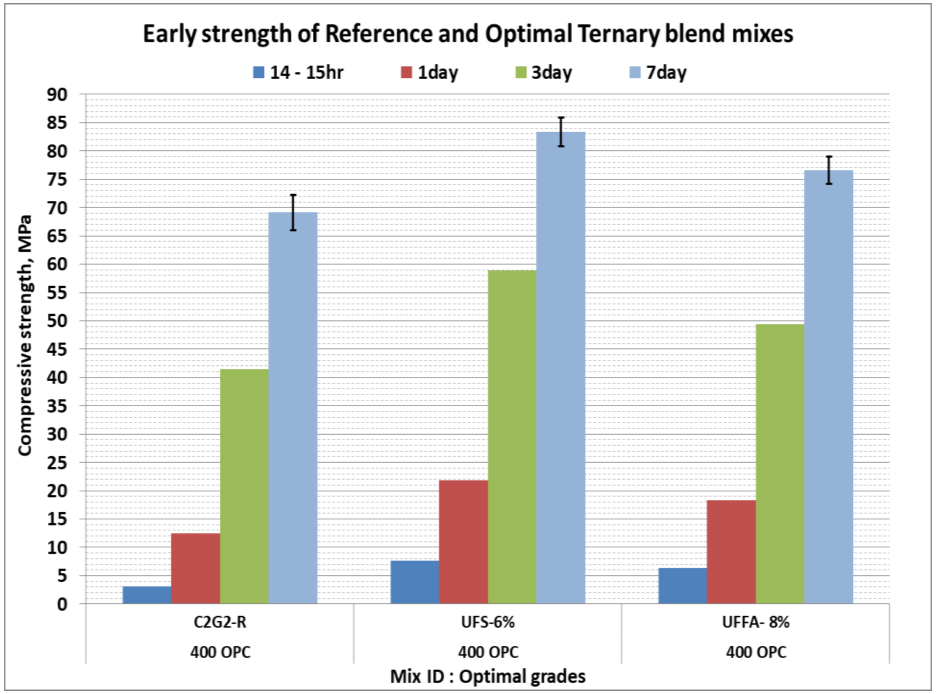
OPC and GGBS as binder
W/b= 0.25
Optimal paste volume= 0.37
Total binder= 635 kg/m^3
(400 OPC + 235 GGBS)
i.e., 37% of GGBS

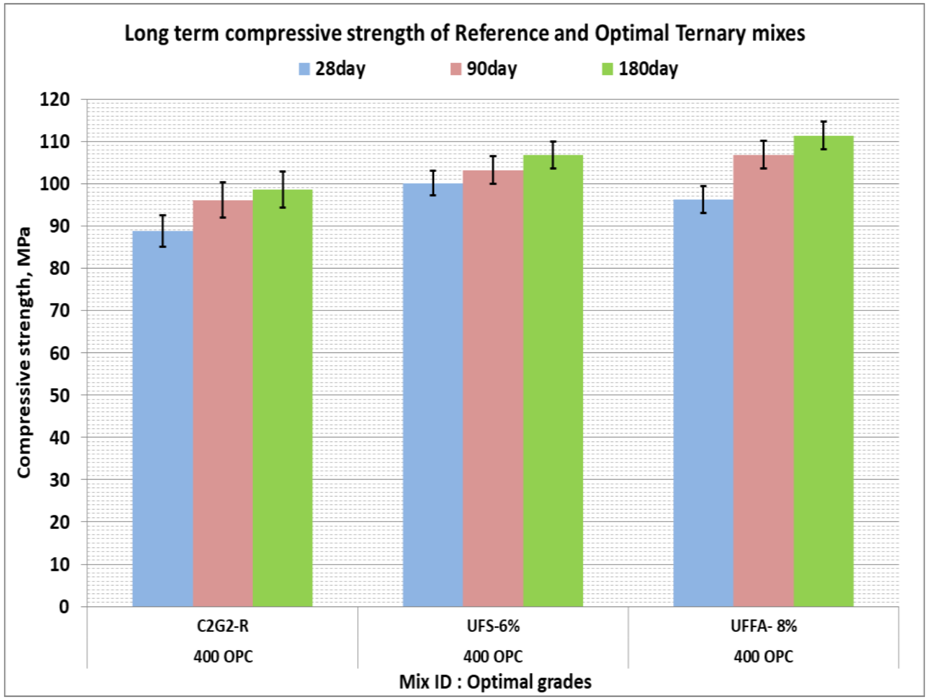
Compressive strength parameters for evaluated mixes



- Strength criteria was satisfactorily achieved for both control mixes
- GGBS replacing OPC clearly indicates reduction in early strength development and improvement beyond 28 days compared to only OPC concrete mix.

Micro mineral admixtures role

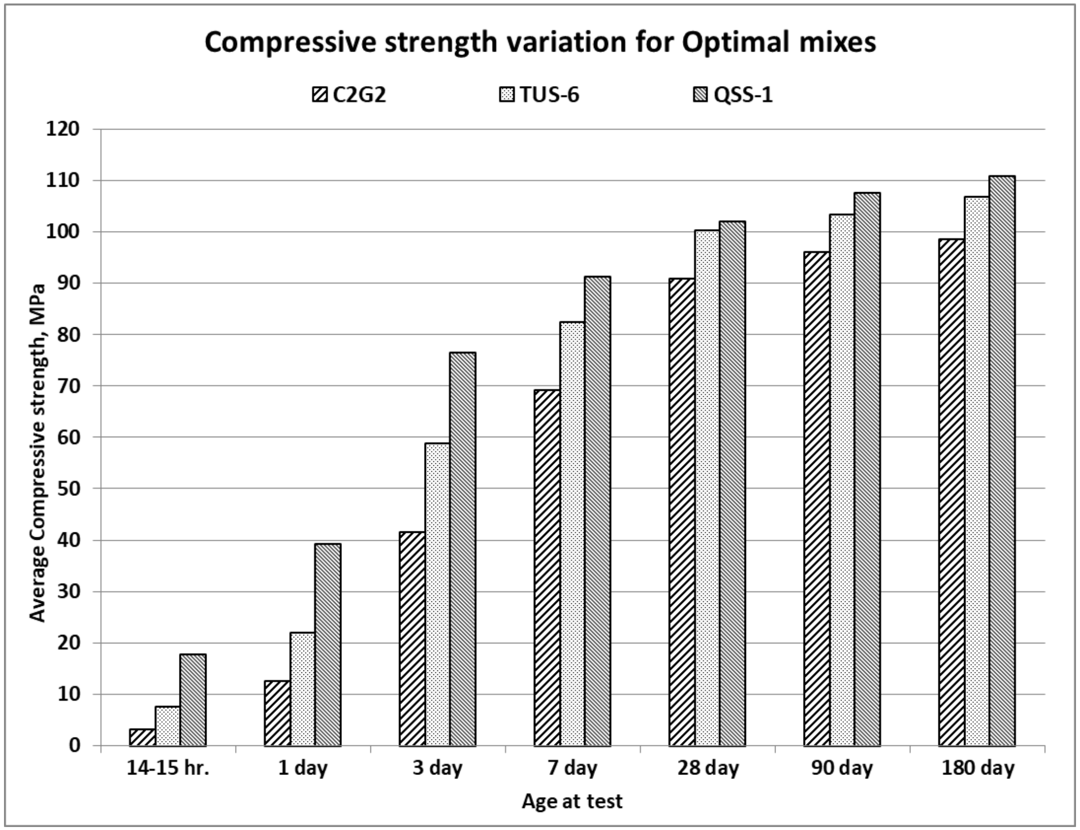




- *For the intended performance criteria of High early strength development: UFS seemed to be better option*

Nano mineral admixtures role

- Ultrafine Silica blended with Ultra fine slag for potential early strength enhancement-within 24 hours



- Mix ID
  - C2G2: Binary with OPC+GGBS
  - TUS-6: UFS blend at 6%
  - QSS-1: UFSi blend at 1%
- High early Strength requirements achieved at 38MPa in 24hours for quaternary blend
- UFS+UFSi selected to be potential combination for High early strength concrete

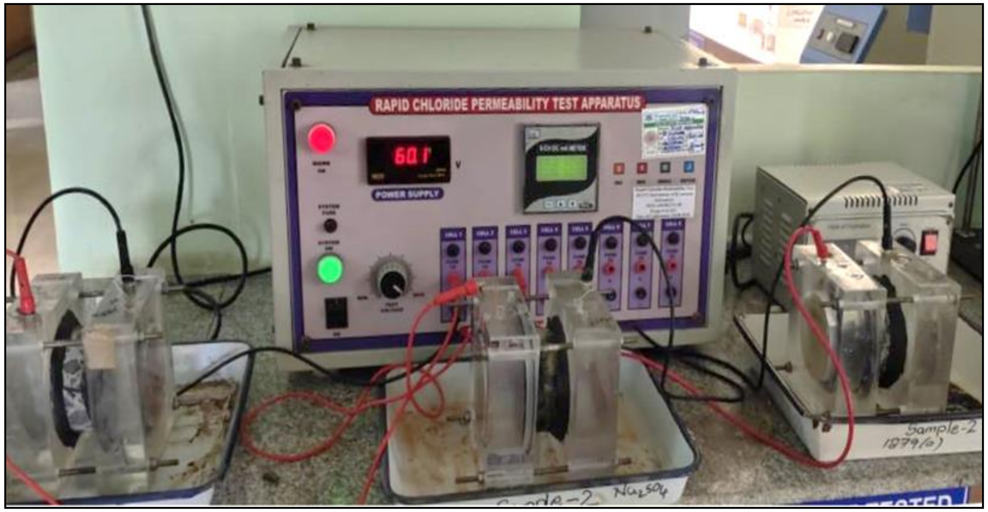
-- The concern now is for durability aspects--

Durability studies

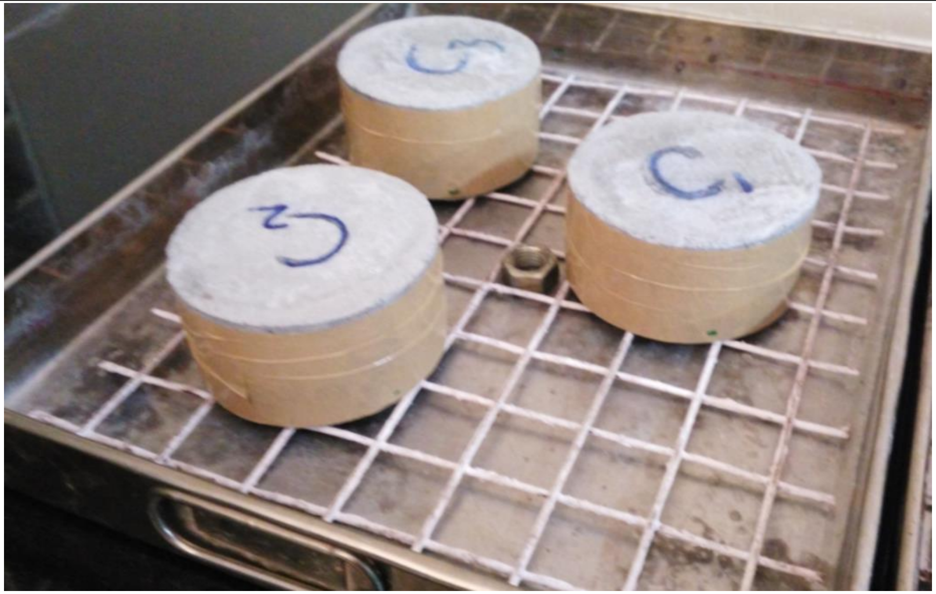
Important Durability indices for special concrete mixes

- RCPT
- Water Permeability
  - Under high pressure
  - Capillary rise
- Shrinkage behaviour

Durability index:
RCPT:
ASTM C1202-12



Durability index:
Water permeability:
DIN 1048(5)

<u>Durability index:</u> **Sorptivity test:** ASTM- C 1585-04	
<u>Shrinkage test</u> ASTM C1581 Shrinkage ring test	

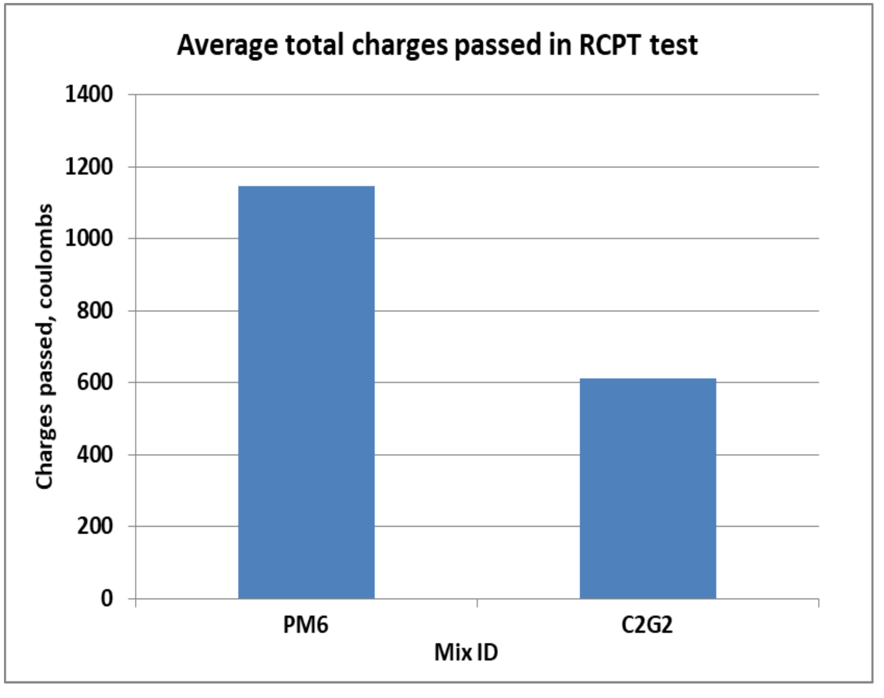
Durability indices:
For Primary and Binary blend system

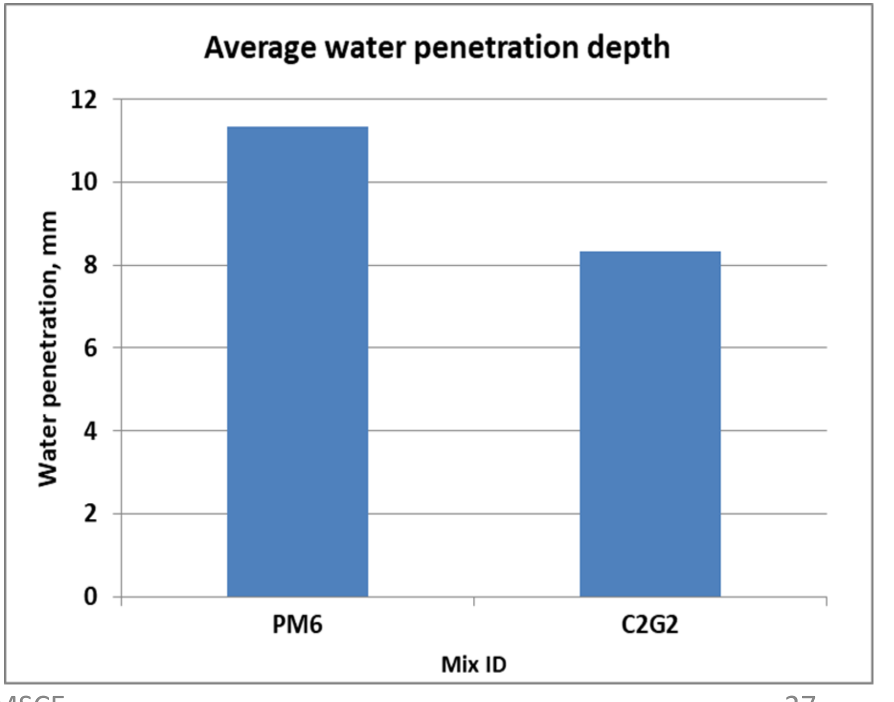
RCPT

Mix ID	Binder	Avg. charges passed, Coulombs	Chloride ion penetrability class as per ASTM C1202
PM6	OPC	1145	Low
C2G2	OPC+ GGBS	610	Very low

Water Permeability

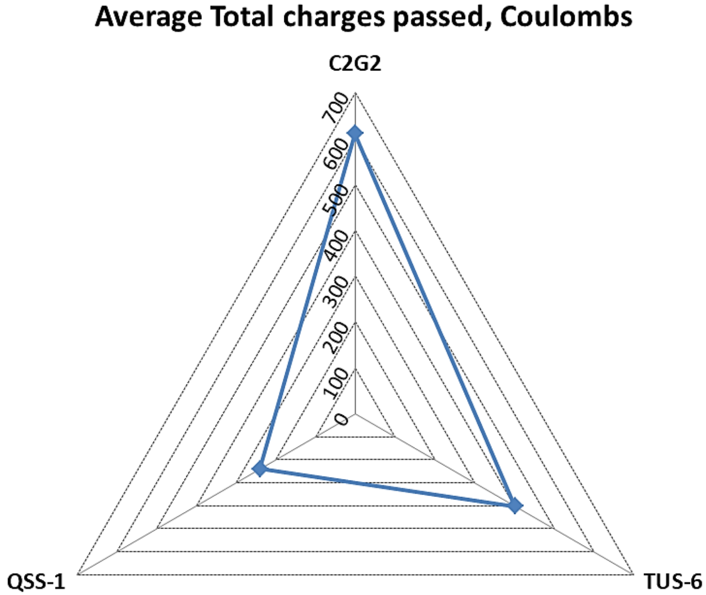
Mix ID	Average. Water penetration, mm
PM6	11.2
C2G2	8.4





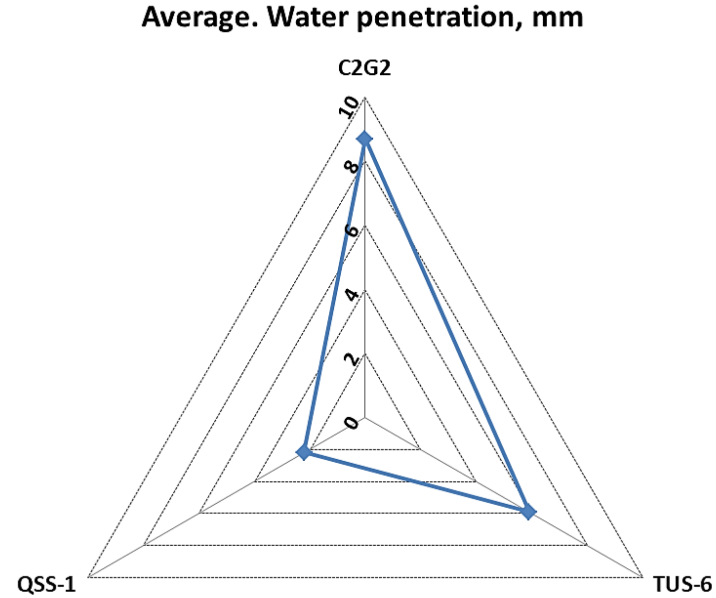
Durability indices:
For Ternary and Quaternary blend system

RCPT



Mix ID	Binders	Avg. charges passed, Coulombs	Chloride ion penetrability
C2G2	OPC+ GGBS	610	Very low
TUS-6	OPC+ GGBS+UFS	402	Very low
QSS-1	OPC+ GGBS+ UFS+UFSi	240	Very low

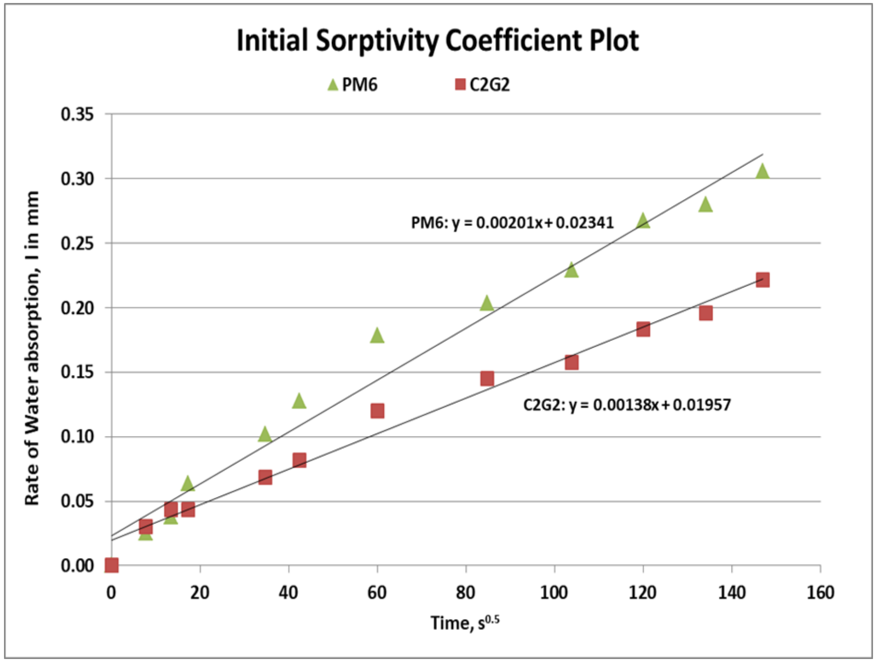
Water Permeability

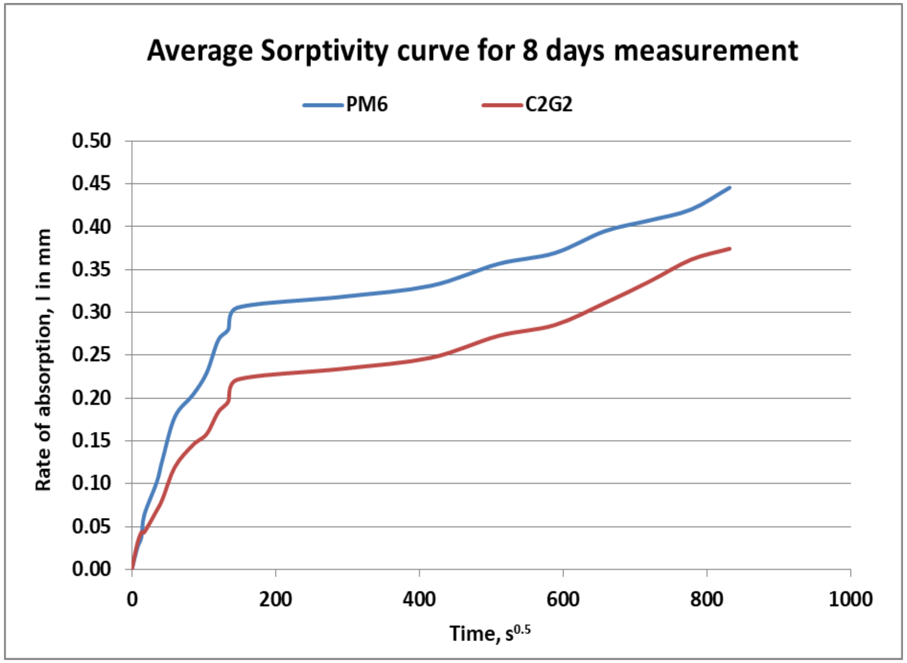


Mix ID	Binders	Avg. Water penetration, mm
C2G2	OPC+ GGBS	8.4
TUS-6	OPC+ GGBS+UFS	5.9
QSS-1	OPC+GGBS+ UFS+UFSi	2.5

Sorptivity test

Mix ID	Binder	Initial rate of Sorptivity Coefficient, $\times 10^{-6} mm/s^{0.5}$	Secondary rate of Sorptivity Coefficient, $\times 10^{-6} mm/s^{0.5}$
PM6	OPC	2010	320
C2G2	OPC+ GGBS	1391	272



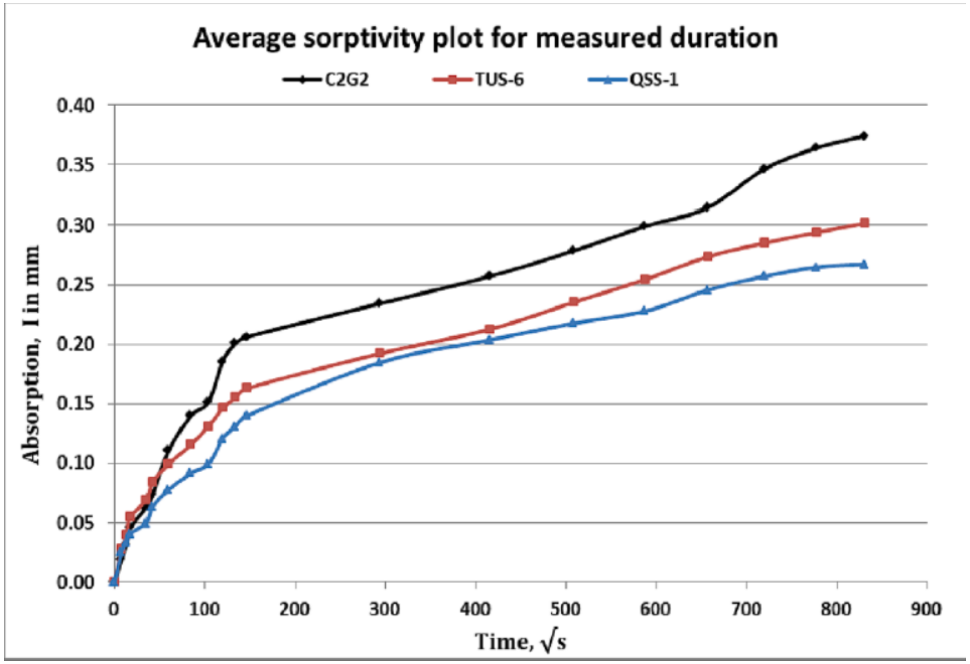


- Soprtivity coefficients, both initial and secondary, reduced to considerable extent for replacement of OPC with GGBS.
- Indicative of reduction in transport mechnism for ingress of external agents into concrete matrix

Sorptivity test
Ternary and Quaternary blend mixes

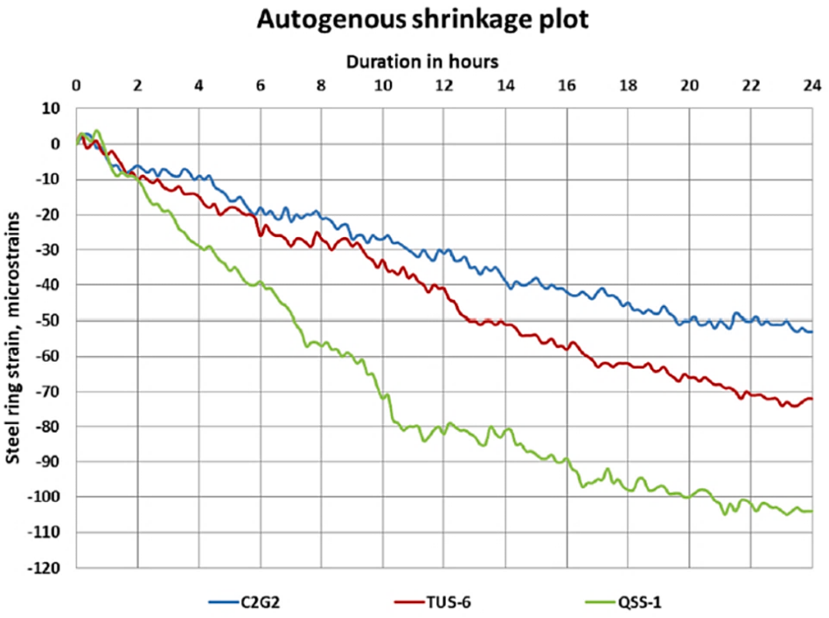
Sorptivity coefficients of optimal mixes.

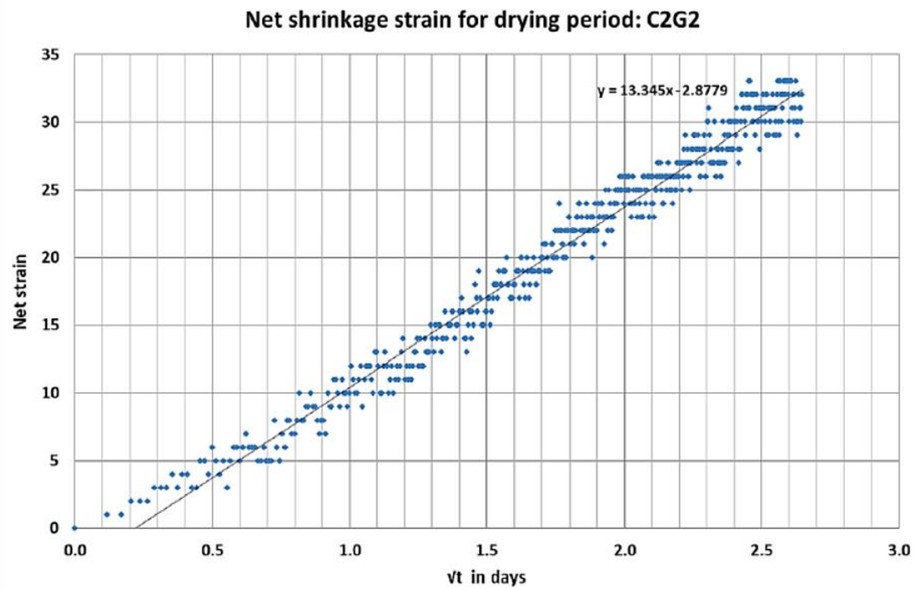
Mix ID	Initial Sorptivity Coefficient, $\times 10^{-6}$ mm/s$^{0.5}$	Secondary Sorptivity Coefficient, $\times 10^{-6}$ mm/s$^{0.5}$
C2G2	1391	272
TUS-6	1013	214
QSS-1	857	162

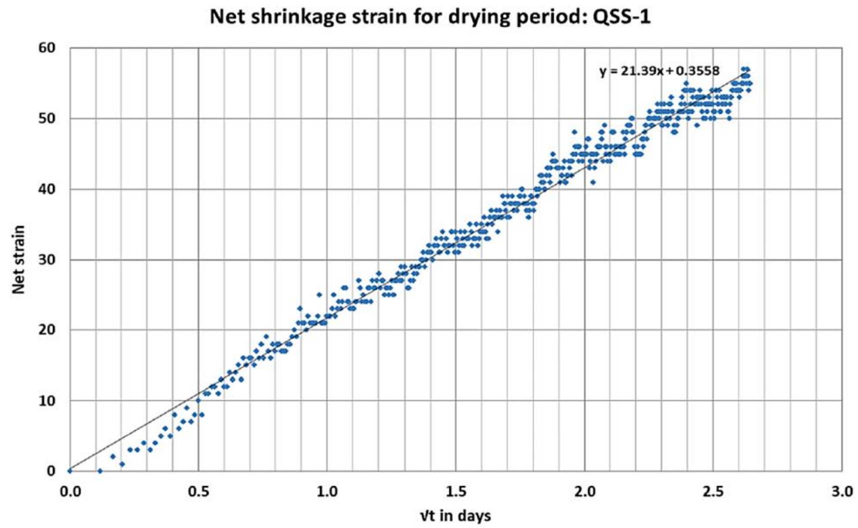


*Shamanth and R V Ranganath, CBM, 2023

Shrinkage behaviour at early age: up to 7 days







Shrinkage behaviour at early age

Mix ID	24 h Autogenous Shrinakge (As), microstrains	7 day Drying Shrinakge (Ds), microstrains	Total shrinkage, (As + Ds), microstrains	Shrinkage induced stress rate during drying, MPa/day	Potential risk of cracking
C2G2	53	36	89	0.18	Moderate High
TUS-6	72	49	121	0.25	Moderate High
QSS-1	104	56	160	0.29	Moderate High

TABLE X1.1 Potential for Cracking Classification

Net Time-to-Cracking, t_{cr}, days	Average Stress Rate, S (MPa/day)	Average Stress Rate, S (psi/day)	Potential for Cracking
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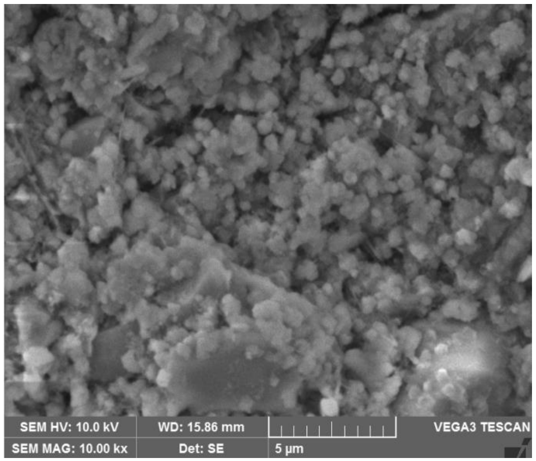
$7 < t_{cr} \le 14$	$0.17 \le S < 0.34$	$25 \le S < 50$	Moderate-High
$14\ t_{cr} \le 28$	$0.10 \le S < 0.17$	$15 \le S < 25$	Moderate-Low
$t_{cr} > 28$	$S < 0.10$	$S < 15$	Low

- *Shrinkage induced potential risk of cracking increases* with multi mineral blend system with a target of *High early compressive strength.*
- In particular, Autogenous shrinkage is of concern when ultra fine mineral admixtures are used.
- **Early curing practice** could be a remedy to ensure overall performance of concrete

Microstructure refinement by secondary hydration and pore filling ability

<table>
<tr><th>Age / Mix</th><th>1 day</th><th>7 day</th><th>28 day</th></tr>
<tr><td>OPC
+
GGBS</td>
<td>
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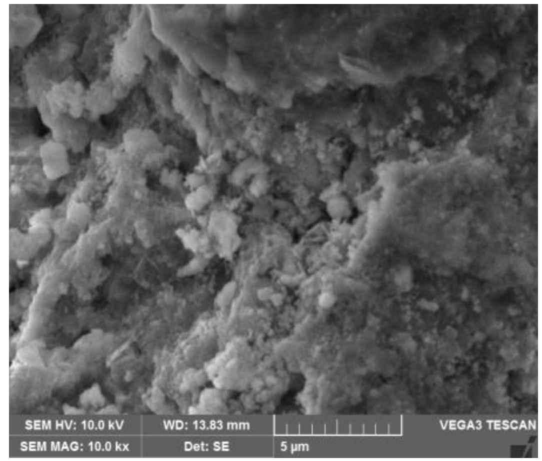
<td>
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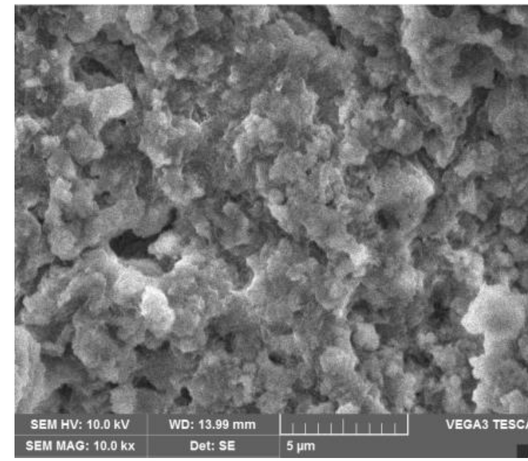
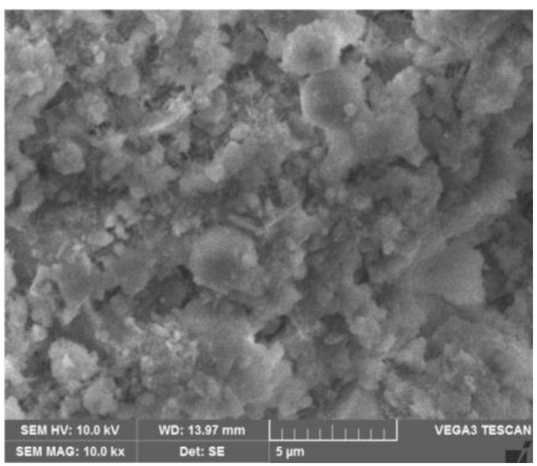
<td>
</td></tr>
<tr><td>OPC
+
GGBS
+
<u>UFFA</u></td>
<td>
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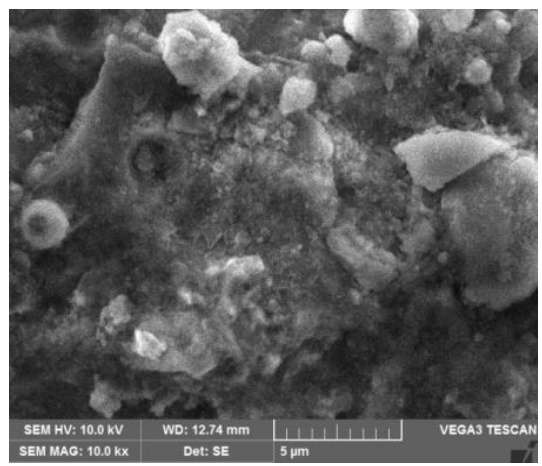
<td>
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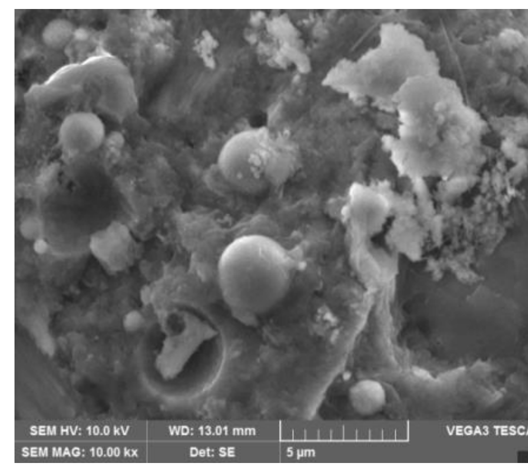
<td>
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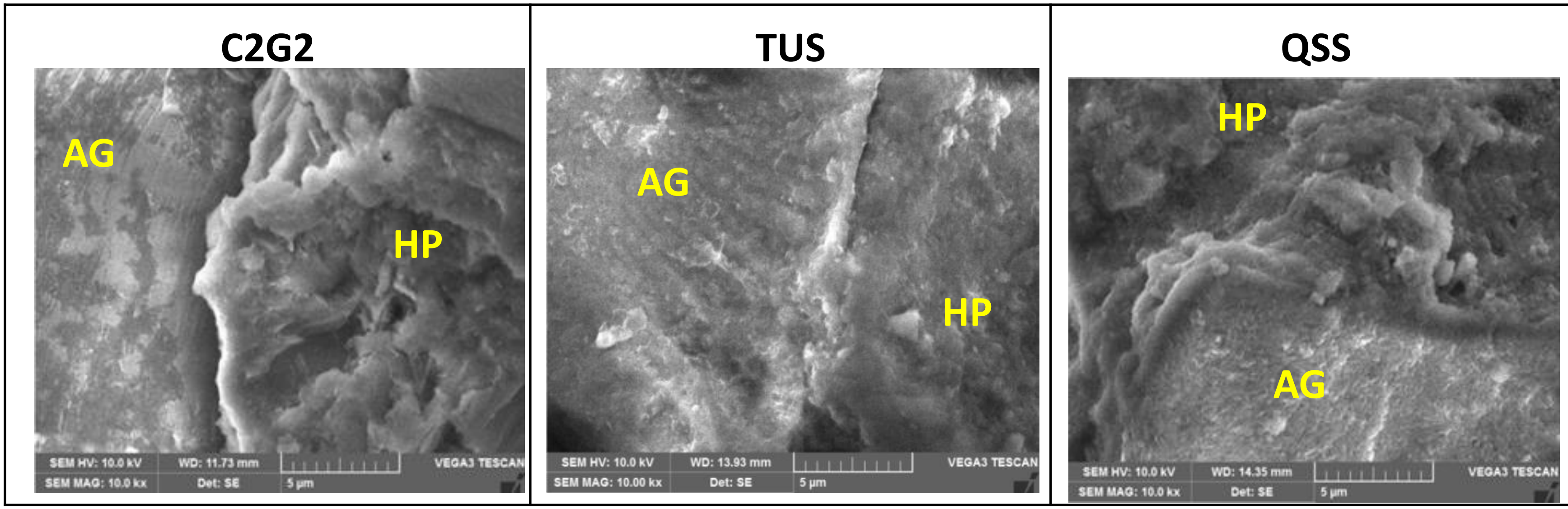
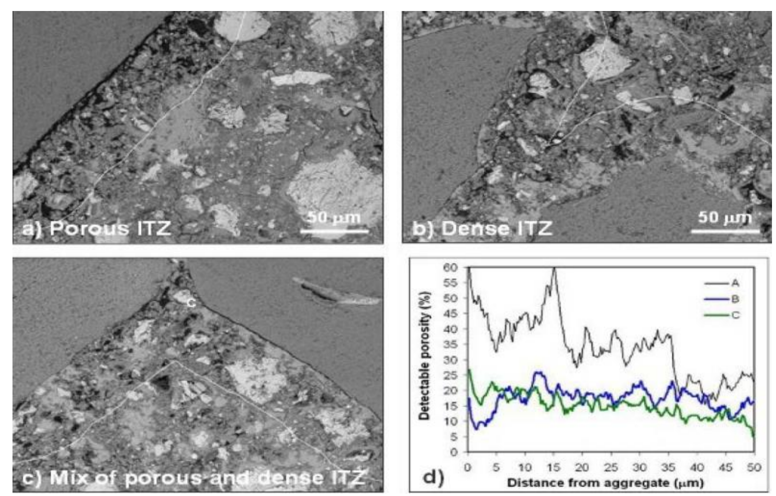
Improvement at ITZ for multi-mineral blend resulting in better bonding integrity of Hydrated paste (HP) and Aggregates (AG)





Case study-1

- Construction of Data Centre, Whitefield, Bengaluru.

  Client: M/s. Bearys Properties and Developments Pvt Ltd.

  Performance Requirement: **M60** grade and **High workability**

  Suggested option:

  Self Compacting Concrete

  Activities conducted:

  – Mix design development using Ggbs

  – Testing for fresh properties SCC (J-ring, V funnel, L box)

  – Durability evaluation: Water Permeability test.

Footing Concreting | Pouring and Compaction monitored

Case study-2

- Construction of Auditorium Block, PES south campus, Bengaluru.

  Client: M/s. PES Constructions.

  Performance Requirement: **M50** grade and **High workability, Temp control.**

  Element details: RC Beams of **1.2 m x 1.9 m** sides and 38 m length.

  Suggested option:

  Self Compacting Concrete with 40% OPC replaced by GGBS

  Activities conducted:

  – Mix design development

  – Thermocouples fixed at various pre-determined locations for monitoring concrete temperature during hydration.

Peak Ambient temperature		23°C ±2		
Thermocouple depth from the top surface	**Thermocouple ID**	**Peak temperature °c**	**Time for Peak temperature**	**Thermal gradient**
250 mm	T3C3, 600mm from surface	**59.2**	31st hour	36.2
500 mm	T3C2, 600mm from surface	**68**	31st hour	45
950 mm	T1C2, 150 mm from surface	**61.3**	30th hour	38.3
950 mm	T1C3, 150 mm from surface	**59.1**	31st hour	36.1
950 mm	T1C4, 150 mm from surface	**62.5**	32ndhour	39.5
950 mm	T2C1, 300 mm from surface	**64.4**	31st hour	41.4
950 mm	T2C2, 300 mm from surface	**68.7**	30th hour	45.7
950 mm	T2C3, 300 mm from surface	**67.1**	30th hour	44.1
950 mm	T2C4, 300 mm from surface	**64.3**	31st hour	41.3
1400mm	T3C4, 600 mm from surface	**69.1**	34thhour	46.1
1650 mm	T3C5, 600 mm from surface	**61.2**	34thhour	38.2

Case study-3

- JST Param, Magadi road, Bengaluru.

Client: M/s. ANP-PMC ; Sundaram Architects; SV Enterprises.

Performance Requirement:

M60 grade , **High workability, Low shrinkage**

Element details: **Large span thin Shell structure of 50 mm thickness.**

Span: 75 m x 75 m

Peak cantilever height: 22.5 m

Suggested option:

Quaternary blend concrete system with inclusion of Ultrafine slag and Microsilica. Maximum aggregate size restricted at 6.3mm

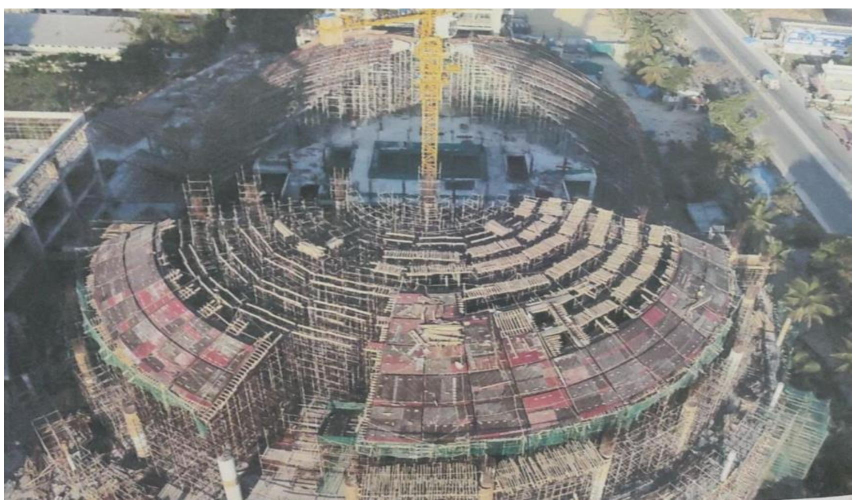
Self Compacting Concrete with flow retention up to 2 hours.

Durability evaluation suggested: Shrinkage potential, Water permeability

Activities conducted:

- Mix design development
- Strength evaluation and Flow parameters under progress
- Mock trials in progress at site for preparedness.

- Overview of the concrete shell element



Work under progress

Summary

- Durable structures needed for long term benefits.
- Sufficient options of SCMs/UFMAs and chemical admixtures now available for proportioning performance specific concrete mixes.
- Change in approach needed towards durability oriented design.
- Training the engineers and related workforce for understanding the necessities of special concrete is crucial in realizing the specific properties at site.


THANK YOU