Materials and Proportioning of High Strength Concrete

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Evolution in Concrete Technology

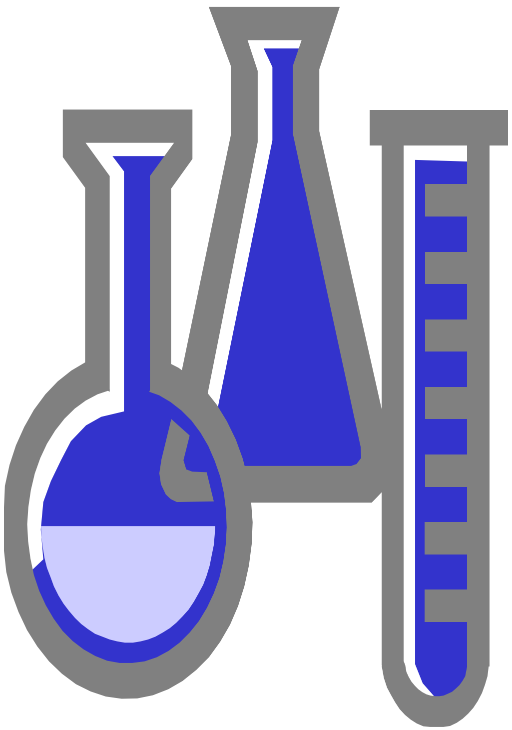
Main Evolution	Other Phases
Normal-Strength Concrete (Usual/Standard Concrete)	High Density Concrete
↓	Low Density Concrete
High-Strength Concrete	High-early Strength Concrete
↓	
High-Performance Concrete	High Volume Fly Ash Concrete
↓	
Ultra High Performance Concrete	Self Compacting Concrete
Geo Polymer Concrete	Ductal Concrete

Hydration chemistry

- Cement chemistry notation

  C=CaO, S=SiO_2, H=H_2O

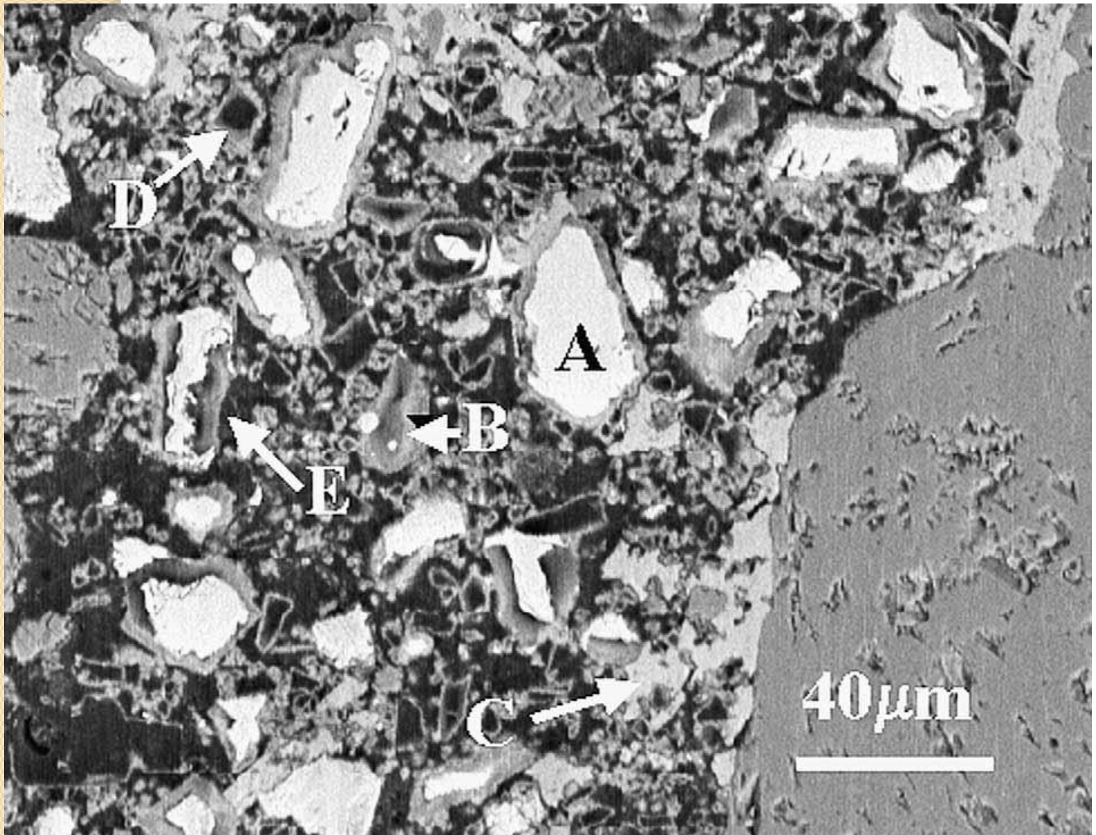
- Approximately
- $2C_3S+6H$ = $\mathbf{C_3S_2H_3}$$+3CH$
- $2C_2S+4H$ = $\mathbf{C_3S_2H_3}$$+CH$
- **C-S-H gel**
  - strength bearing phase



C-S-H gel

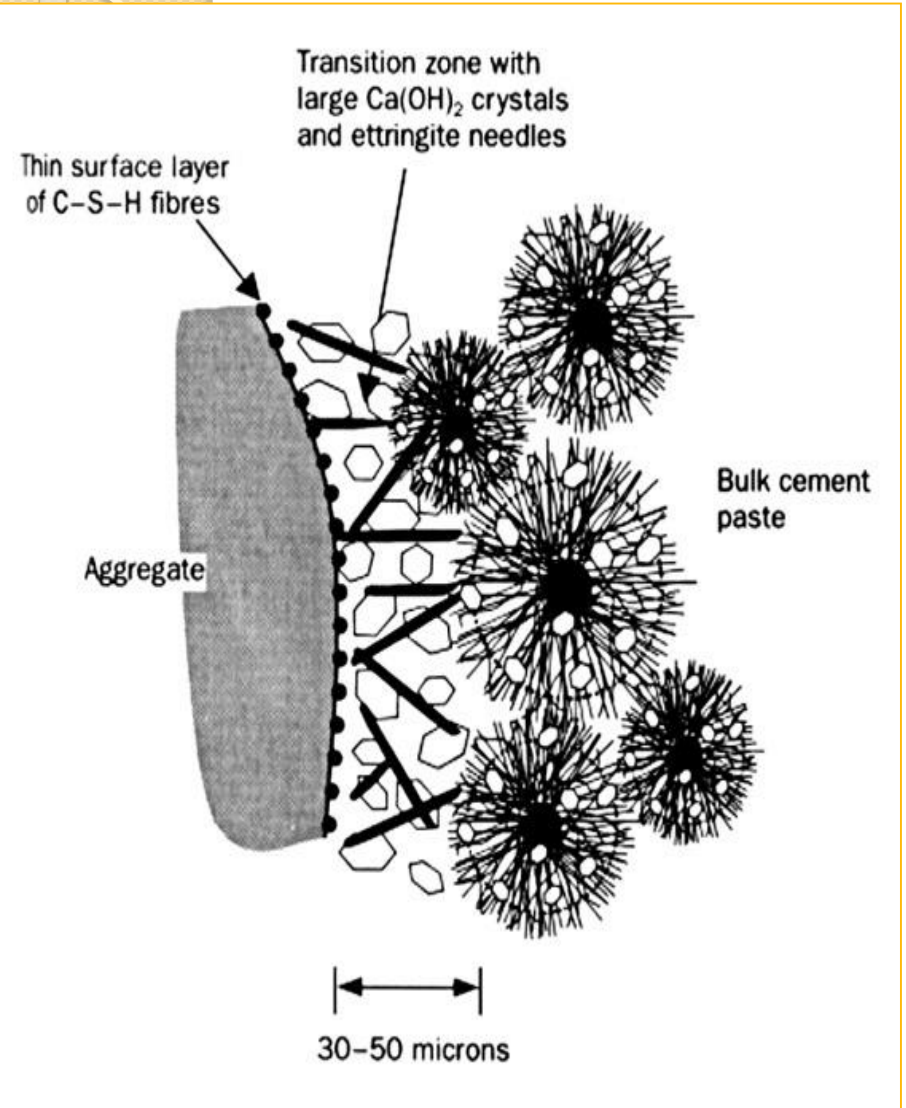
- Non-crystalline, insoluble hydrate
  - variable composition
  - complex structure: fibrillar to 'crumpled foil', a few molecules thick
  - huge surface area 100-700 m^2/g: van der Waals bonding gives strength
- Porosity controls properties
  - **10-1000 nm: capillary pores**
  - **1-10 nm: gel pores**

Microstructure

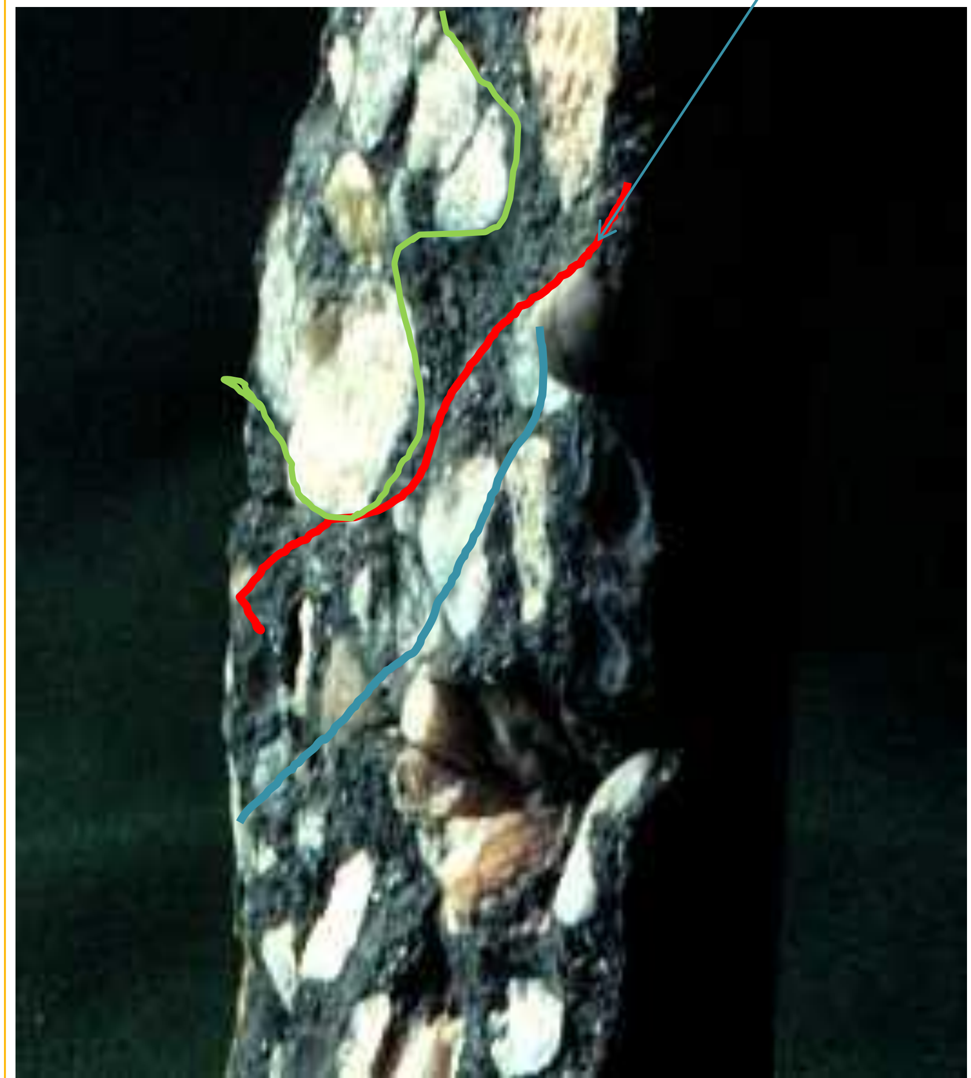


- Sidney Diamond, Purdue U., USA, 2004
- A: Unhydrated cement
- B: Inner CSH
- C: CH
- D,E: Groundmass
- **CSH too fine to see…**

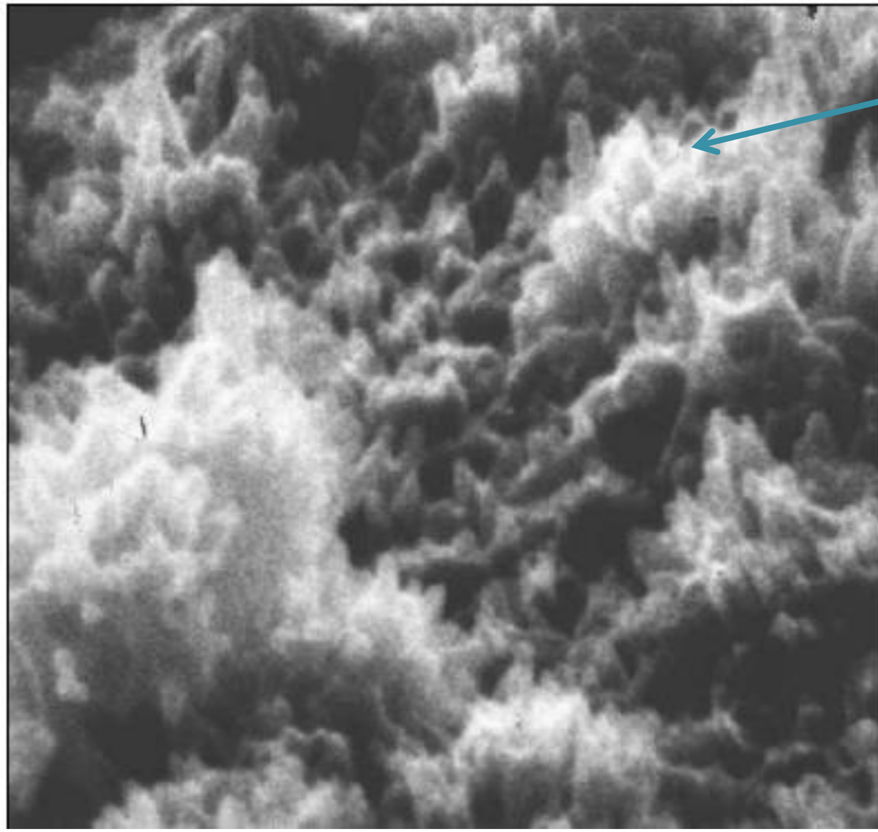
Phases in Microstructure



Failure planes..



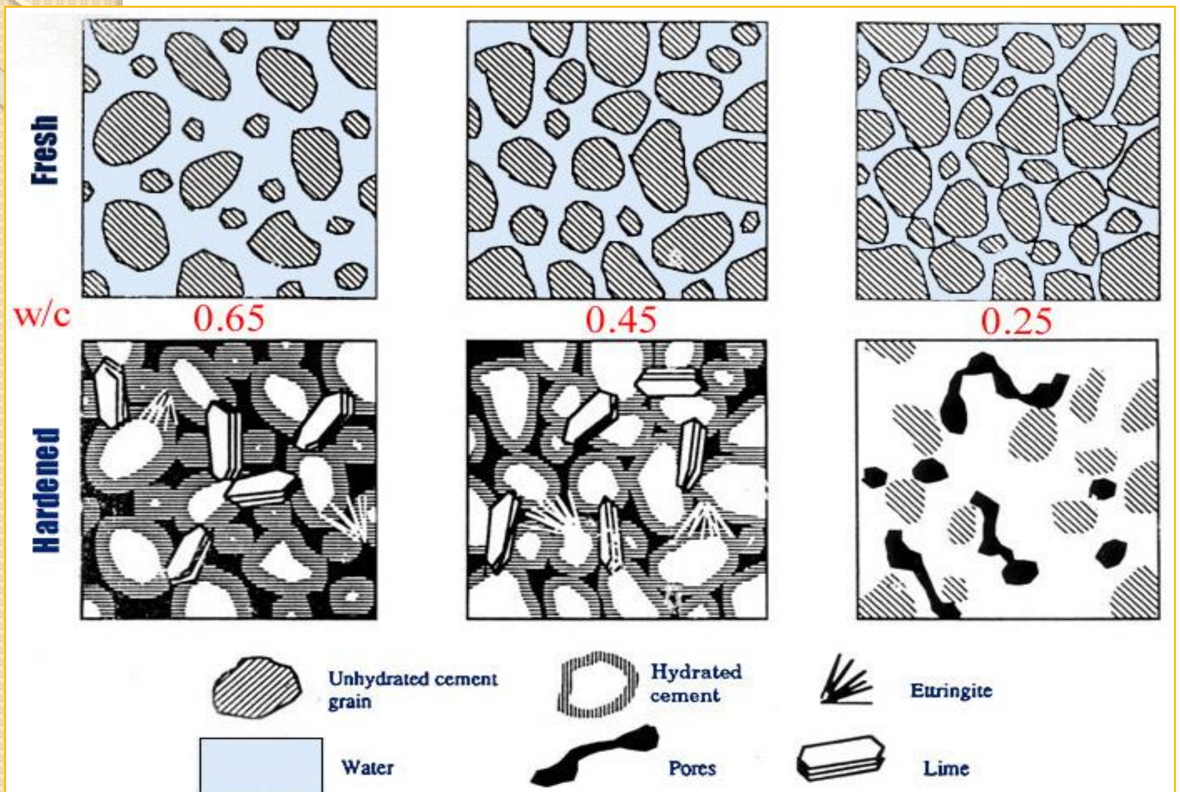
C-S-H

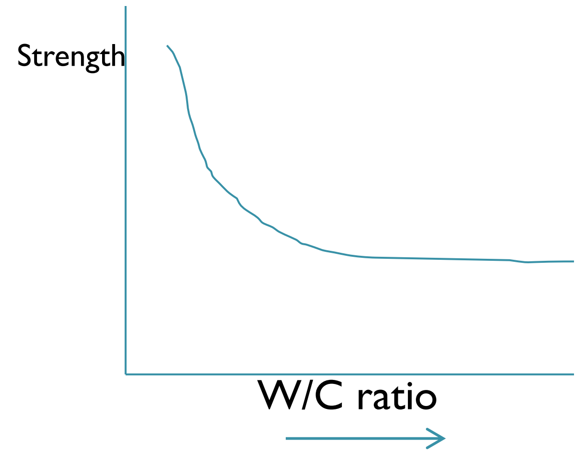


Needle like structures..

Calcium Hydroxide

Microstructure -role of Water





HSC/HPC

What is it..?

- High strength/performance concrete (HSC/HPC) with compressive strength in range of 65-100MPa (IS-10262-19, ACI committee, Singapore guidelines, Japan society of Civil Engineers)
- Strength is predominantly decided by the Compressive strength at 28days.
- Performance is governed by other specific mechanical and durability parameters of Concrete

Why HSC/HPC.?

- Changing Construction practices
- Challenging Situations for Concrete
- Faster production cycle
- Durability under severe conditions
- Longer service life
- Maintenance

What are the benefits ..?

- Resists loads that cannot be resisted by conventional concrete
- Increased strength per unit weight and unit volume
- Increased MOE which increases stability and reduces deflection.
- Higher impermeability thereby by greater durability.
- Size reduction in concrete elements with reduced dependency on steel for reinforcement.

Related Characteristics of HSC/HPC

- Greater Compressive strength/ Early strength
- Improved Flexural strength
- Higher Flexural Toughness
- Enhanced MOE
- High abrasion resistance
- Dense Hydrated phase
- Reduced pores with greater impermeability
- High Workability (SCC)

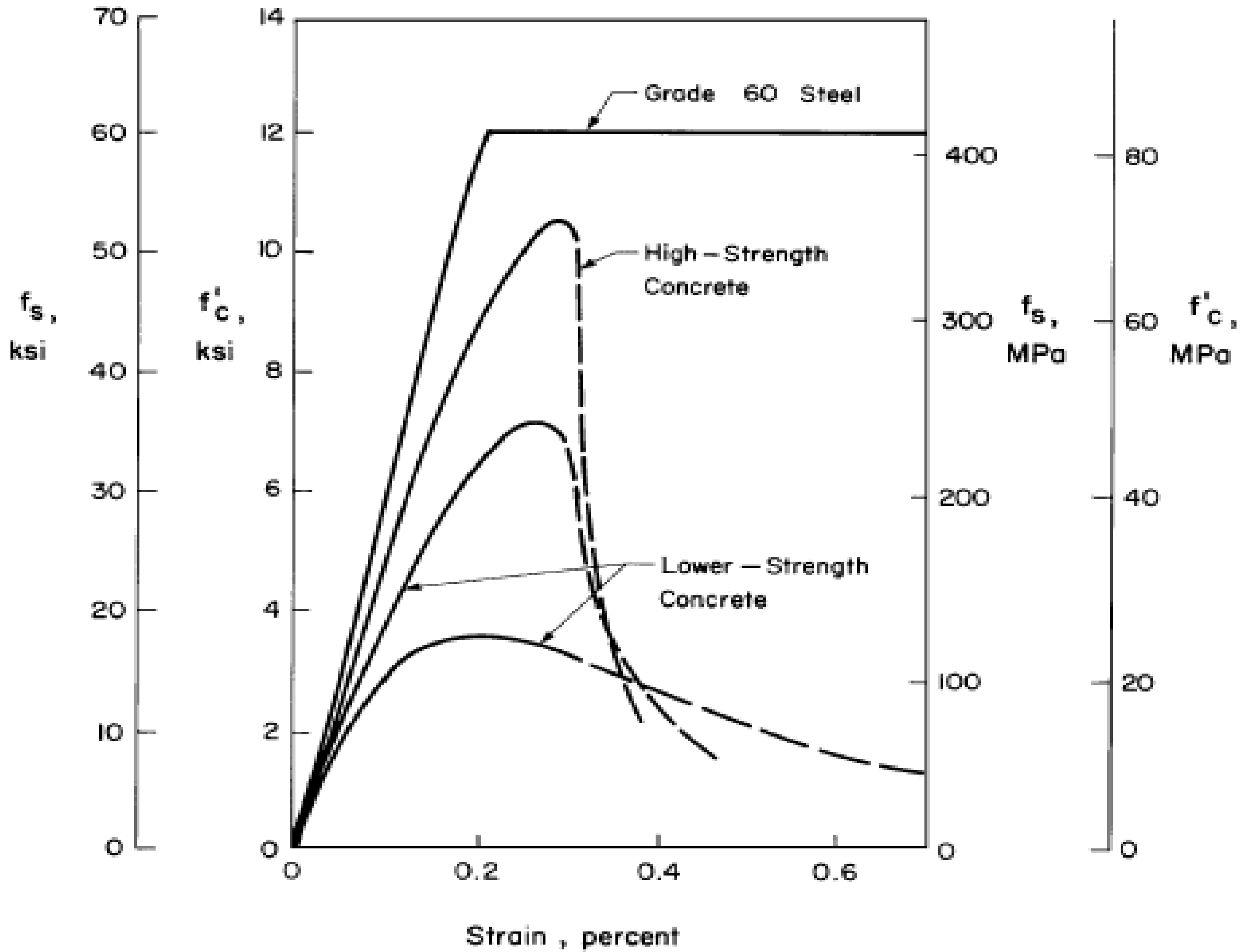


Fig. 7.1—Concrete and steel stress-strain curves.

Materials for HSC

Same materials as Conventional Concrete but at an engineered proportions.

- Cement
- Aggregates
- Mineral Admixtures
- Chemical Admixtures
- Fibers
- Ultra fine/ Nano additives

-Cement

- Cement composition and fineness is crucial to achieve HSC
- 53 grade OPC is more suitable in achieving HSC.
- Also low C_3A cements are preferable
- Special cements like Sulphate resistant cement, RHPC, LHPC can also be used in production.
- A higher OPC content cannot always lead to higher strength and hence demands addition of SCMs.

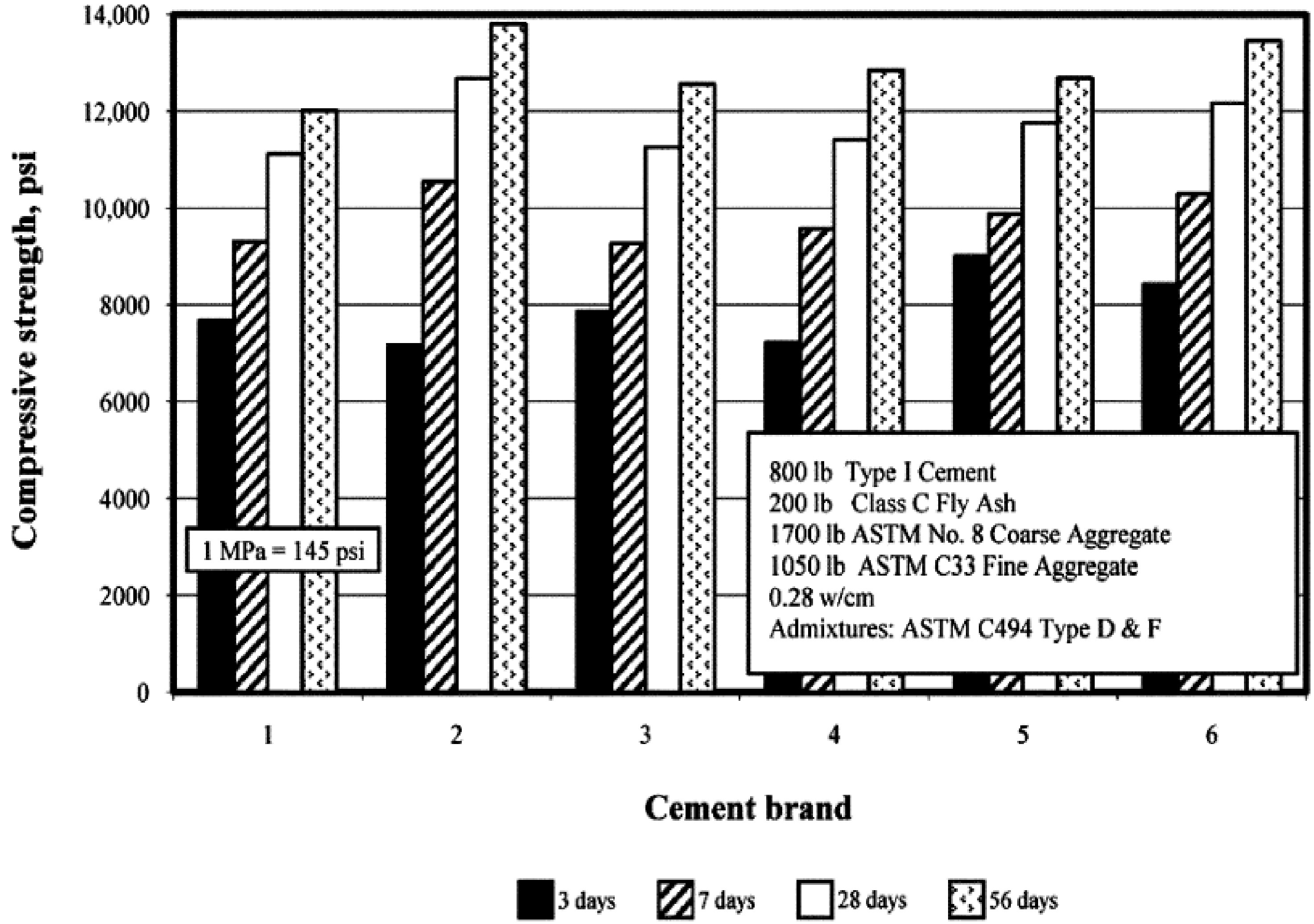


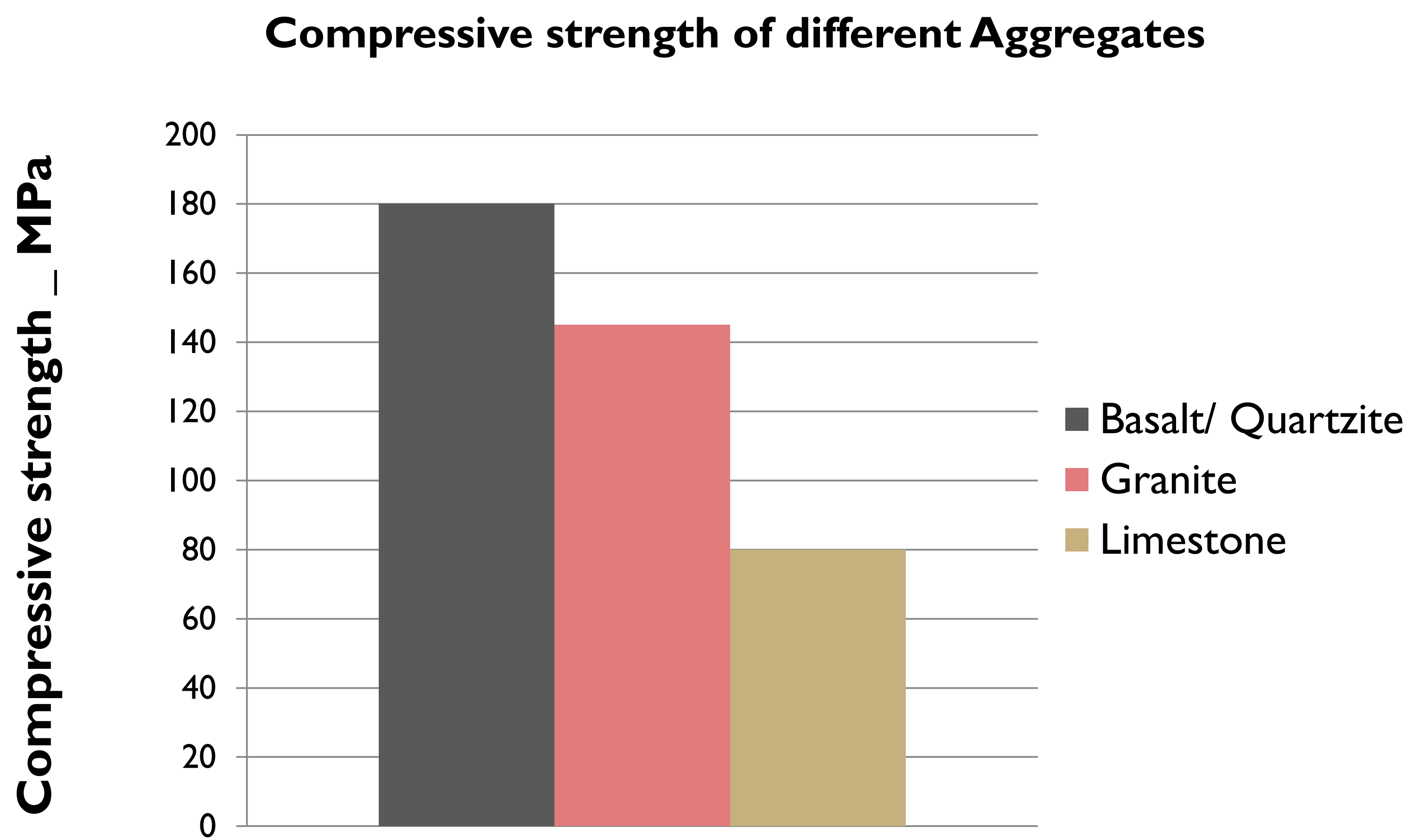
Fig. 4.1—Effects of various brands of cement on concrete compressive strength.

-Aggregates

- Aggregates can both improve and limit the property of HSC/ HPC depending on their physico-chemical properties.
- Gradation and proportioning of Fine and Coarse aggregates is equally important as their crushing value and shape.
- Maximum aggregate size is usually 12mm and can be less than 8mm based on required concrete parameters.
- However, Researchers have successfully produced strength greater than 100MPa with 20mm downsize aggregates.
- High-strength concretes have been produced using blends of manufactured and natural fine aggregates.
- IS 10262-2019 – Similar guidelines…..

Aggregate shape, an important contributor

Aggregate strength is crucial as well



(Modified from Re Ku Wu Et al., Cem and Conc Research 2001)

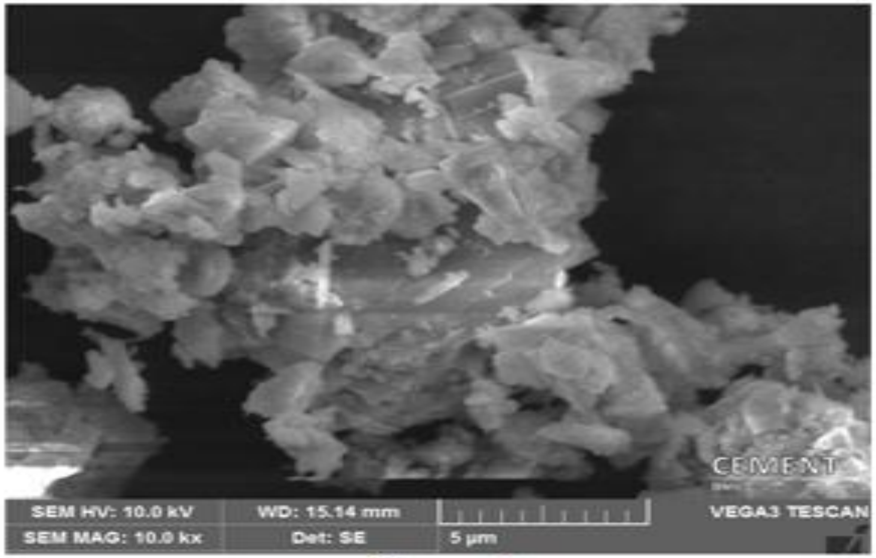
-Mineral Admixtures

- Very much essential to convert Normal Concrete into HSC and HSC to evolve into HPC.
- Silica fume, GGBS, Fly ash, Metakaolin, RHA and other natural pozzolans can be used.
- They can act as carbon footprint reducers as well as workability enhancers.
- The recommended cementitious material content is in the range of 400 to 600kg/m^3 for HSCs. (NRMCA report, CIP 33)

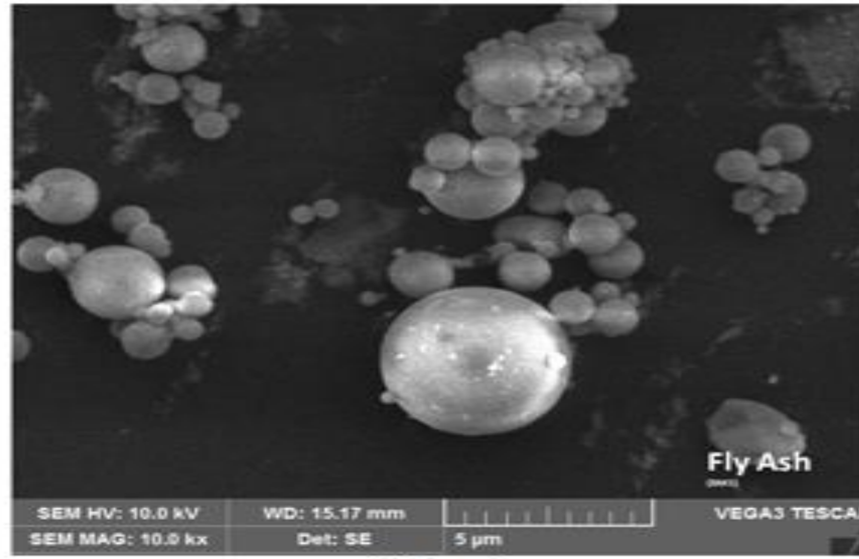
Common Mineral admixtures used in HSC

[Source: National Ready Mixed Concrete Association (NRMCA)]

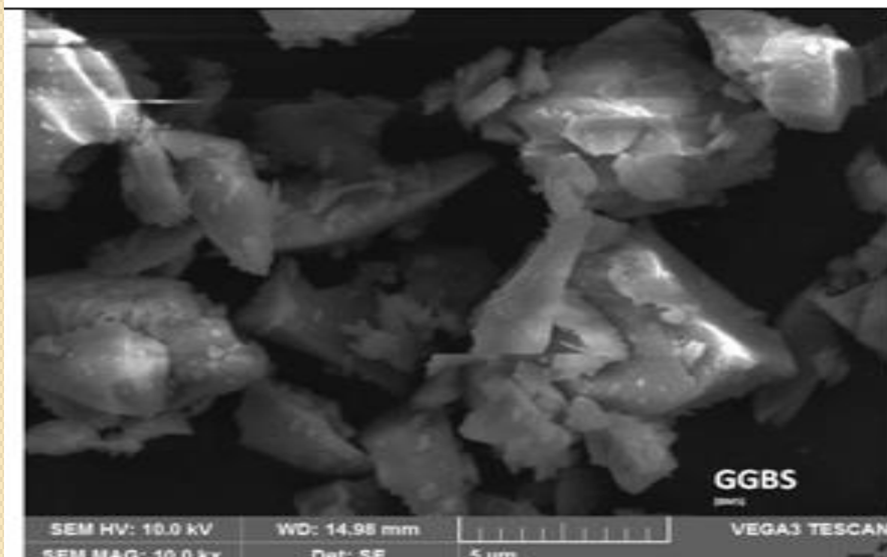
SEM profiles of Cementing materials



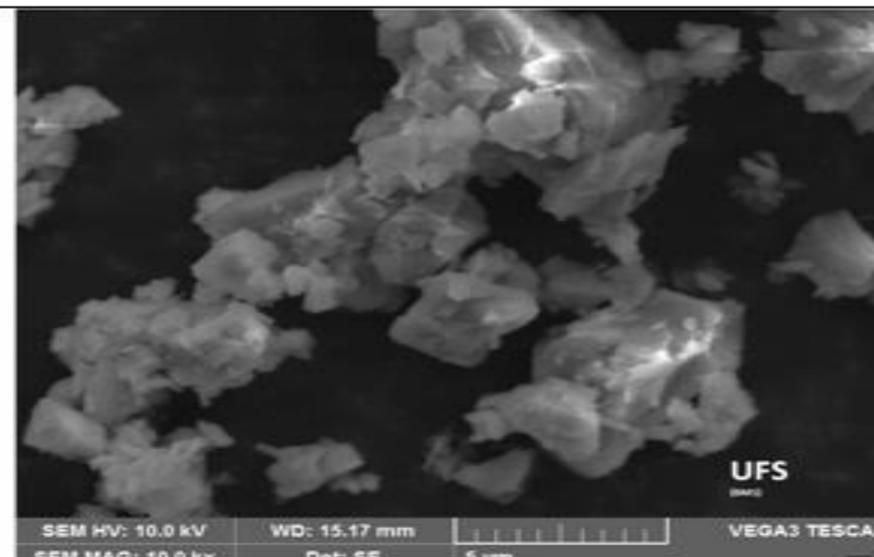
Cement



Fly ash



GGBS

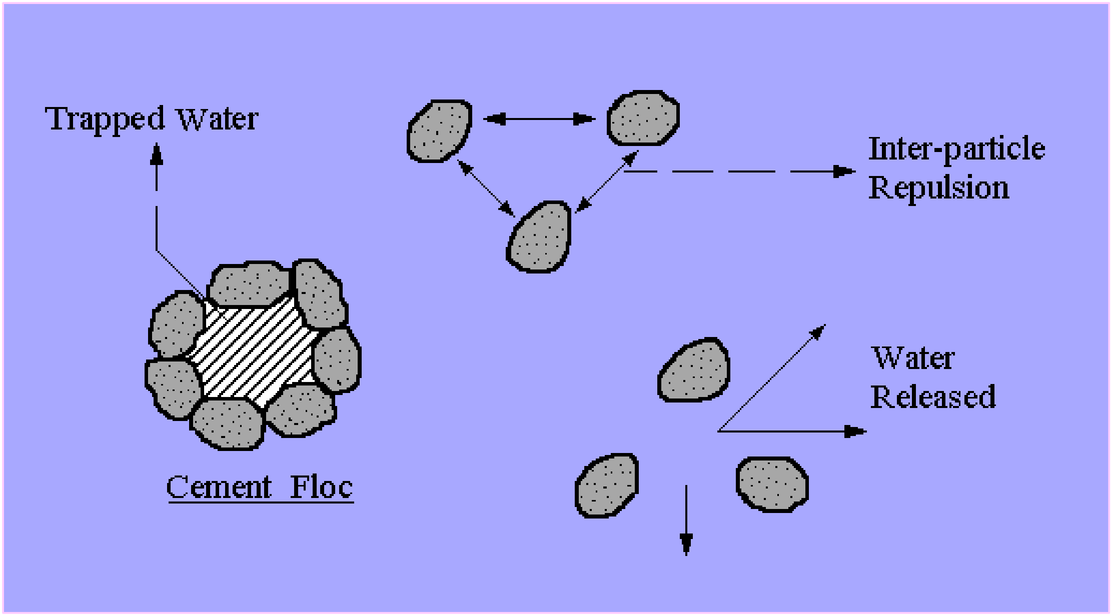


UFS

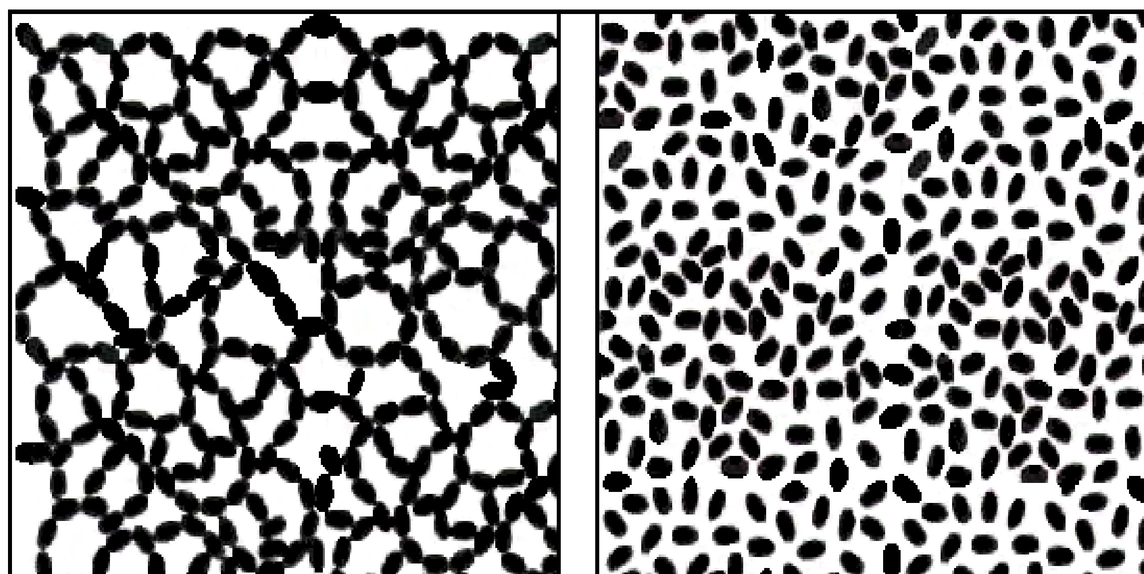
-Chemical Admixtures

- Super plasticizers, VMAs and retarders are most common chemical admixtures used.
- While HRWRA results in lowering water to binder ratio, VMAs and Retarders helps in maintaining a workable mix till the point of execution.
- A high dosage of chemical admixtures greater than 2% of binder content is also acceptable depending on the workability required
- With the addition of super plasticizers, concrete can be successfully produced and placed with a water-to cement ratio as low as 0.2.

Working mechanism of super plasticizers



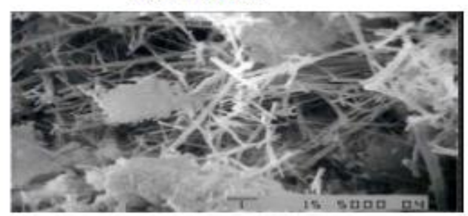
De-flocculation of cement grains in the presence of superplasticizer.

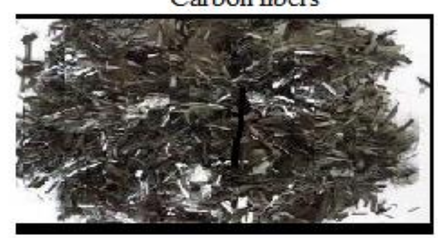


-Fibres

- As the strength increases with paste content, the brittleness of the concrete also increases.
- In order to increase the material properties such as the tensile behaviour, flexural toughness and crack resistance of the concrete and to control the brittle failure, certain small, discrete fibres are added to concrete in its fresh state


Steel fibers

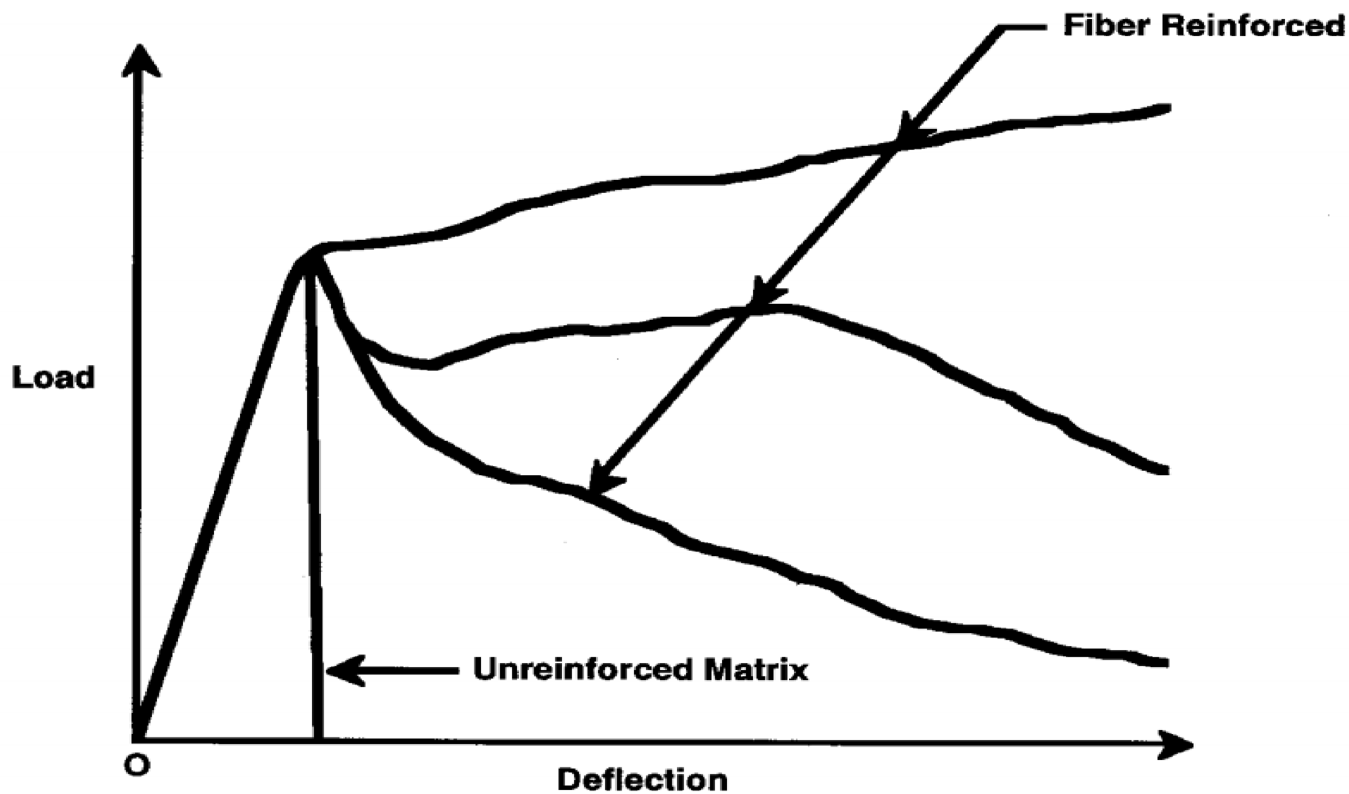

Natural fiber


Carbon fibers


Glass fiber


Synthetic fiber

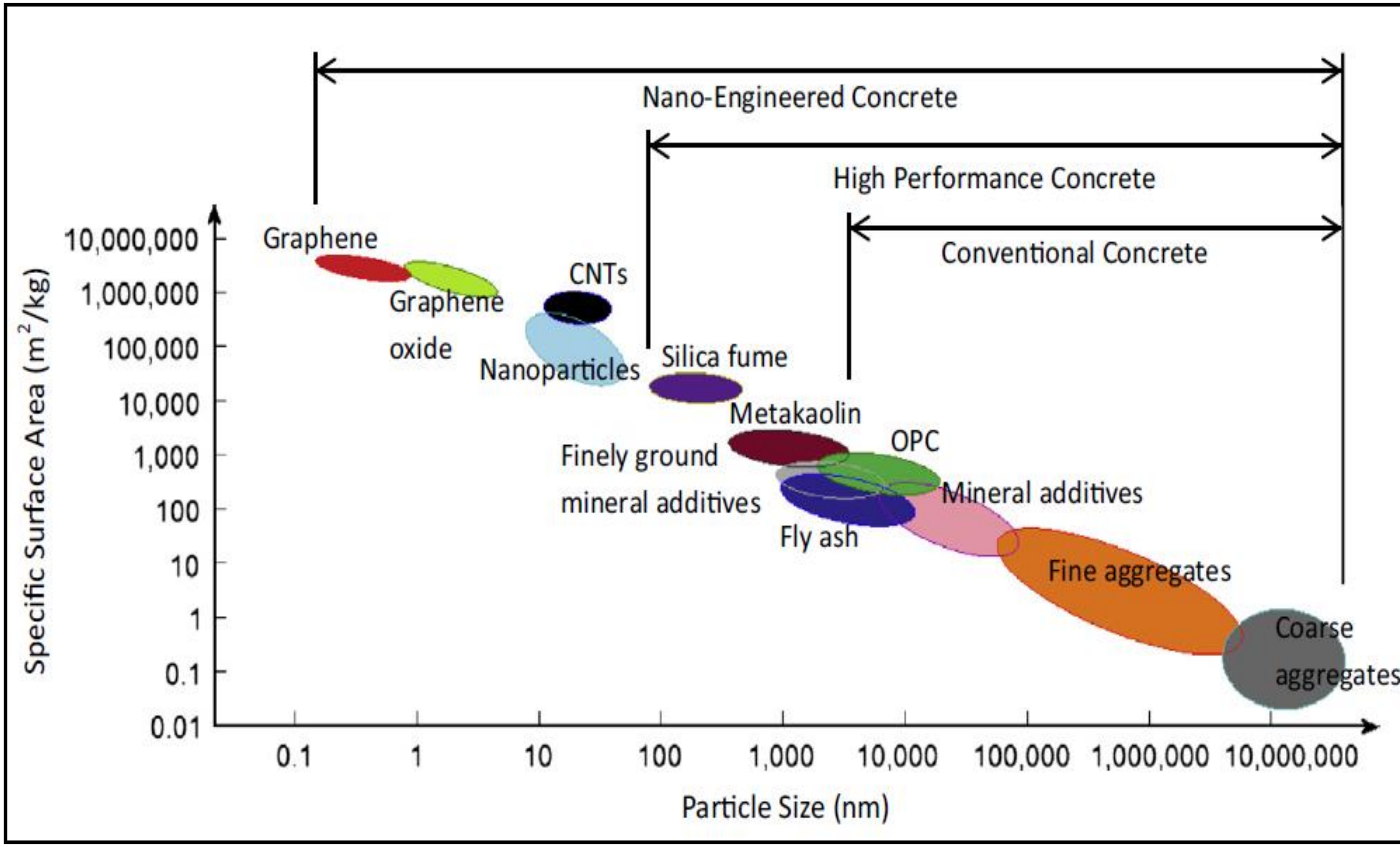

Basalt fibers



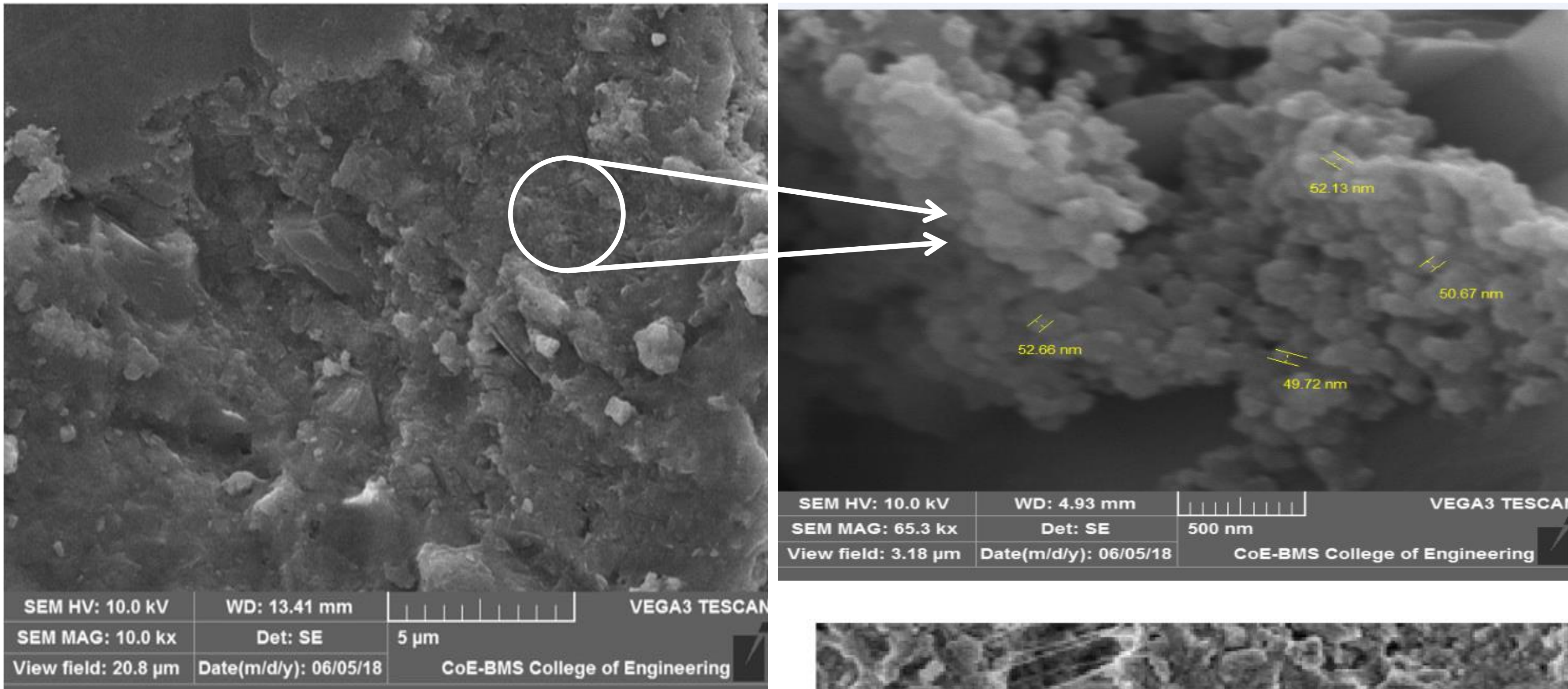
Typical post-cracking behaviour of Fibre added Concrete [ACI 544.1R-96]

Nano additives:

- Ultra fine additives (reactive/ inert) with particle size in the range of micron to nano level are found to be useful in enhancing strength.
- Nano Silica, the most explored admixture is found to result in high early strength with a greater pozzolanic activity. Graphene Oxide has shown a good promise.
- Nano fibres such as CNTs are capable of arresting micro cracks and their propagation very effectively and contribute to overall performance of Concrete.

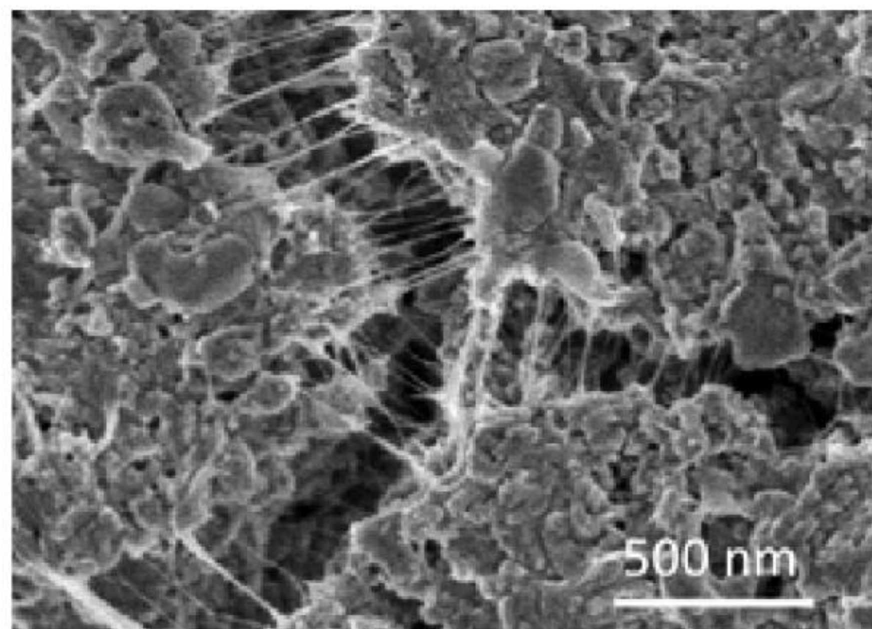


Specific Surface areas of different concrete additives
(American Ceramic Society Bulletin)

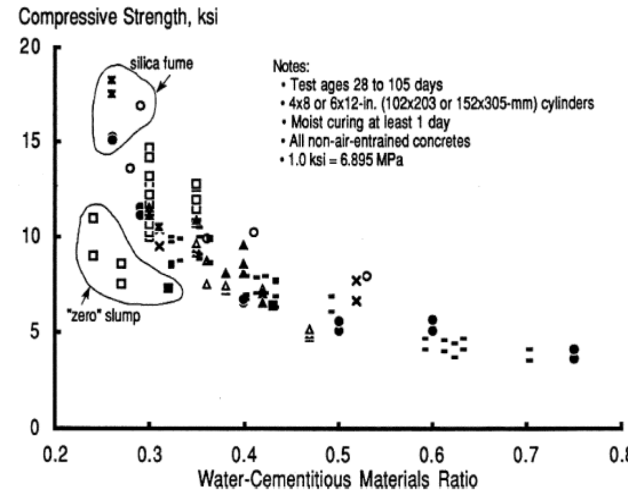


Dense micro structure in Nano silica added Concrete
(BMSCE, Bengaluru)

Crack bridging by CNTs
(Materials Today: Proceedings 4)



Proportioning techniques



- **Lower water to binder ratio**
  - Backed by Duff Abrams law
  - Use of Chemical admixtures
  - For HSC/ HPCs water binder ratio is generally less than 0.23 -0.35
  - However, it is necessary to establish an optimum w/b ratio to avoid excess dependency on chemical admixtures which can create variations in desired concrete parameters.
  - Proper compaction is an important factor to attain HSC at low water content.

IS Recommendation

SECTION 3 HIGH STRENGTH GRADES OF CONCRETE

6 HIGH STRENGTH CONCRETE (GRADE M 65 AND ABOVE)

High strength concrete is the concrete that has characteristic compressive strength of 65 N/mm^2 or more. This section provides the guidance for selecting mix proportion for M65 or above.

Usually, for high strength concrete mixes specially selected cementitious materials and chemical admixtures, that is, super plasticizers are used, and achieving a low water–cementitious materials ratio (w/cm) is considered essential.

The procedure for proportioning high strength concrete is similar to that required for ordinary/standard strength concrete. The procedure consists of series of steps that, when completed, provide a mixture meeting workability, strength and durability requirements based on the combined properties of the individually selected and proportioned ingredients.

6.1 Materials

IS 383. Generally, for high strength, a fine aggregate of coarser size is preferred (Zone I or Zone II), due to availability of high fines content from the cementitious materials.

6.1.4 *Chemical Admixtures*

High strength concrete mixes usually have a low water-cementitious materials ratio (w/cm). These low w/cm ratios are generally only attainable with high-range water-reducing admixtures (HRWRA). PCE type (Poly carboxylate ether based) super plasticisers which reduce water content by 30 percent or above at appropriate dosages, maybe used.

6.2 Concrete Mix Proportioning

6.2.1 *Target Strength for Mix Proportioning*

See **4.2**.

6.2.2 *Selection of Maximum Size of Aggregate*

Based on the strength requirement, the maximum size of aggregates is generally restricted to 20 mm; however, for grades M80 and above, aggregates of maximum size 10.0 mm to 12.5 mm may be preferable.

Table 8 Recommended w/cm for High Strength Concrete made with HRWRA
(*Clause* 6.2.5)

Sl No.	Target Compressive Strength at 28 Days N/mm^2	Water–Cementitious Materials Ratio — Nominal Maximum Size of Aggregate 10.0 mm	12.5 mm	20.0 mm
(1)	(2)	(3)	(4)	(5)
i)	70	0.36	0.35	0.33
ii)	75	0.34	0.33	0.31
iii)	80	0.32	0.31	0.29
iv)	85	0.30	0.29	0.27
v)	90	0.28	0.27	0.26
vi)	100	0.26	0.25	0.24

NOTE — The recommended w/cm are for 28 days cement strength 53 MPa and above; for cement of other strength values, suitable adjustments may be made by reducing the w/cm.

Table 9 Recommended Dosages of Mineral Admixtures Materials for High Strength Mixes
(*Clause* 6.2.6)

Sl No.	Mineral Admixtures	Recommended Dosages, Percentage by Mass of Total Cementitious Materials
(1)	(2)	(3)
i)	Fly ash	15 - 30
ii)	Ground granulated blast furnace slag	25 - 50
iii)	Metakaoline	5 - 15
iv)	Silica fume	5 - 10

- **Aggregate packing approach**
  - A basic approach to attain a proportion of aggregates with least void content.
  - Aggregate **gradation and shape** is an important factor
  - Aggregates of each batch are to be tested before developing a mix
  - Improper proportioning of aggregates can result in **too much of voids** which demands for **higher paste content** and **become potential site for capillary pores** during the hardening process of Concrete.

- The basic concept of adding fine particles into the concrete mix is based on packing theory. It is found that packing density of concrete governs the performance of concrete to a large extent.

- Effective particle packing depends on the relative size of particles and the number of different sizes [Gray, W.A. (1968), *"The Packing of Solid Particles", Chapman & Hall, London,*U.K]

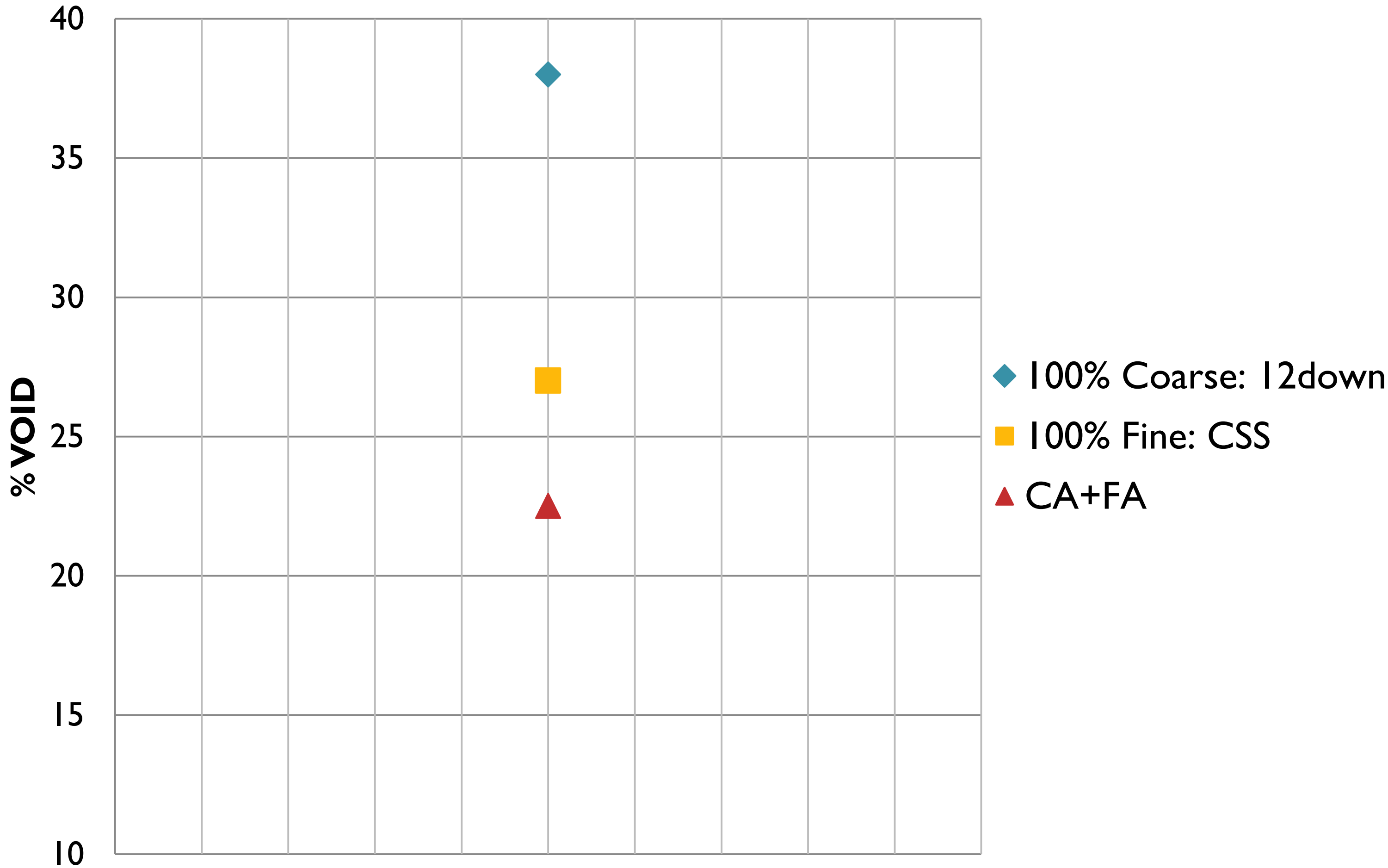
- **Consider a blend of particles of different sizes**.
- When mixed together the gaps between the larger particles are filled up successively by smaller size particles.
- If the filling up process is extended infinitely by incorporating particles of extremely fine size, all the voids can be filled up by solid particles, leading to a packing density very close to 1.
- **Yet**, due to practical limit to the size range and shape of the particles there is always some voids remaining unfilled. (Kwan and Mora 2001)

Only Coarse Agg : 38% voids

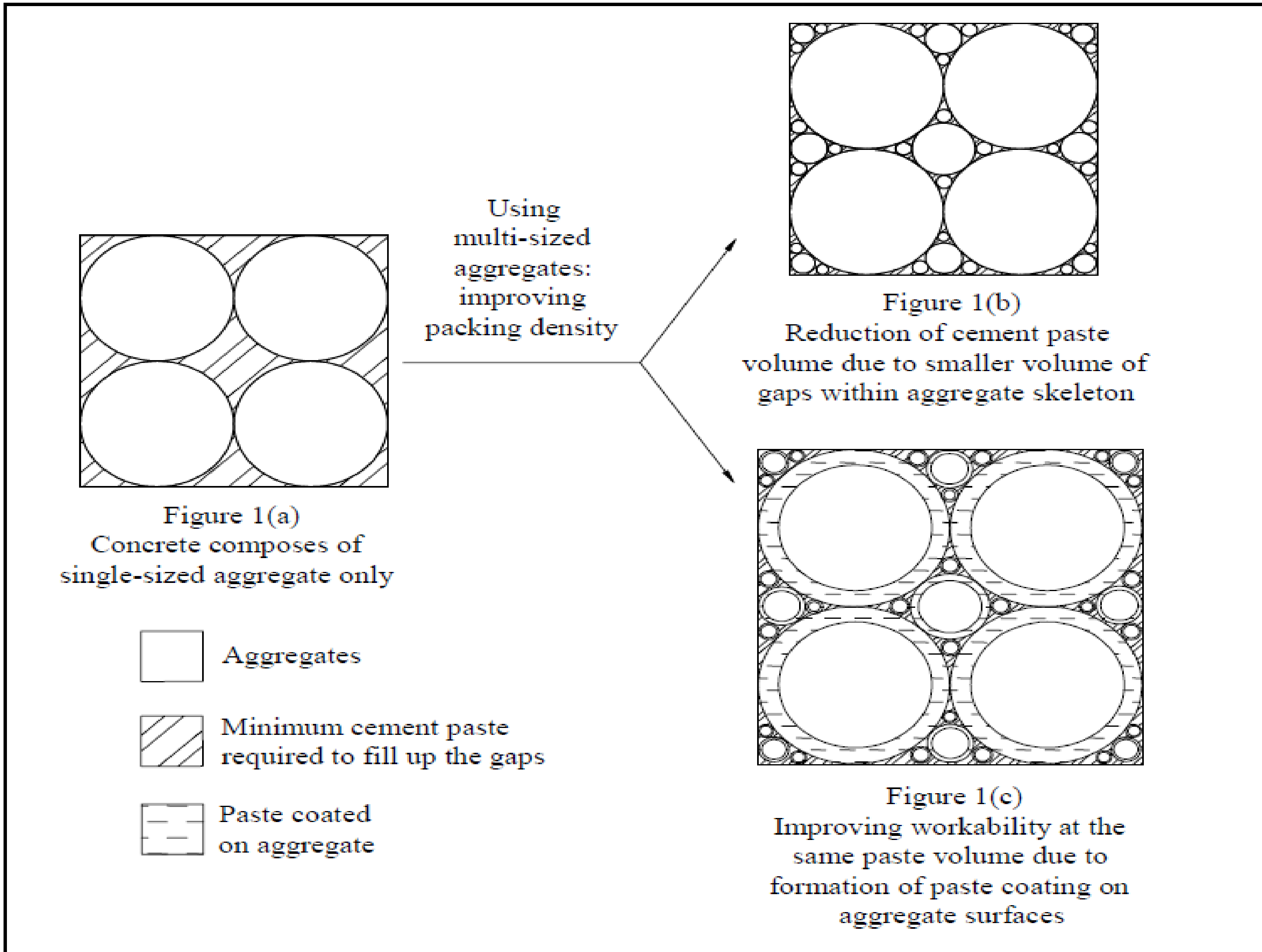
Only Fine Agg : 27% voids

Combined : 23% voids

Voids in aggregates



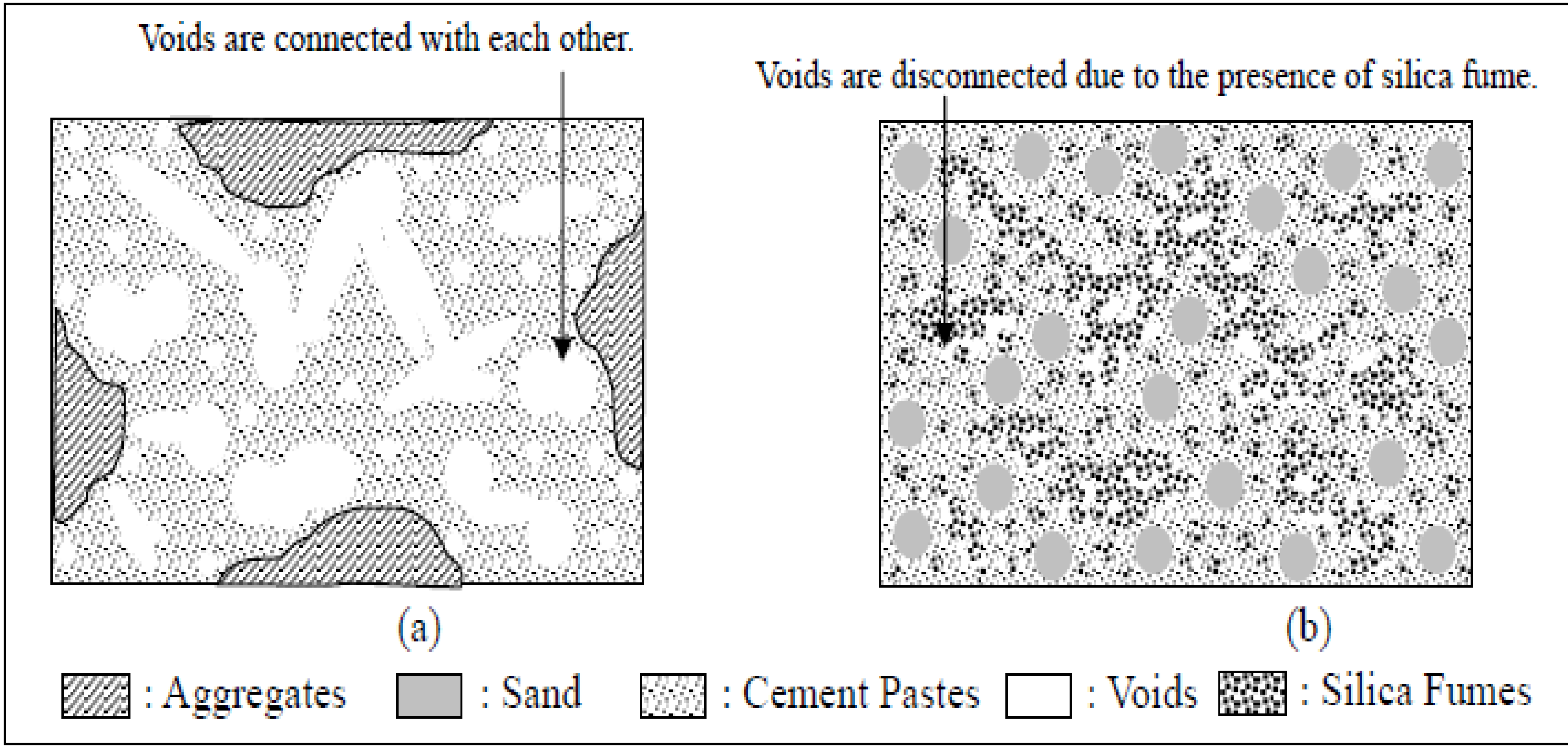
(Data from Research works, BMSCE, Bengaluru)



Aggregate packing principle

- **Paste densification**

  - Achieved by increasing the paste volume of concrete
  - HSC/ HPC can be realized for paste volume of greater than 30% unlike conventional concrete which has higher aggregate volume
  - OPC aided with mineral admixtures at different combinations have successfully resulted in increasing the paste phase in concrete.



Pore connectivity in paste: (a) Normal Concrete (b) HSC

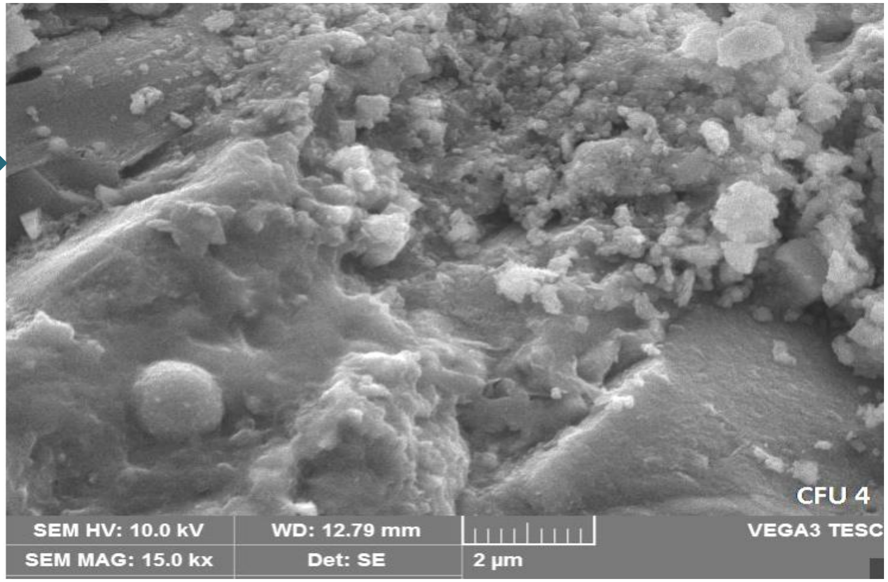
(Ref- **Oral Büyüköztürk and Denvid Lau, "High Performance Concrete: Fundamentals and Application"** Department of Civil and Environmental Engineering, Massachusetts Institute of Technology.

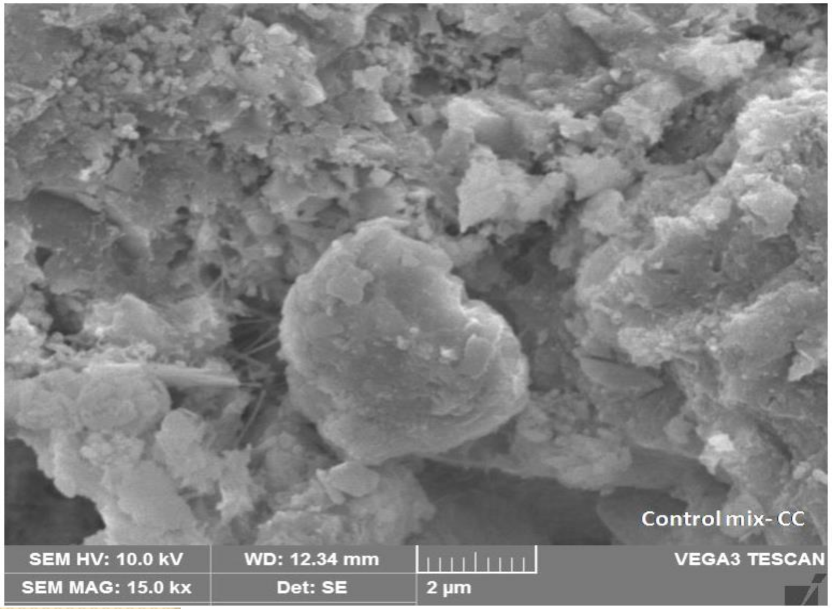
- The effect of paste packing density may be summarised as an improved packing method to reduce the voids content and the water demand.
- The reduced water demand would increase the excess water ratio to increase the flow of the paste.
- However, the particle shape and fineness of the cementitious materials could also affect the flow.

(A. K. H. Kwan & H. H. C. Wong, "Packing density of cementitious materials: part I and II", Materials and Structures, 2008)

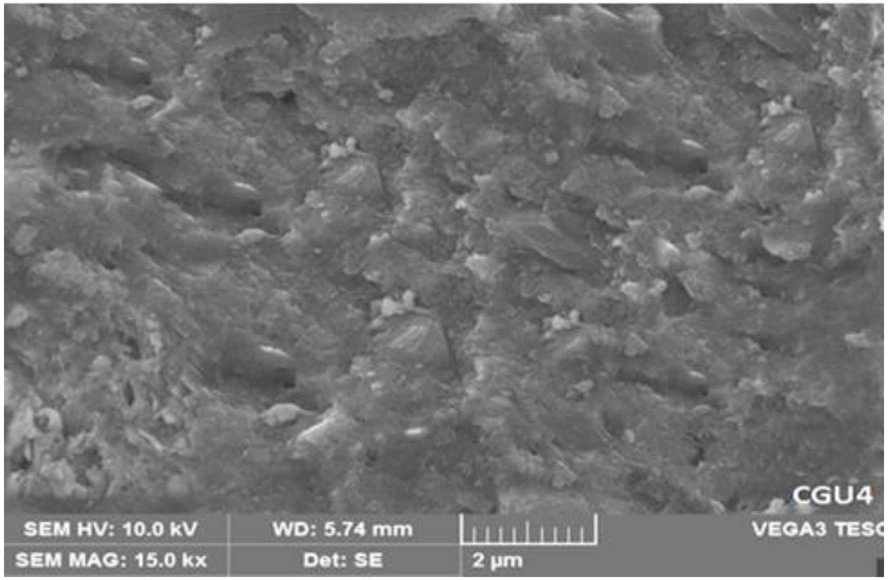
Microstructure Comparison

Binary Blend Concrete



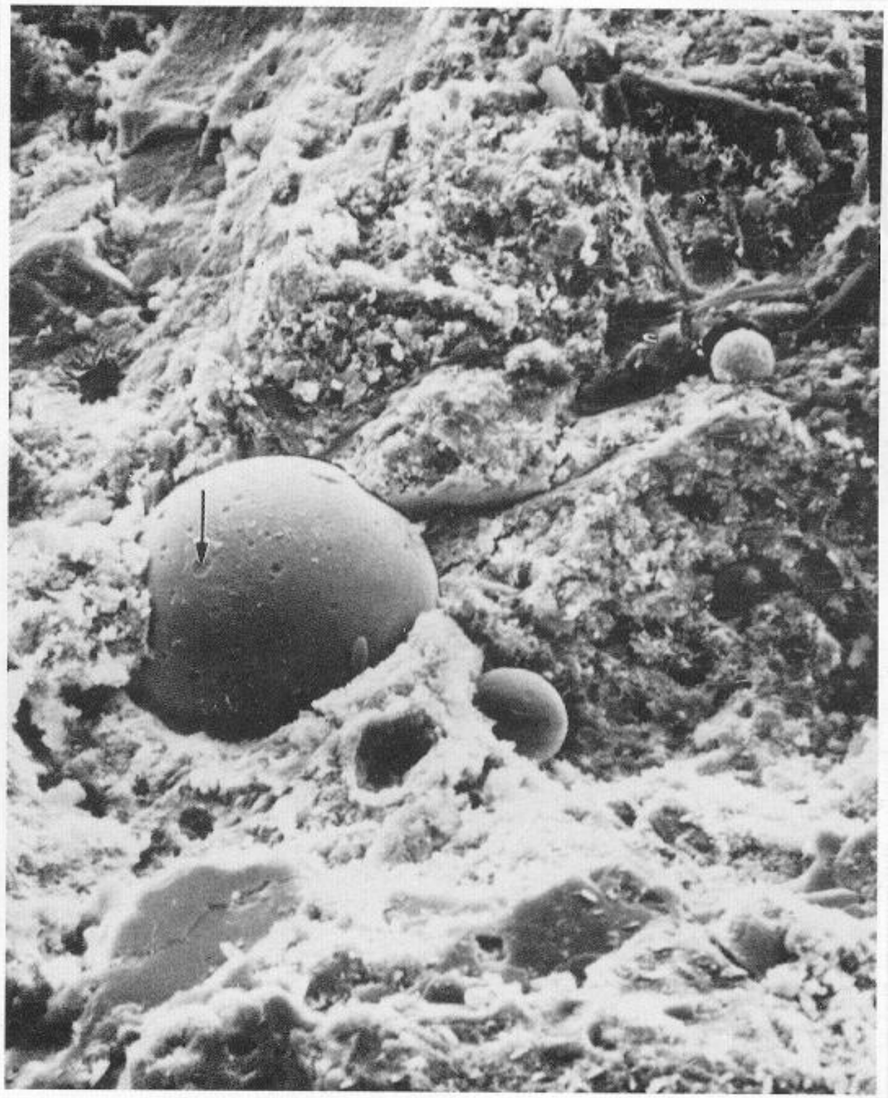


Cement Concrete



Ternary blend Concrete

(Data from Research work, BMSCE, Bengaluru)

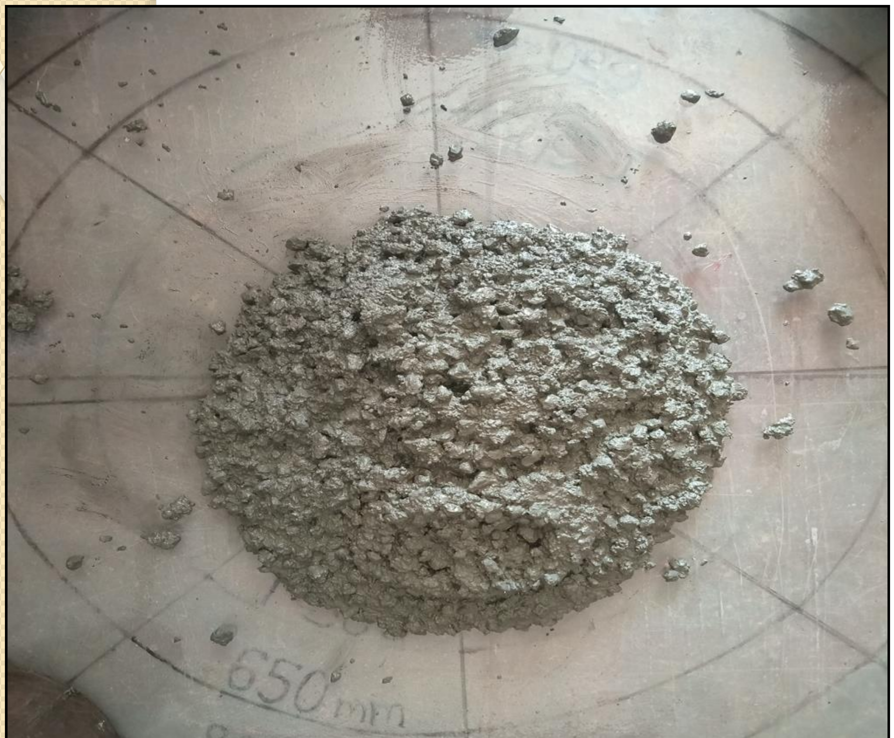


Left: An electron microscope reveals tiny flaws in a conventional mixture of concrete. These "holes" can trap water and thus weaken the concrete. Right: Fly ash particles (which look like bubbles) bind with other components in concrete to create a stronger, more durable concrete. The photographs were taken by Dr. Marcelle Gillott of UWM's Biological Sciences department.

- **High speed mixing**
  - Normal mixing methods (Pan and drum mixers) can result in poor and non uniform distribution of powder materials (SCMs) at a lower w/b ratios thereby bringing down the mix efficiency.
  - Also **at normal speed** a **high duration of mixing** (more than 15mins) **is required** to attain certain uniformity.
  - The above reasons demand for special mixing techniques involving high speed mixers.
  - Mixing at high speed enhances the uniformity of distribution of ultra fine additives even at w/b ratios less than 0.25.

Pan Mixer – 30 to 40rpm

High Speed Mixer – >500rpm



Pan Mixed Concrete (360mm spread)

High speed Mixed Concrete (520mm flow)

For same mix with only mix speed variations- 40 to 50% flow increment.

Strength is also observed to increase by 15 to 20% at early age

-BMSCE, Bengaluru.

Some Example HSC Mixtures

CHARACTERIZATION OF MATERIALS

SL NO	MATERIAL	SOURCE	SPECIFIC GRAVITY	FINENESS
1	OPC 53 GRADE	BIRLA	3.15	276 Sqm/kg
2	GROUND GRANULATED BLAST FURNACE SLAG (GGBS)	JSW	2.9	386 Sqm/kg
3	ULTRAFINE SLAG (Alccofine)	AMBUJA CEMENTS	2.6	1000 Sqm/Kg

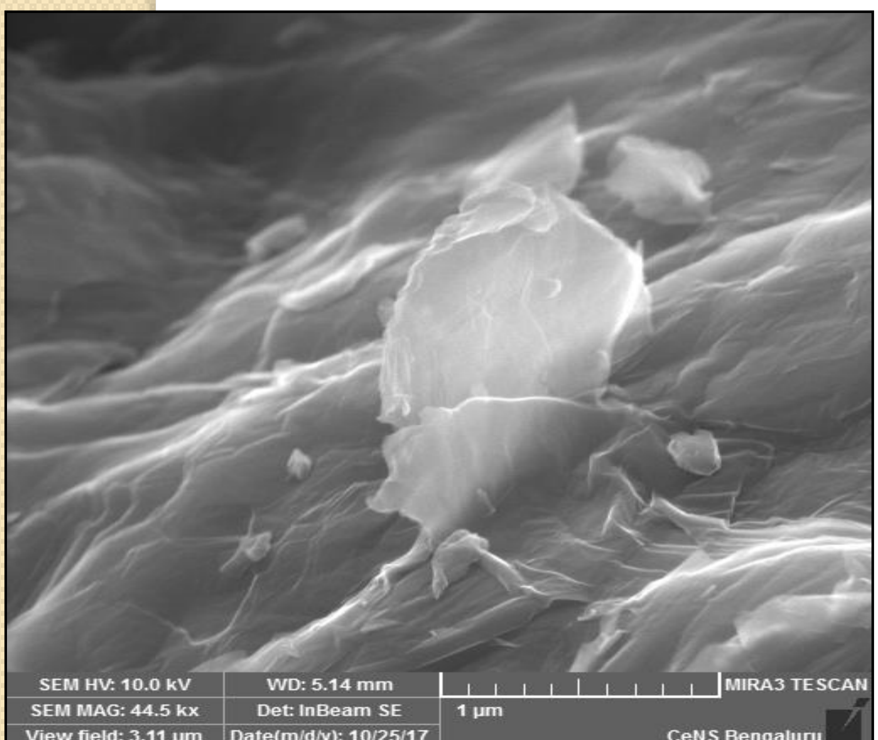
AGGREGATES

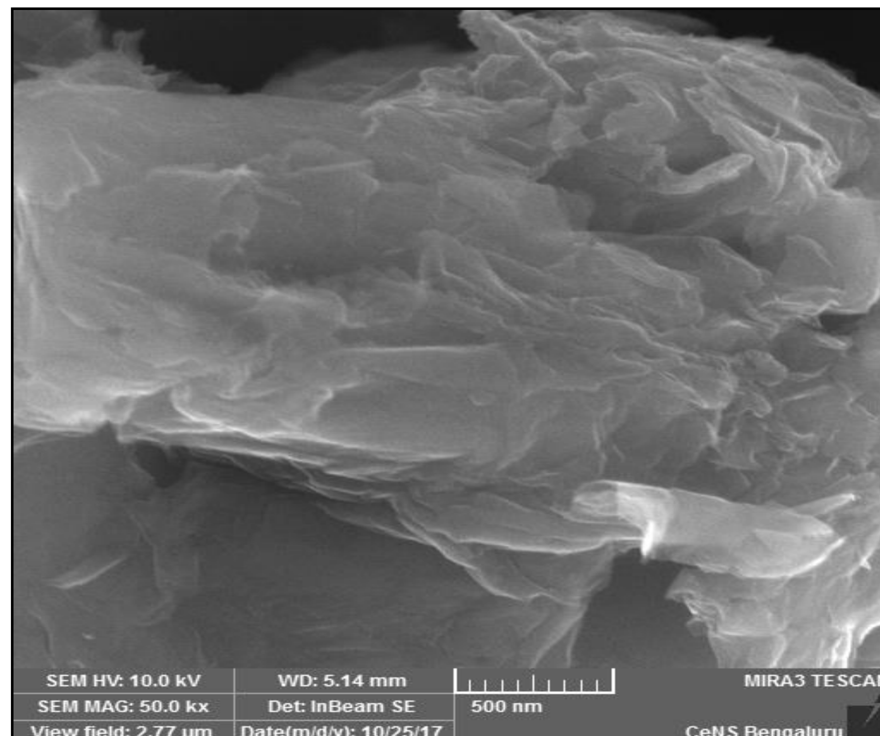
PARAMETER	COARSE AGGREGATE	FINE AGGREGATE (Zone 2)
Specific gravity	2.67	2.62
Water Absorption	0.3%	1.3%

GRAPHENE OXIDE

Parameters	Approx. Value
Thickness	0.8 to 2nm
Lateral dimension	5-10 μm
Surface area	> 120 m^2/g
Carbon Purity	~99%
Specific gravity	1.009

(SOURCE : United Nano Tech Innovations Private Limited)

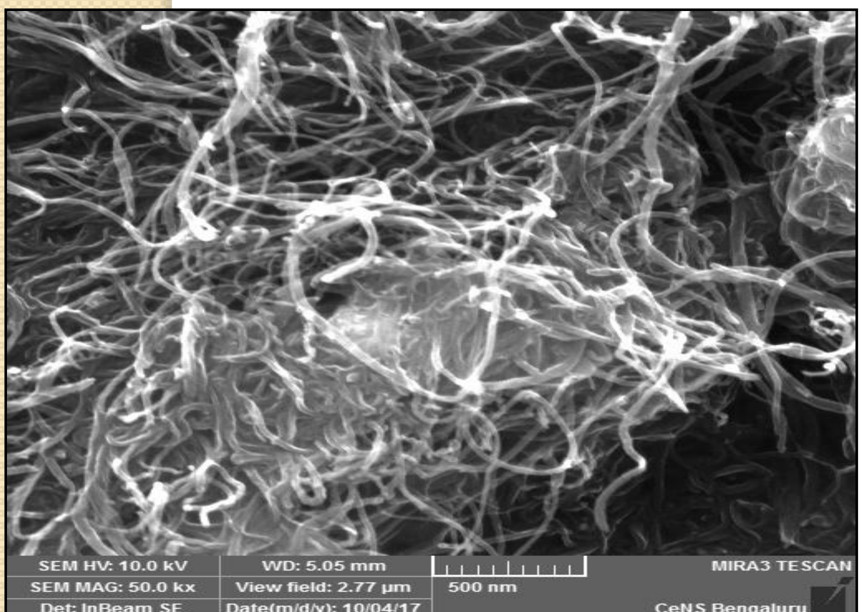


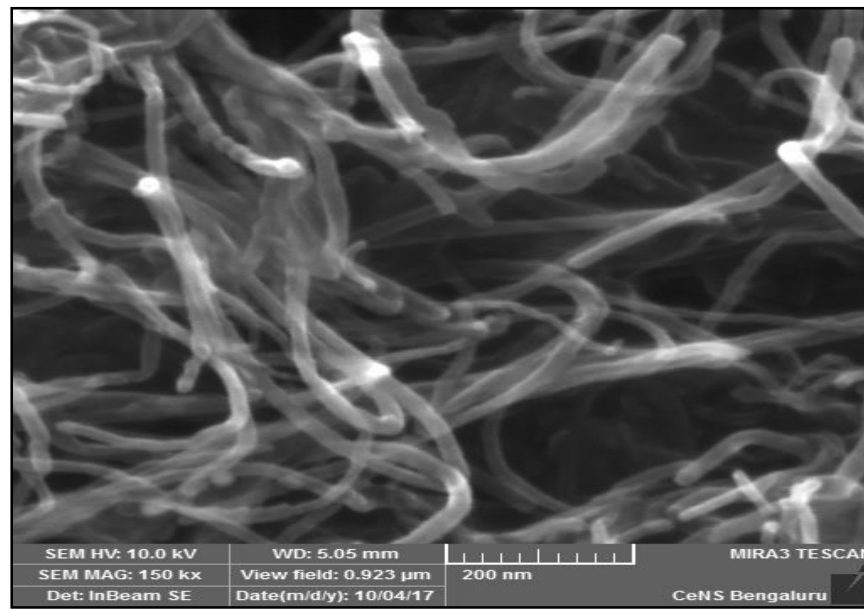


MULTI WALL CARBON NANO TUBE (MWCNT)

MWCNT Parameters	Approx. Value
Diameter	10-30 nm
Length	10 micron
Surface area	330 m^2/g
Carbon Purity	> 95%
Specific gravity	1.007

(SOURCE : United Nano Tech Innovations Private Limited)



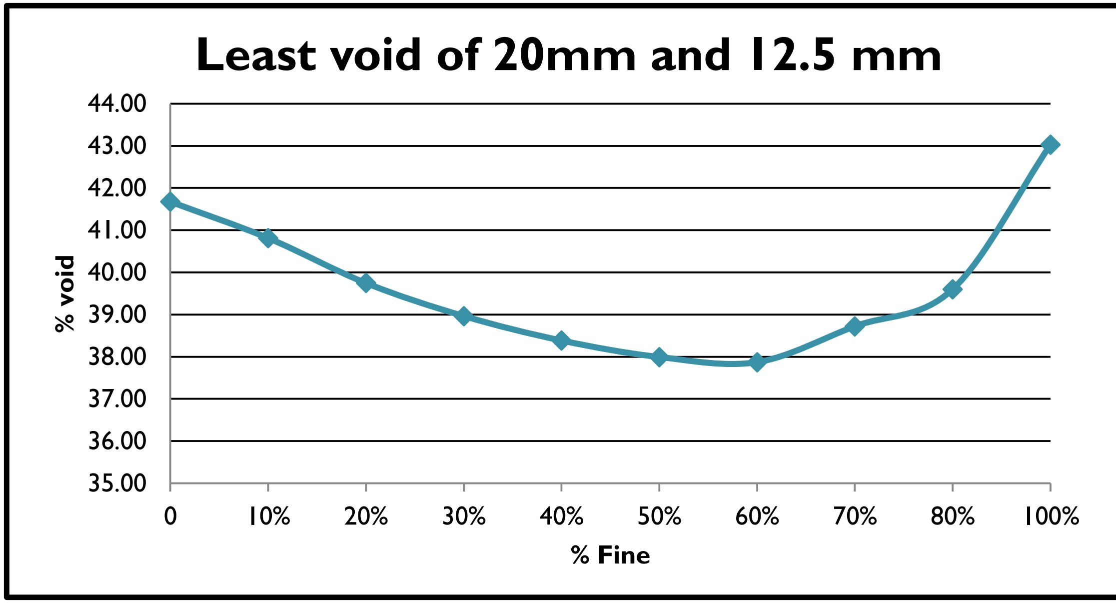


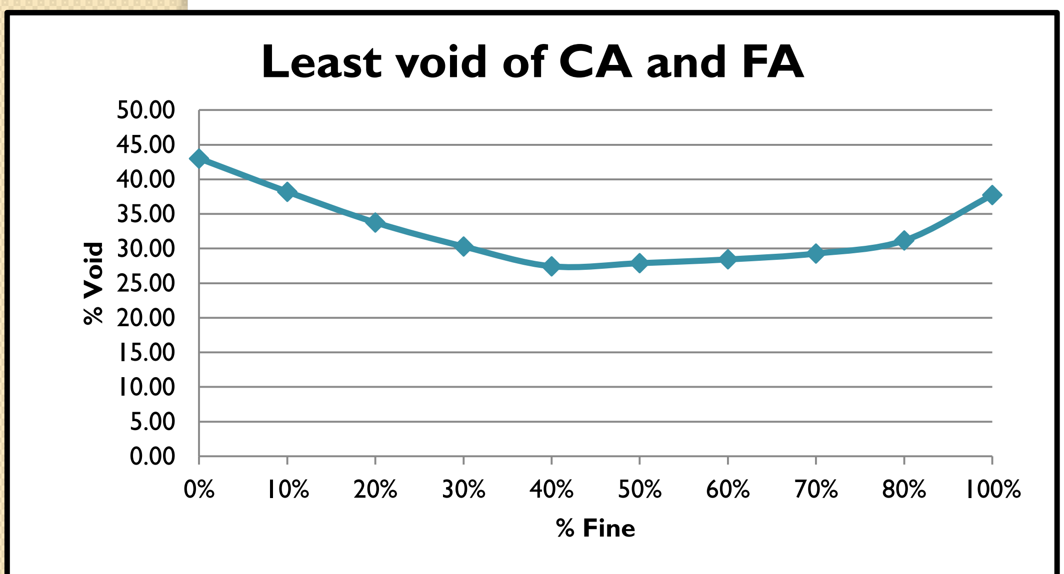
Super Plasticizer : Master Glenium 8233 is used

METHODOLOGY

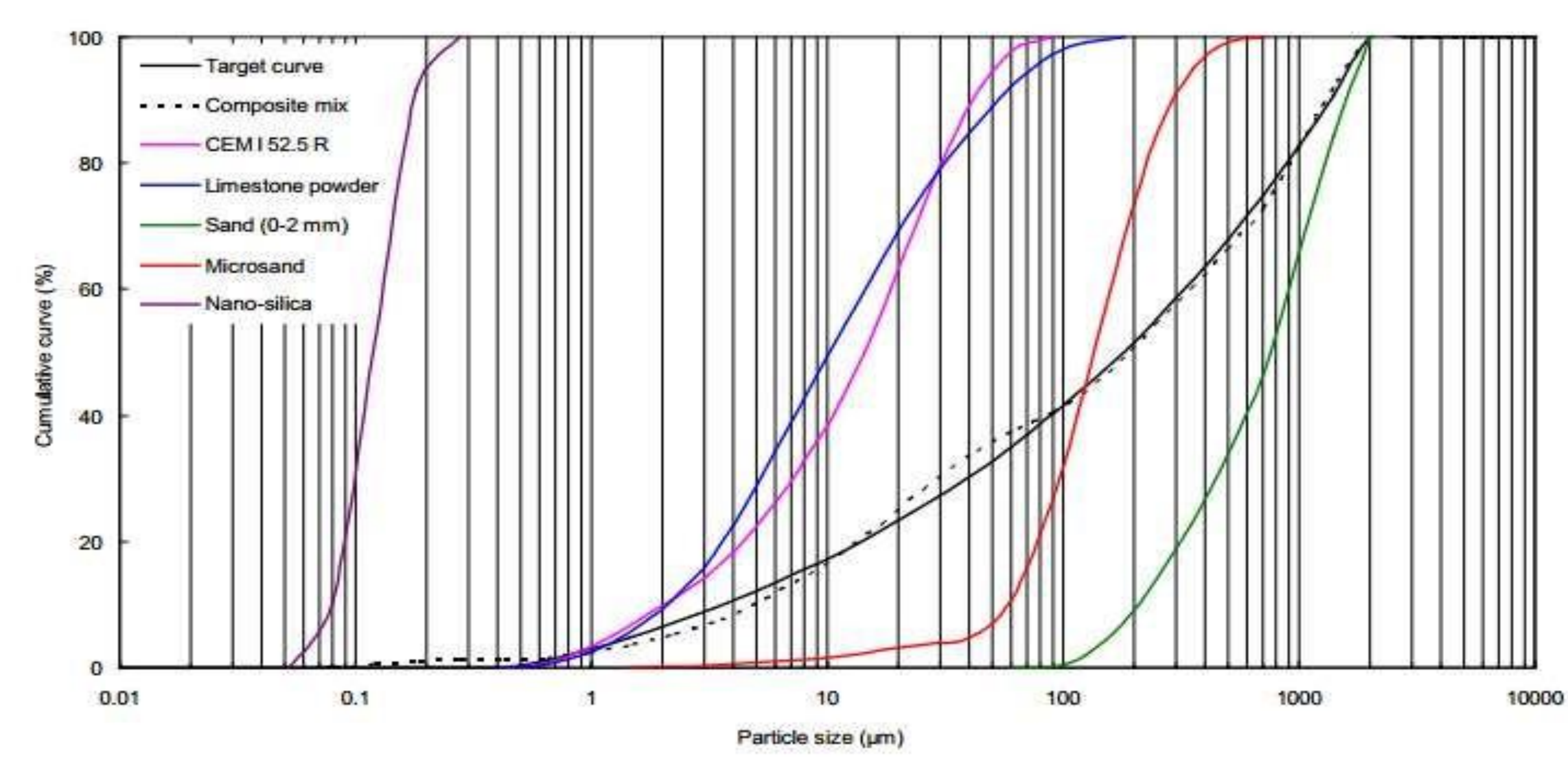
LEAST VOID OF AGGREGATES

% Void – 37.9
40 %(20mm) : 60 %(12.5mm)





% Void – 27.4 %
60 % CA : 40 % FA



Particle size distribution of the involved ingredients, the target curve and the resulting integral grading curve of the mixtures.

Mix proportioning of control mixes

MIX	Paste volume	Cement Kg/m^3	GGBS Kg/m^3	Water Kg/m^3	CA (20mm) Kg/m^3	CA (12.5mm) Kg/m^3	FA Kg/m^3
CM -1	0.27	424	-	135.7	467.8	696.4	765.0
CM 2	0.29	450	-	144	454.9	677.3	744.0
CM 3	0.30	450	29	144	450.4	670.7	736.8
CM 4	0.32	450	107.3	144	433.2	645	708.4
CM 5	0.35	450	185.6	144	415.9	619.1	680.2
CM 6	**0.38**	**450**	**264**	**144**	**398.6**	**593.4**	**652**
CM 7	0.40	450	327.7	144	384.5	572.4	628.8
CM 8	0.42	450	385.7	144	371.7	553.3	607.8

Mix proportioning of Alccofine mixes

MIX	Cement Kg/m³	GGBS Kg/m³	Alccofine Kg/m³	Water Kg/m³	CA(20mm) Kg/m³	CA(12.5mm) Kg/m³	FA Kg/m³
CM-6	450.0	264.0	-	144.0	467.8	696.4	765.0
AL-1(2%)	450.0	264.0	9.0	144.0	395.3	588.5	646.5
AL-2(4%)	450.0	264.0	18.0	144.0	394.3	586.9	644.7
AL-3(6%)	450.0	264.0	27.0	144.0	392.1	583.7	641.1
AL-4(6%)	**450.0**	**264.0**	**27.0**	**150.0**	**392.1**	**583.7**	**641.1**

Nano Materials in Concrete

Mix proportioning of Graphene Oxide (GO) mixes

Mix	Cement Kg/m³	GGBS Kg/m³	Alccofine Kg/m³	GO Kg/m³	Water Kg/m³	CA (20mm) Kg/m³	CA (12.5mm) Kg/m³	FA Kg/m³
AL-4 (6%)	**450.0**	**264.0**	**27.0**	-	**150**	**392.1**	**583.7**	**641.1**
GO-1 (0.03%)	450.0	264.0	27.0	0.11	150.0	392.1	583.7	641.1
GO-2 (0.05%)	450.0	264.0	27.0	0.23	150.0	392.1	583.7	641.1
GO-3 (0.10%)	450.0	264.0	27.0	0.45	150.0	392.1	583.7	641.1
GO-4 (0.15%)	450.0	264.0	27.0	0.7	150.0	392.1	583.7	641.1

Mix proportioning of Carbon Nano Tubes (CNT) mixes

Mix	Cement Kg/m³	GGBS Kg/m³	Alccofine Kg/m³	CNT Kg/m3	Water Kg/m3	CA (20mm) Kg/m³	CA (12.5mm) Kg/m³	FA Kg/m³
AL-4 (6%)	450.0	264.0	27.0	-	150.0	392.1	583.7	641.1
CNT 0.05%	450.0	264.0	27.0	0.23	150.0	392.1	583.7	641.1

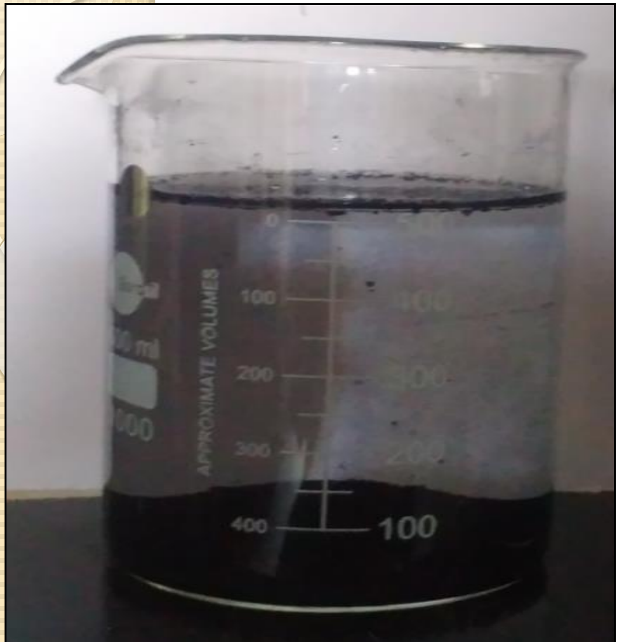
Different CNT mix methods

MIX	Dispersion agent
CNT 1	CNT in Plain Water dispersion
CNT 2	CNT in PEG aided water dispersion
CNT 3	CNT in PVP(1: 0.5) aided water dispersion

- Since their size and density are very less, uniform distribution in concrete cannot be ensured if mixed directly with other powder material.
- When used as a water suspension, it was observed the particles tend to agglomerate and settle in water.
- To overcome the problem of agglomeration and to disperse them uniformly in water and later into mix, ‘Bath Sonication’ method of dispersion is used.

Graphene Oxide Mix after Sonication

Plain dispersion of CNT, before and after sonication.



CNT Dispersing with PEG-200

CNT Dispersion using Poly Vinyl Pyrrolidone (P

Slump/ Slump flow test.

1. Control Mixes

Mixes	Volume of paste Vp	GGBS Addition kg/m³	slump, mm	SP dosage %
CM 1	0.27	-	25	0.3
CM 2	0.29	-	60	0.25
CM 3	0.30	29.0	65	0.35
CM 4	0.32	107.3	200	0.4
CM 5	0.35	185.6	550	0.5
CM **6**	**0.38**	**264**	**650**	**0.67**
CM 7	0.40	327.7	770	0.75
CM 8	0.42	385.7	765	0.8

slump loss of CM 1

slump loss of CM 6

2. Alccofine Mixes

Mixes	Alccofine %	Water	Slump flow (mm)	SP dosage %
AL-1	2	144	740	0.8
AL-2	4	144	700	0.8
AL-3	6	144	730	1.1
AL-4	6	150	725	0.54

Flow of mix AL-4

3. Graphene Oxide Mixes

Mix	GO % addition	Slump flow (mm)	SP dosage %
GO-1	0.025	715	0.54
GO-2	0.05	730	0.54
GO-3	0.10	725	0.54
GO-4	0.15	725	0.54

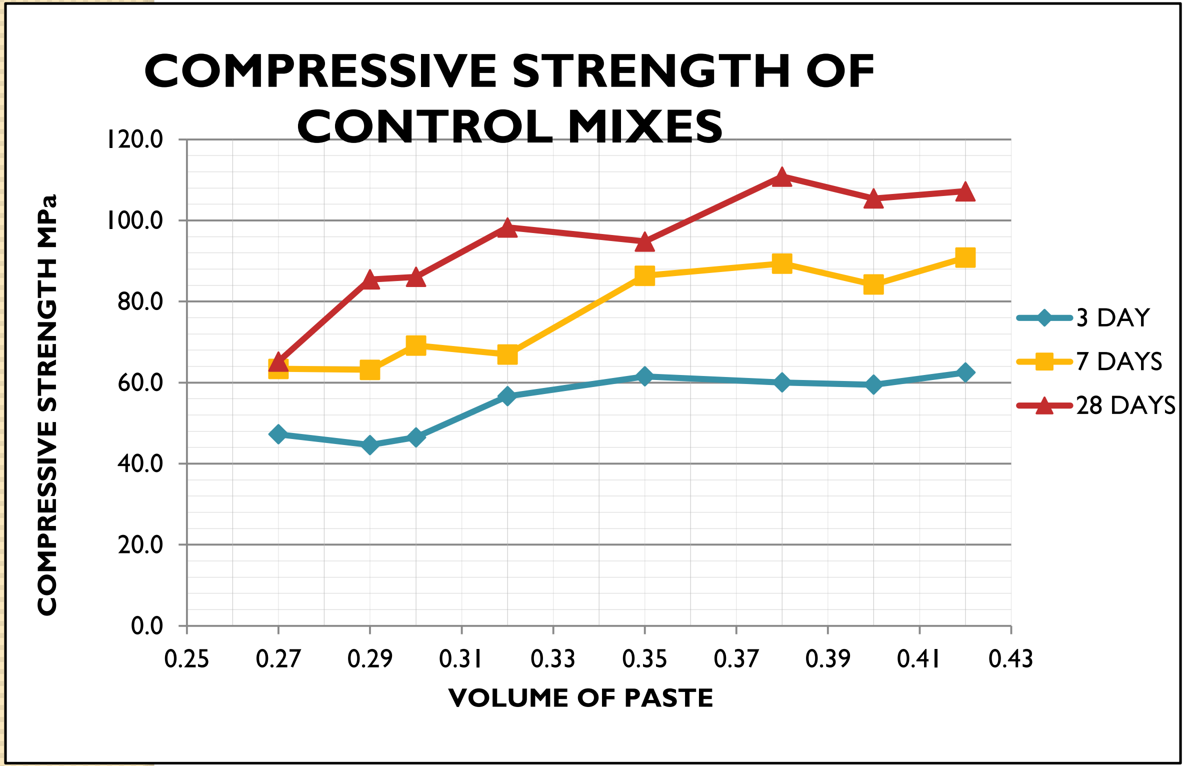
4. Carbon Nano Tube (CNT) Mixes

MIX	CNT % addition	Slump flow (mm)	SP dosage, %
CNT 1	0.05	725	0.54
CNT 2	0.05	725	0.54
CNT 3	0.05	720	0.54

COMPRESSIVE STRENGTH TEST

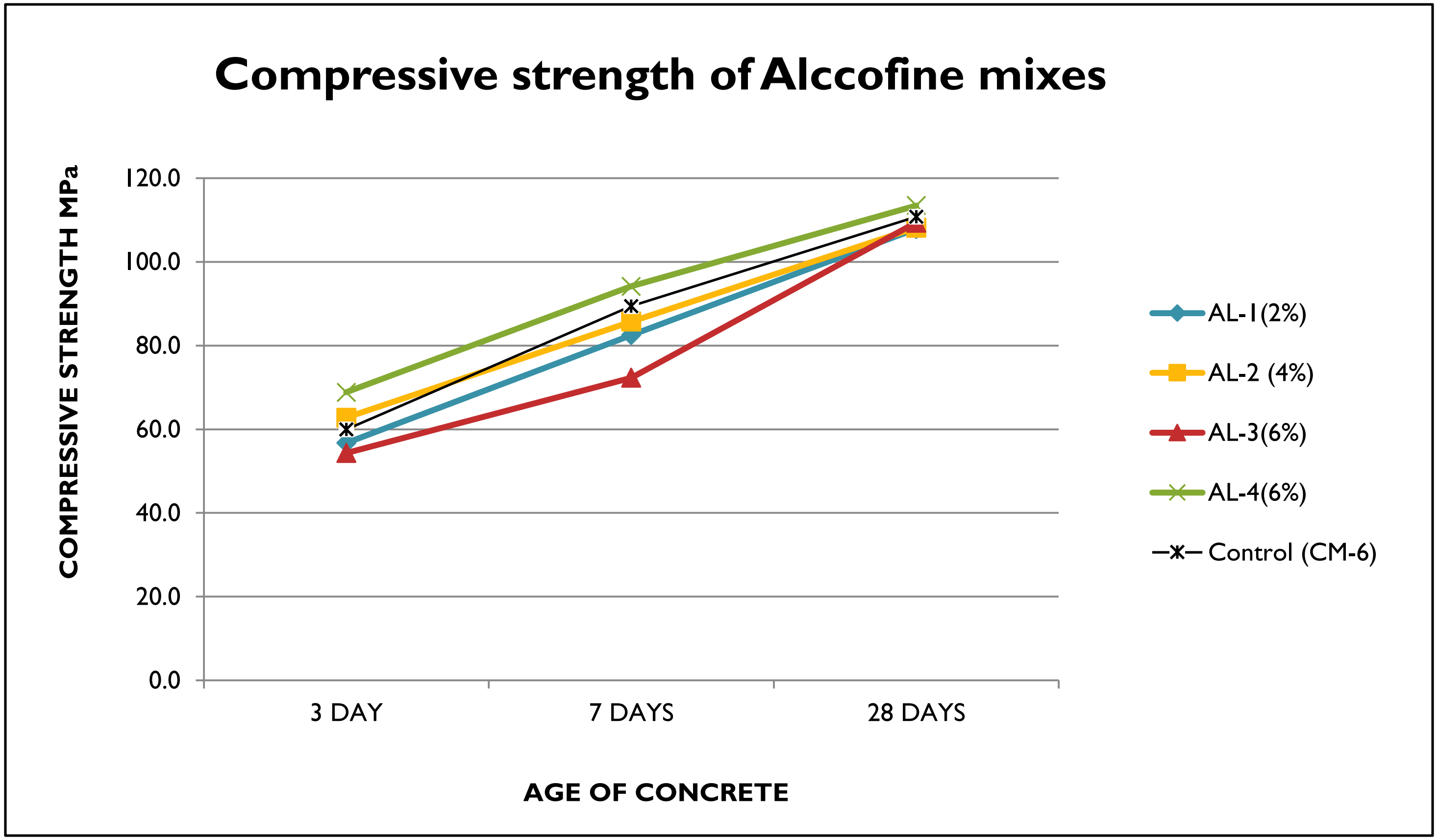
I. Control Mixes

MIX	Volume of Paste	Compressive strength		
		3 DAY	7 DAYS	28 DAYS
CM 1	0.27	47.2	63.4	65.2
CM 2	0.29	44.6	63.1	85.5
CM 3	0.30	46.5	69.2	86.1
CM 4	0.32	56.7	66.9	98.3
CM 5	0.35	61.5	86.3	94.8
CM6	**0.38**	**60.0**	**89.4**	**110.8**
CM 7	0.40	59.5	84.2	105.4
CM 8	0.42	62.5	90.8	107.2



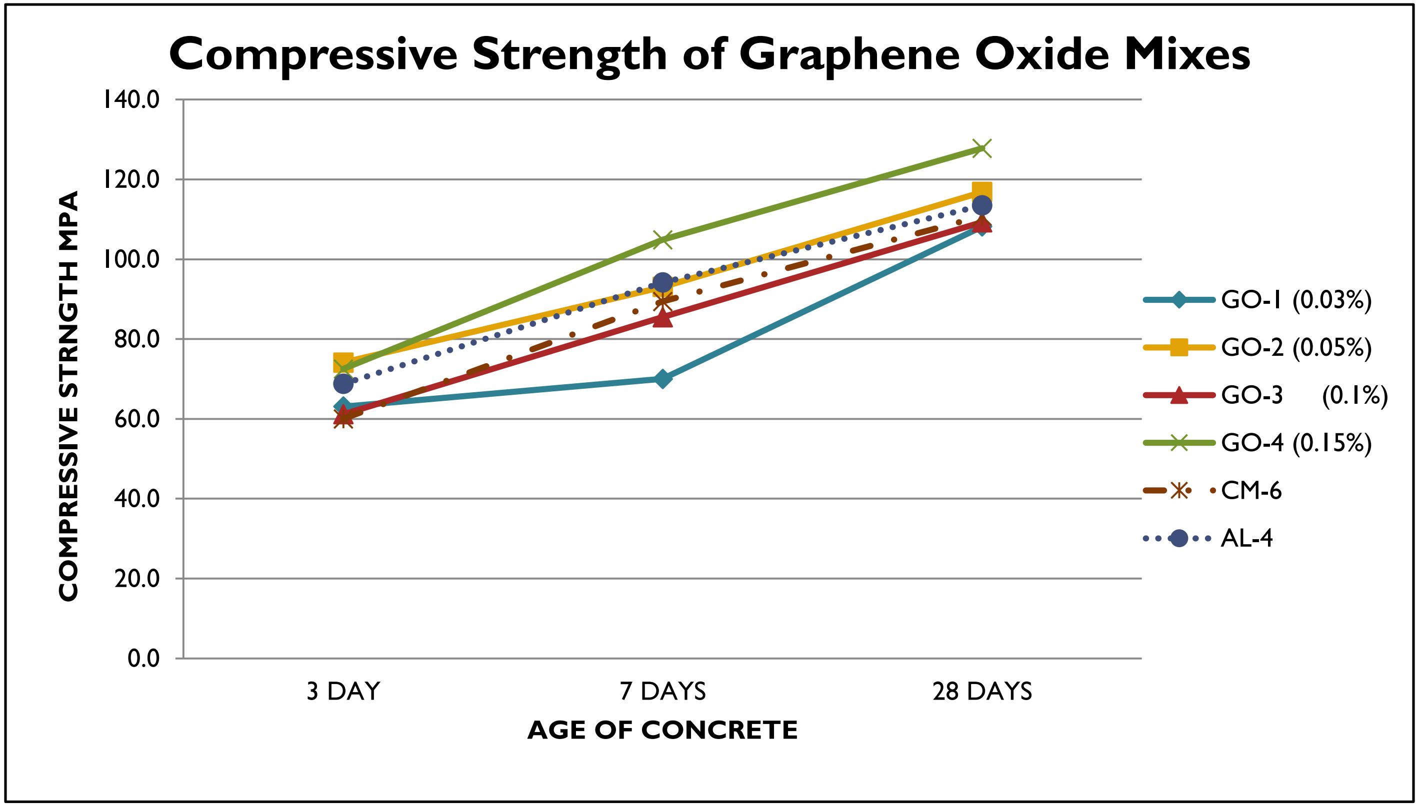
2. Alccofine Mixes

Mix Designation	Alccofine %	Compressive strength		
		3 DAY	7 DAYS	28 DAYS
Control (Mix 6)	**-**	**60.0**	**89.4**	**110.8**
AL-1	2	56.7	82.5	107.9
AL-2	4	62.8	85.7	108.2
AL-3	6	54.3	72.3	109.4
AL-4	**6**	**68.8**	**94.2**	**113.5**



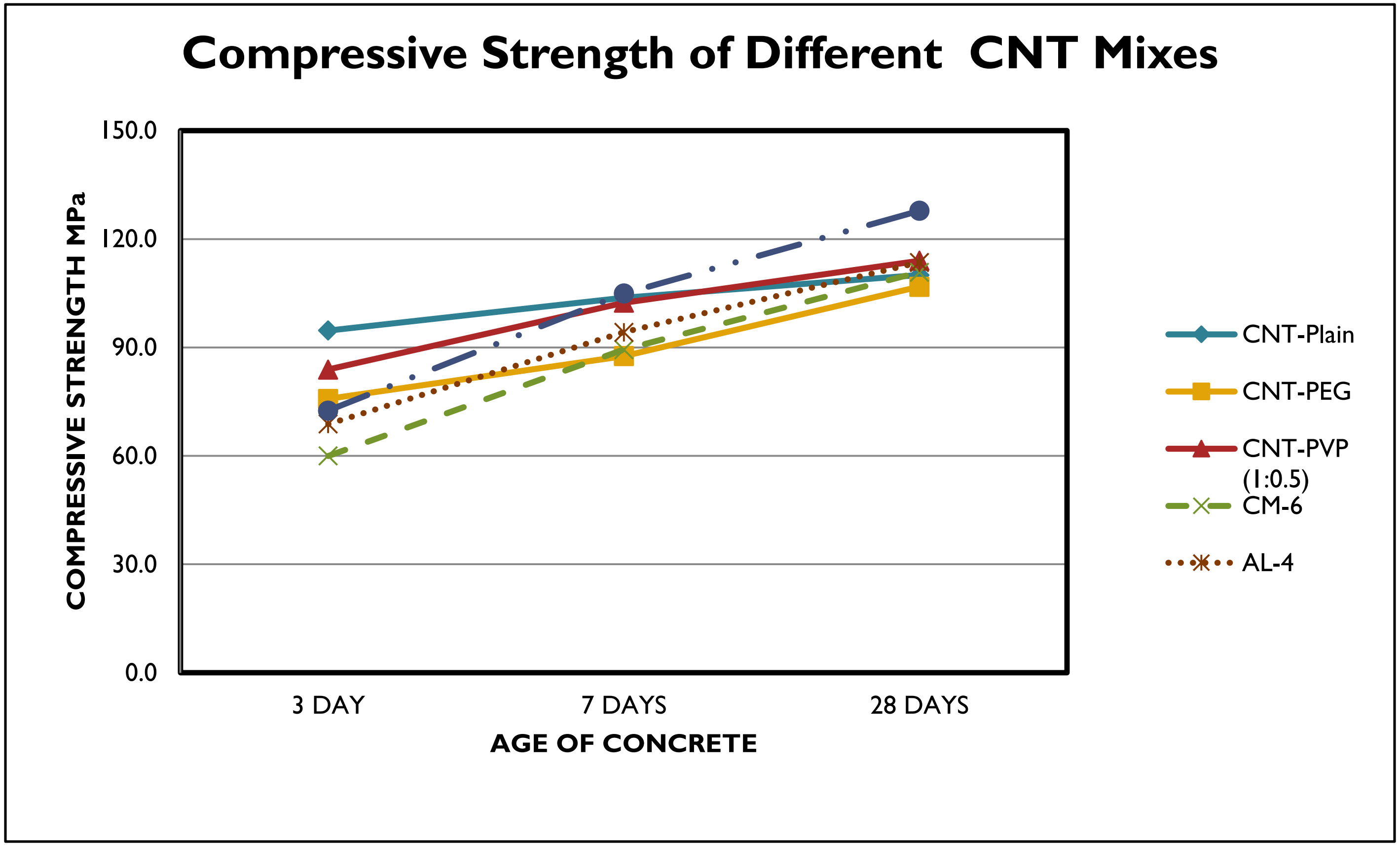
3. Graphene Oxide Mixes

Mix Designation	GO % Addition	Compressive strength		
		3 DAY	7 DAY	28 DAY
CM-6	**-**	**60**	**89.4**	**110.8**
AL-4	**-**	**68.8**	**94.2**	**113.5**
GO-1	0.025	63.1	70.0	108.2
GO-2	0.05	74.1	93.1	116.9
GO-3	0.10	61.2	85.5	109.3
GO-4	**0.15**	**72.5**	**104.9**	**127.8**



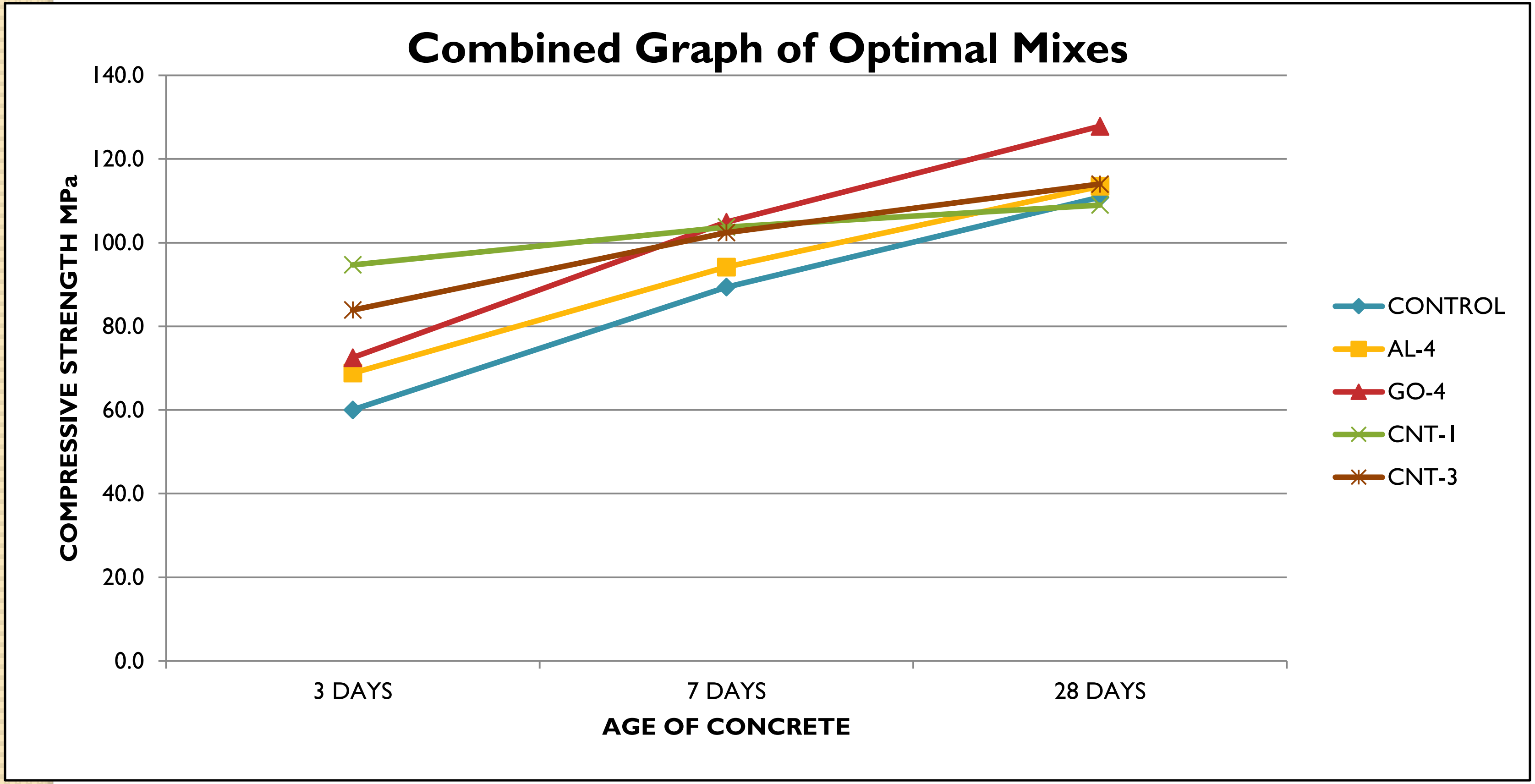
4. Carbon Nano Tube (CNT) Mixes

Mix Designation	CNT % addition	Compressive strength		
		3 DAY	7 DAYS	28 DAYS
AL-4	**-**	**68.8**	**94.2**	**113.5**
CNT -1 (Plain)	0.05	94.7	103.8	110.0
CNT-2 (PEG)	0.05	75.8	87.6	106.8
CNT -3 (PVP 1:0.5)	0.05	83.9	102.4	114.0

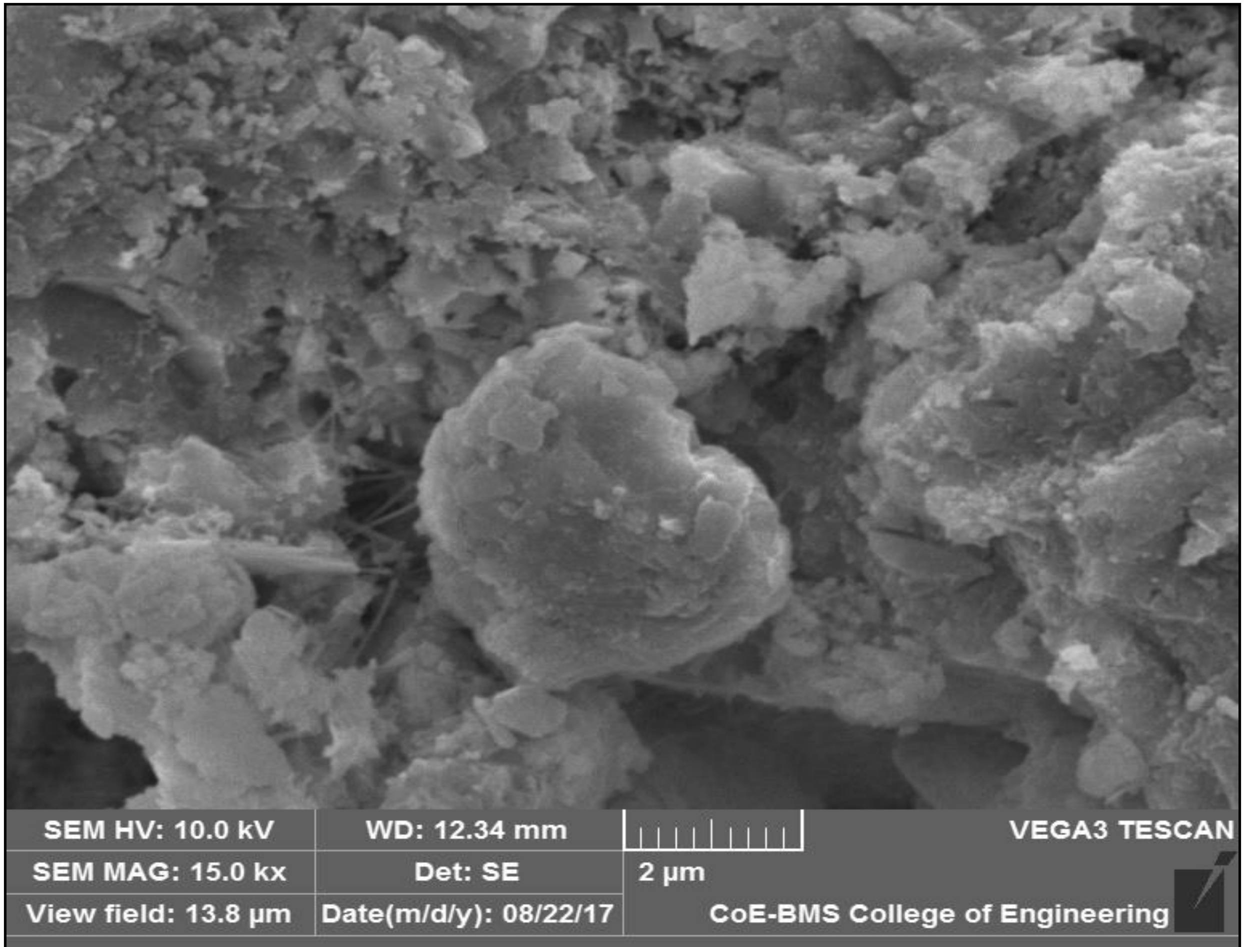


Compressive strength of optimum mixes.

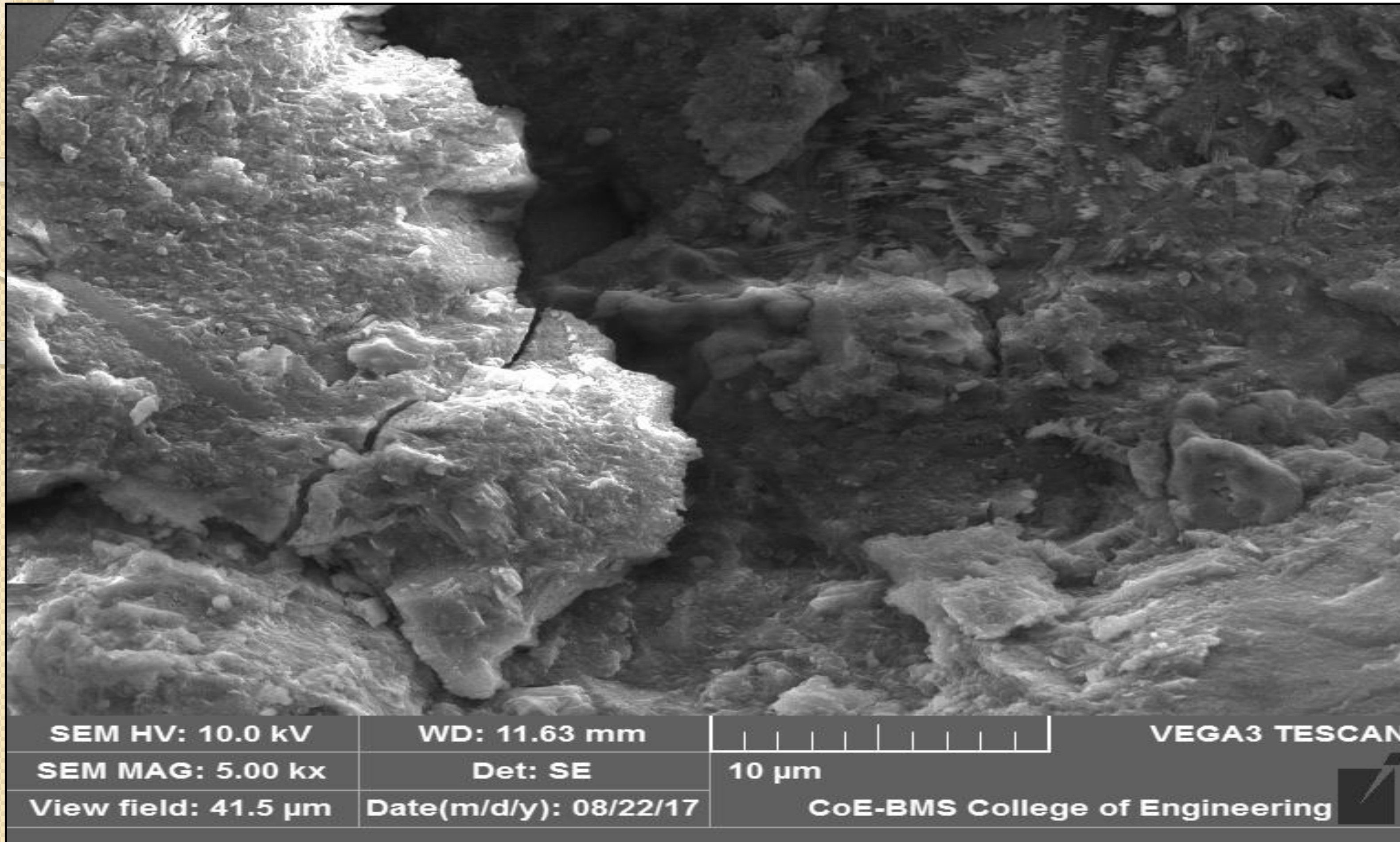
Mix Designation	3 DAYS	7 DAYS	28 DAYS
CONTROL CM-6	60.0	89.4	110.8
AL-4	68.8	94.2	113.5
GO-4	72.5	104.9	127.8
CNT- 1 (Plain)	94.7	103.8	110.0
CNT -3 (PVP 1:0.5)	83.9	102.4	114.0



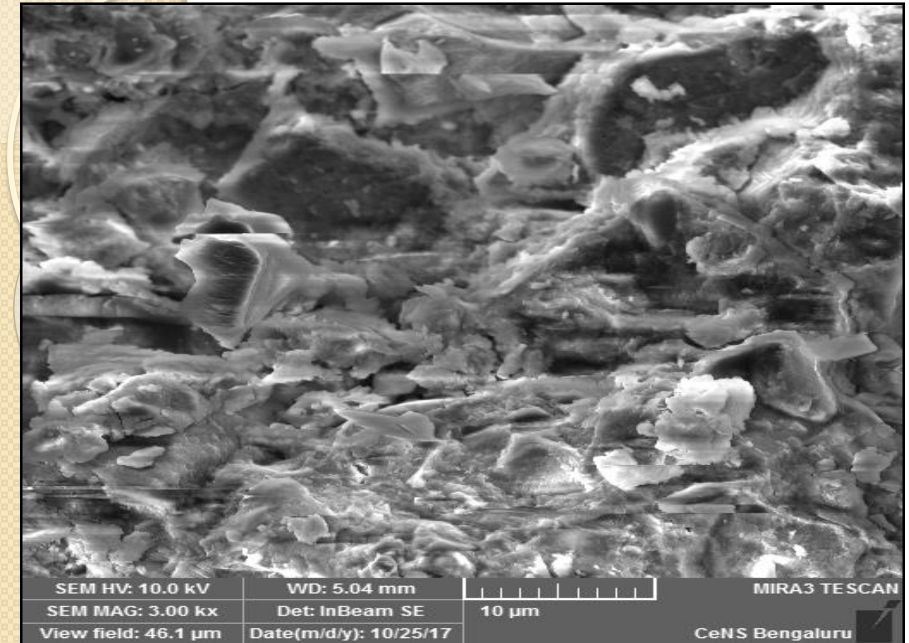
SEM Studies



Control mix 6 (CM-6)

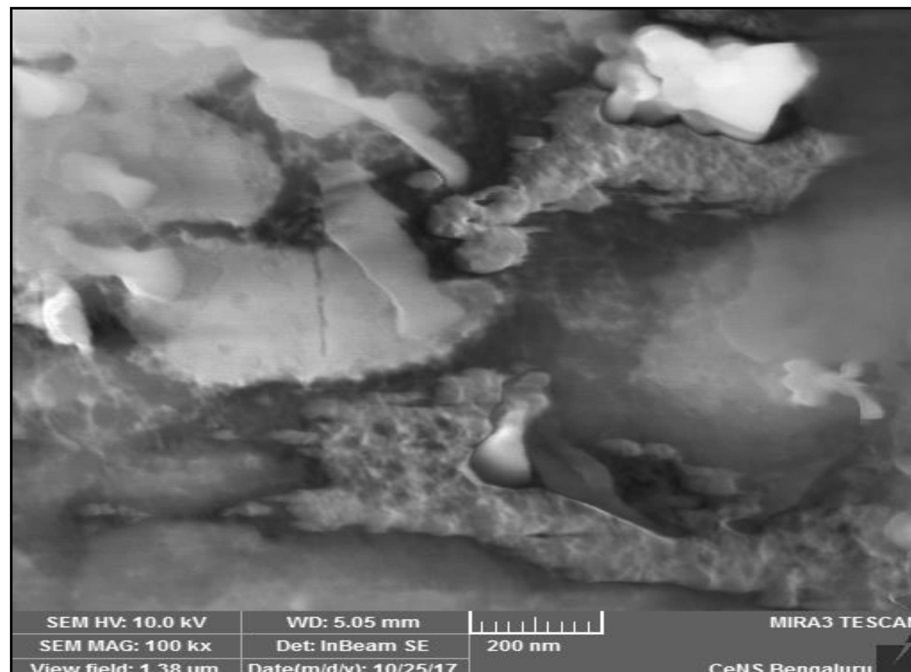


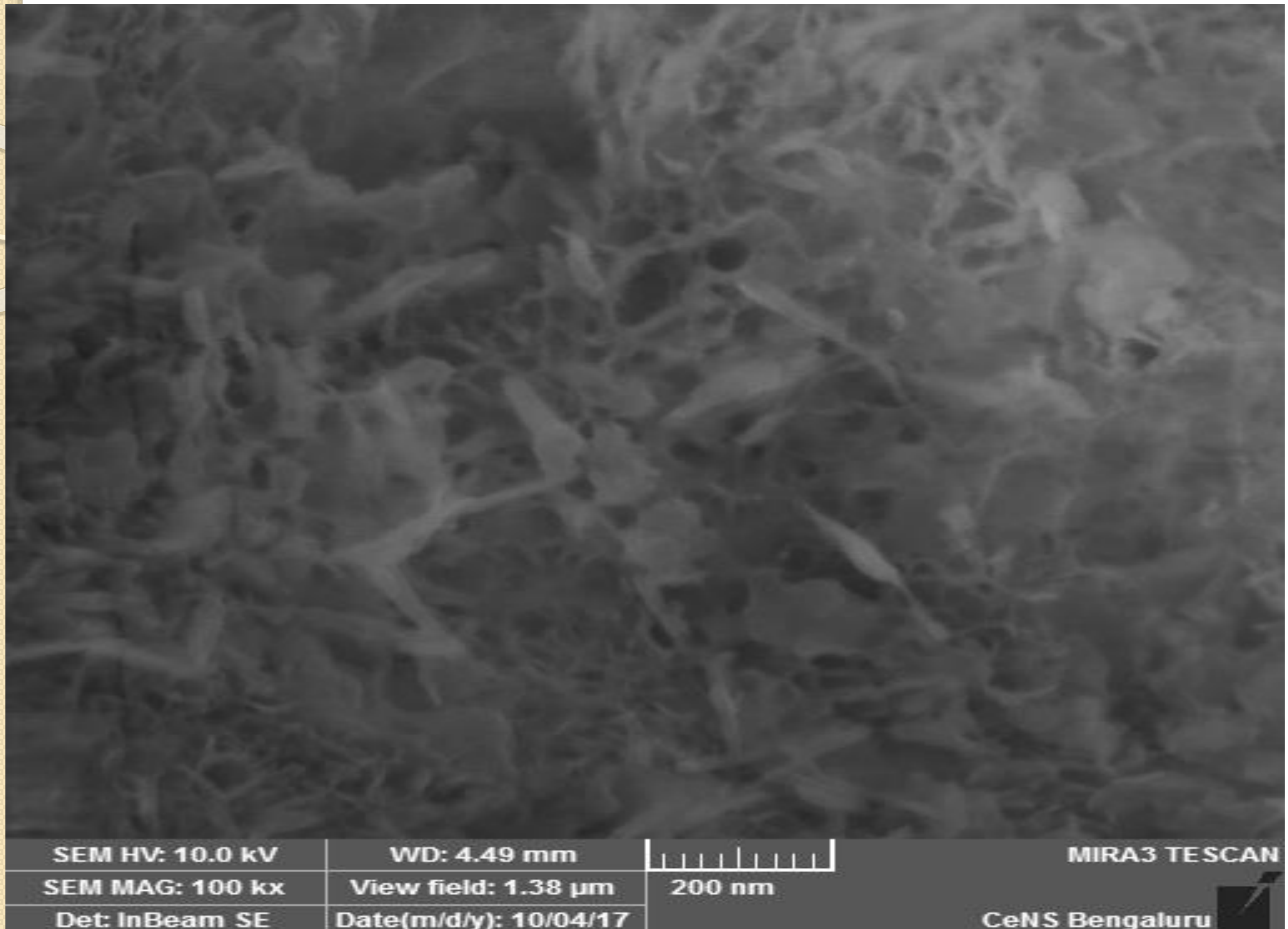
SEM image of Alccofine control at 5kx



SEM image of GO-4 at 3kx

SEM image of GO-4 at 100kx





SEM of CNT-3 mix at 100kx

High Early Strength Concrete

MATERIAL CHARACTERIZATION

Physical properties of cement, fly ash and Alccofine.

Property	Cement	Fly Ash	Alccofine
Specific Gravity	3.14	2.1	2.6
Fineness, m^2/Kg	280	400	1200×10^3

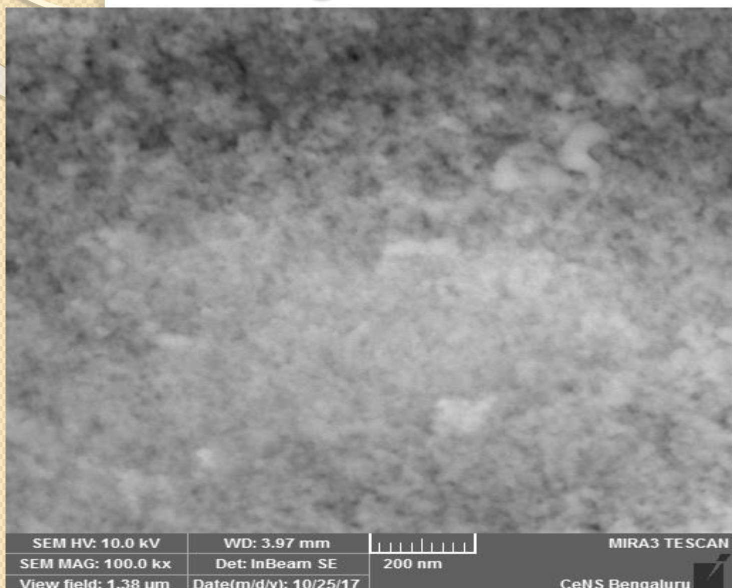
AGGREGATES

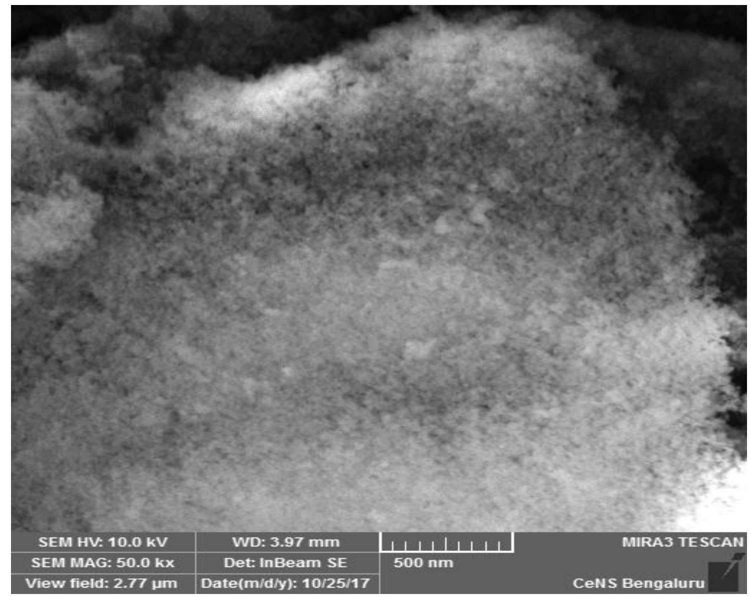
Property	Coarse Aggregate		Fine Aggregate
	20mm	12.5 mm	River sand
Specific Gravity	2.67	2.65	2.62
Water Absorption (%)	0.3	0.3	1.3

Physical and Chemical Properties of Nano Silica. (SOURCE: supplier)

Test item	Standard Requirements	Test results
Specific Surface area (m^2/Kg)	200000 ± 20000	202000
pH value	3.7 - 4.5	4.12
Loss on drying @105 degree celsius (%)	≤ 1.5	0.47
Loss on ignition @100 degree celsius (%)	≤ 2.0	0.66
Sieve Residue (%)	≤ 0.04	0.02
Tamped Density (gm/ltr)	40 – 60	44
SiO_2 Content (%)	≥ 99.8%	99.88%
Carbon Content (%)	≤ 0.15	0.06
Chloride Content (%)	≤ 0.0202	0.009
Al_2O_3	≤ 0.03	0.005
TiO_2	≤ 0.02	0.004
Fe_2O_3	≤ 0.003	0.001
Specific Gravity	-	2.3
Mean particle size	-	17 nano meter

FESEM Images of NS



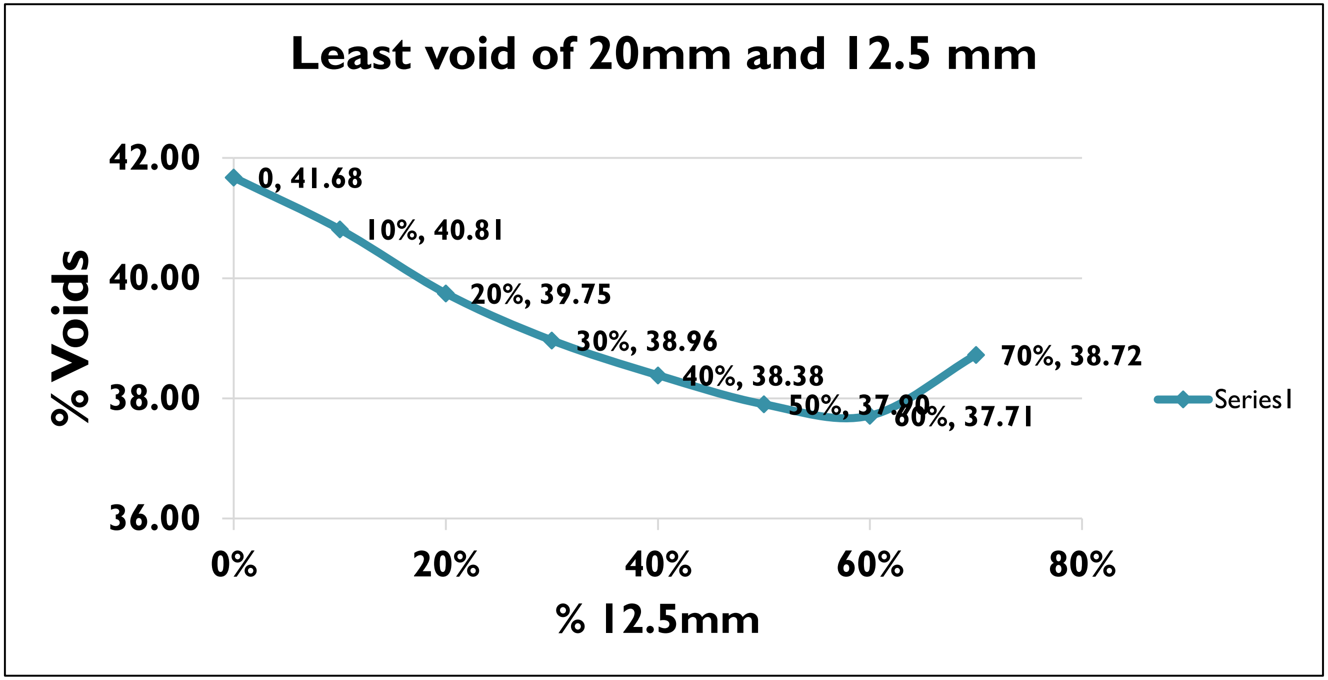


CHEMICAL ADMIXTURE

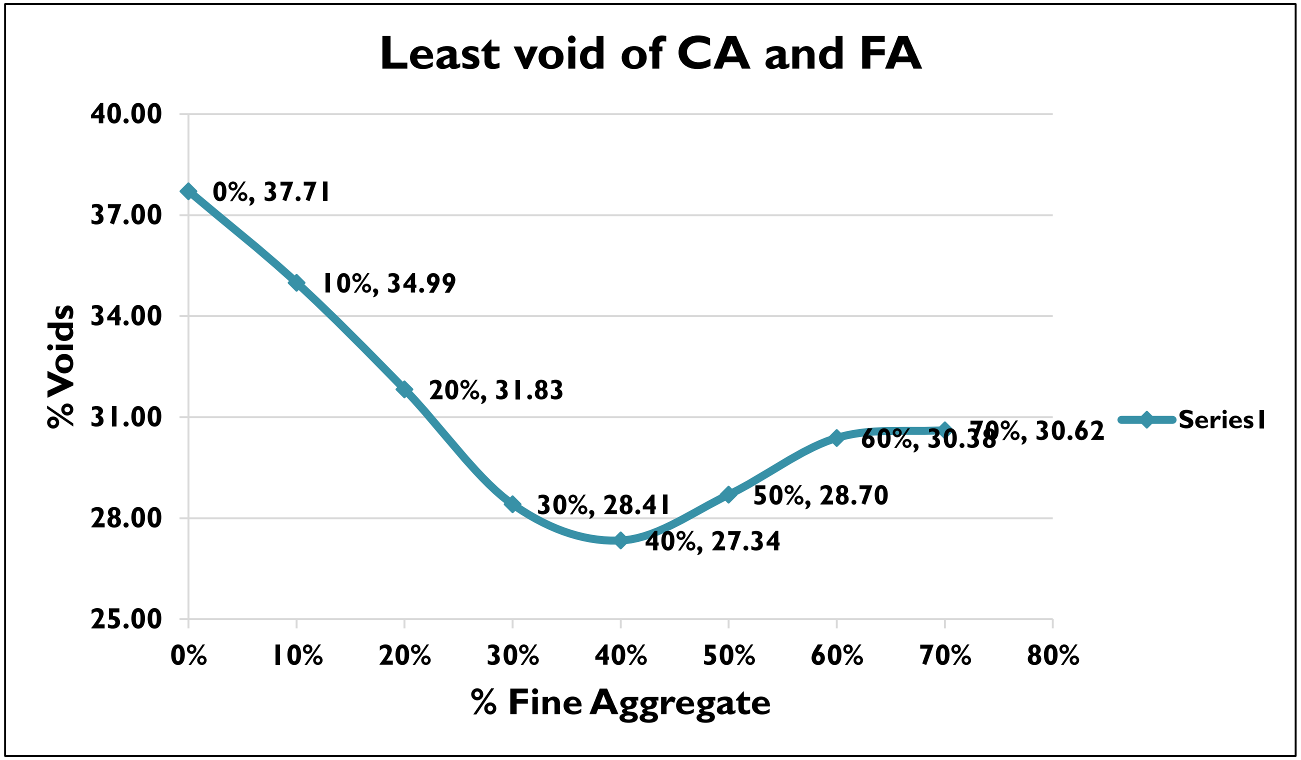
- For current studies BASF MasterGlenium Sky 8233 is used. It is a High Range Water Reducing admixture based on Poly Carboxylic Ether (PCE).
- In all mixes, the amount of superplasticizer is added such that no bleeding or segregation was reported.

Methodology

LEAST VOID OF AGGREGATES



% Void – 37.71
40 %(20mm) : 60 %(12.5mm)



% Void – 27.4 %
60 % CA : 40 % FA

Mix proportioning of control mixes

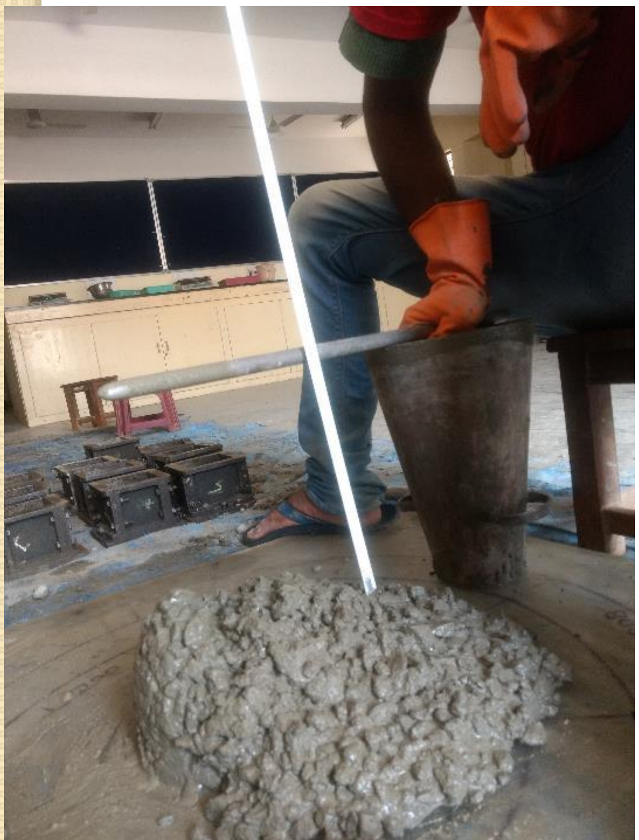
Mix	Vp	Cement Kg/m^3	Fly Ash Kg/m^3	Water Kg/m^3	CA (20 mm) Kg/m^3	CA (12.5 mm) Kg/m^3	FA Kg/m^3	Slump/ Flow (mm)	3 days Strength (MPa)
C-1	0.27	425	-	135.5	467.8	696.4	765	55	47.2
C-2	0.29	450	-	144	454.9	677.3	744	100	44.6
C-3	0.30	450	21	144	450.4	670.7	736.8	150	64.7
C-4	**0.32**	**450**	**77.7**	**144**	**433.2**	**645**	**708.4**	**205**	**70.0**
C-5	0.35	450	134.4	144	415.9	619.1	680.2	530	65.5
C-6	0.38	450	191.1	144	398.6	593.3	652	595	56.1

Mix	Cement Kg/m³	Fly Ash Kg/m³	Alccofine Kg/m³	nS Kg/m³	Water Kg/m³	CA (20 mm) Kg/m³	CA (12.5 mm) Kg/m³	FA Kg/m³	Slump (mm)	3 days Strength (Mpa)
CSD-1 (0.25%)	450	77.7	54	1.125	144	420.2	625.5	686.8	200	72.1
CSD-2 (0.5%)	450	77.7	54	2.25	144	420.2	625.5	686.8	190	76
CSD-3 (1%)	**450**	**77.7**	**54**	**4.5**	**144**	**420.2**	**625.5**	**686.8**	**190**	**76.9**
CSD-4 (1.5%)	450	77.7	54	6.75	144	420.2	625.5	686.8	185	81.8
CSP-1 (0.25%)	450	77.7	54	1.125	144	420.2	625.5	686.8	200	81.6
CSP-2 (0.5%)	450	77.7	54	2.25	144	420.2	625.5	686.8	185	83.7
CSP-3 (1%)	**450**	**77.7**	**54**	**4.5**	**144**	**420.2**	**625.5**	**686.8**	**175**	**85.1**
CSP-4 (1.5%)	450	77.7	54	6.75	144	420.2	625.5	686.8	165	86.9

Incorporation of nano silica

nS addition in dispersed state (CSD)

nS addition in powdered state (CSP)

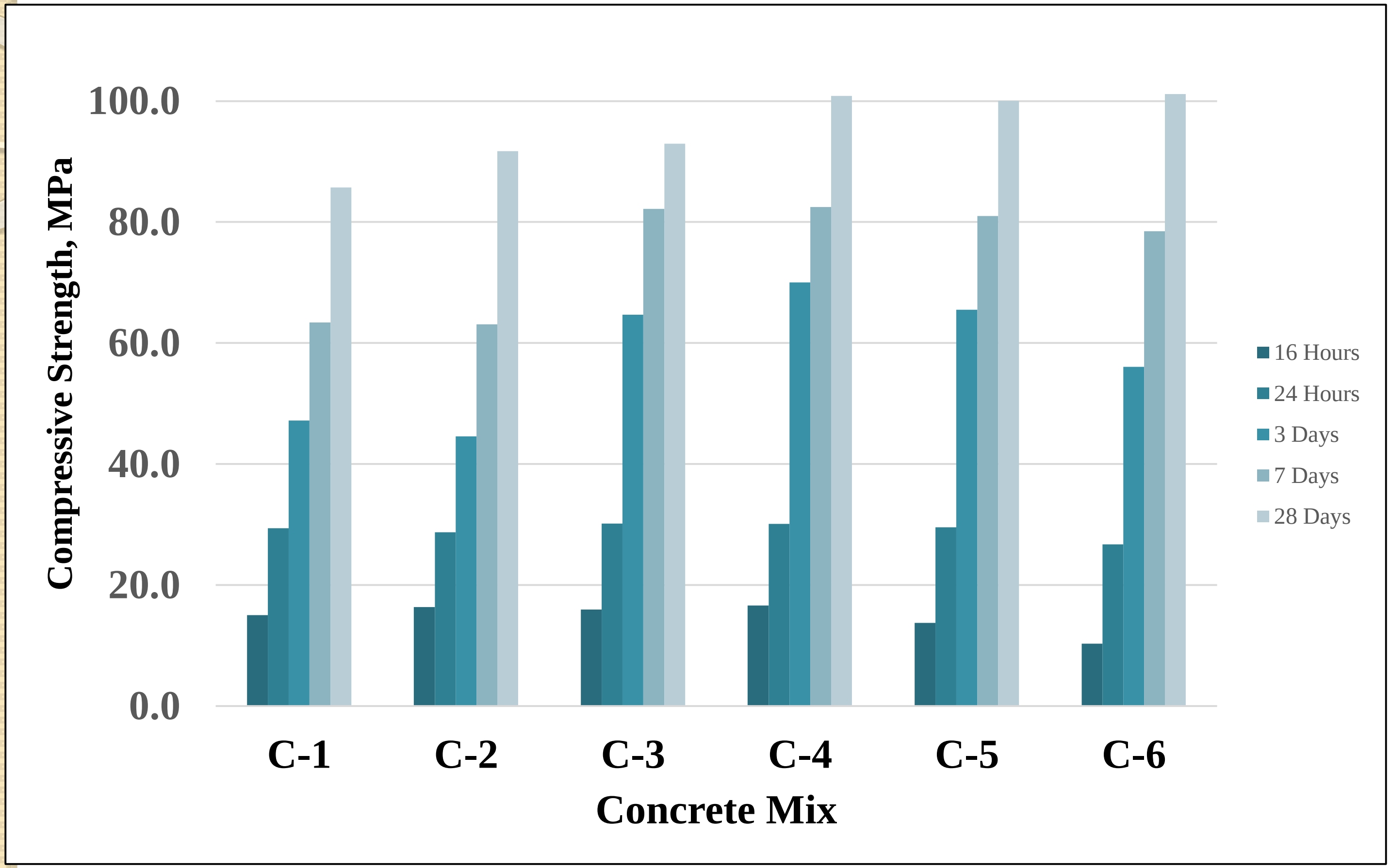


Slump of C-4/ Control-1

Slump of CSP-3

Compressive Strength Of Preliminary Mixes

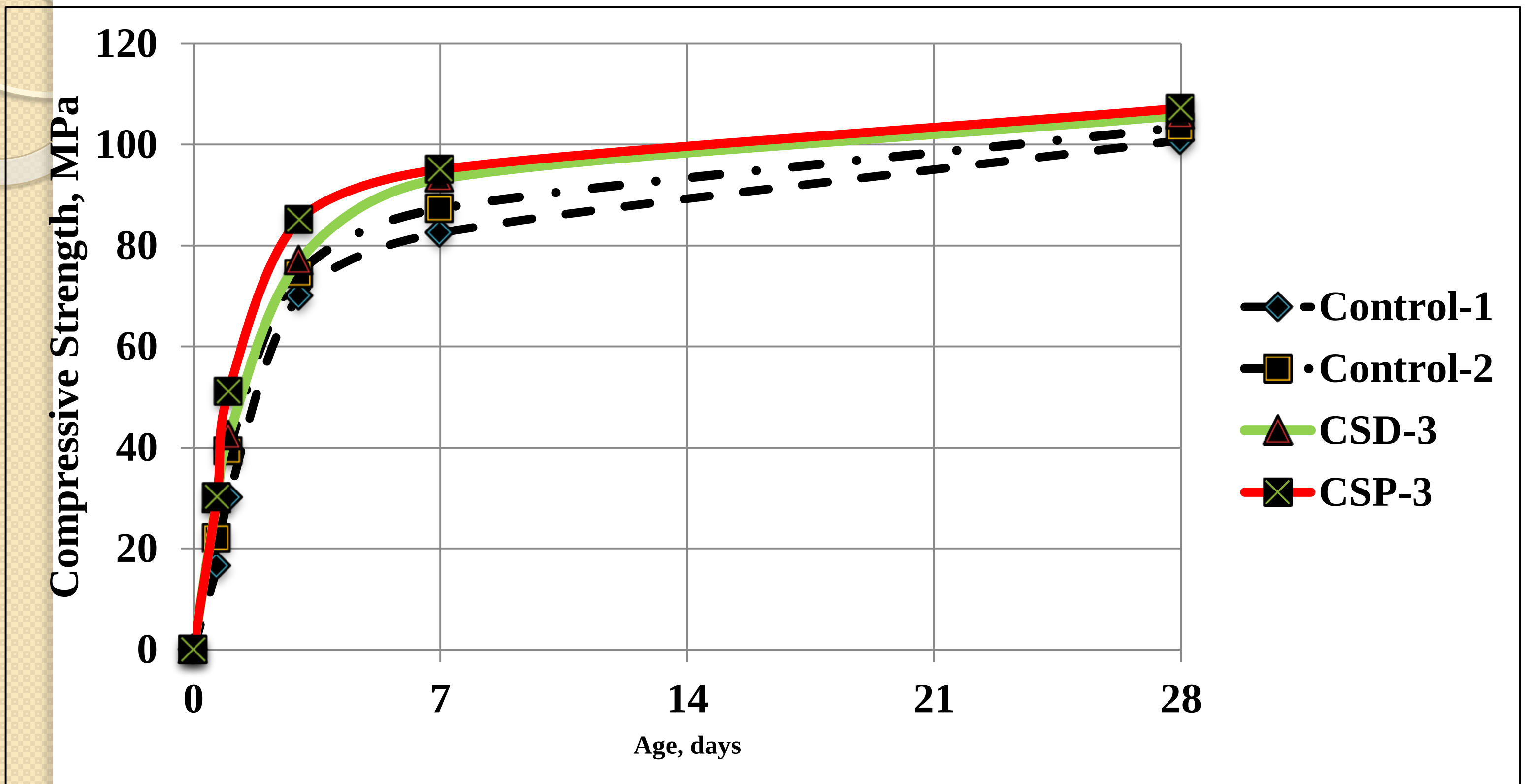
Mix	Compressive Strength, MPa				
	16 hours	24 hours	3 days	7 days	28 days
C-1	15.0	29.4	47.2	63.4	85.7
C-2	16.4	28.7	44.6	63.1	91.7
C-3	16.0	30.2	64.7	82.2	93.0
C-4	**16.6**	**30.1**	**70.0**	**82.5**	**101.0**
C-5	13.8	29.5	65.5	81.0	100.0
C-6	10.3	26.7	56.1	78.5	101.2



Compressive strength of hardened concrete samples preliminary mixes.

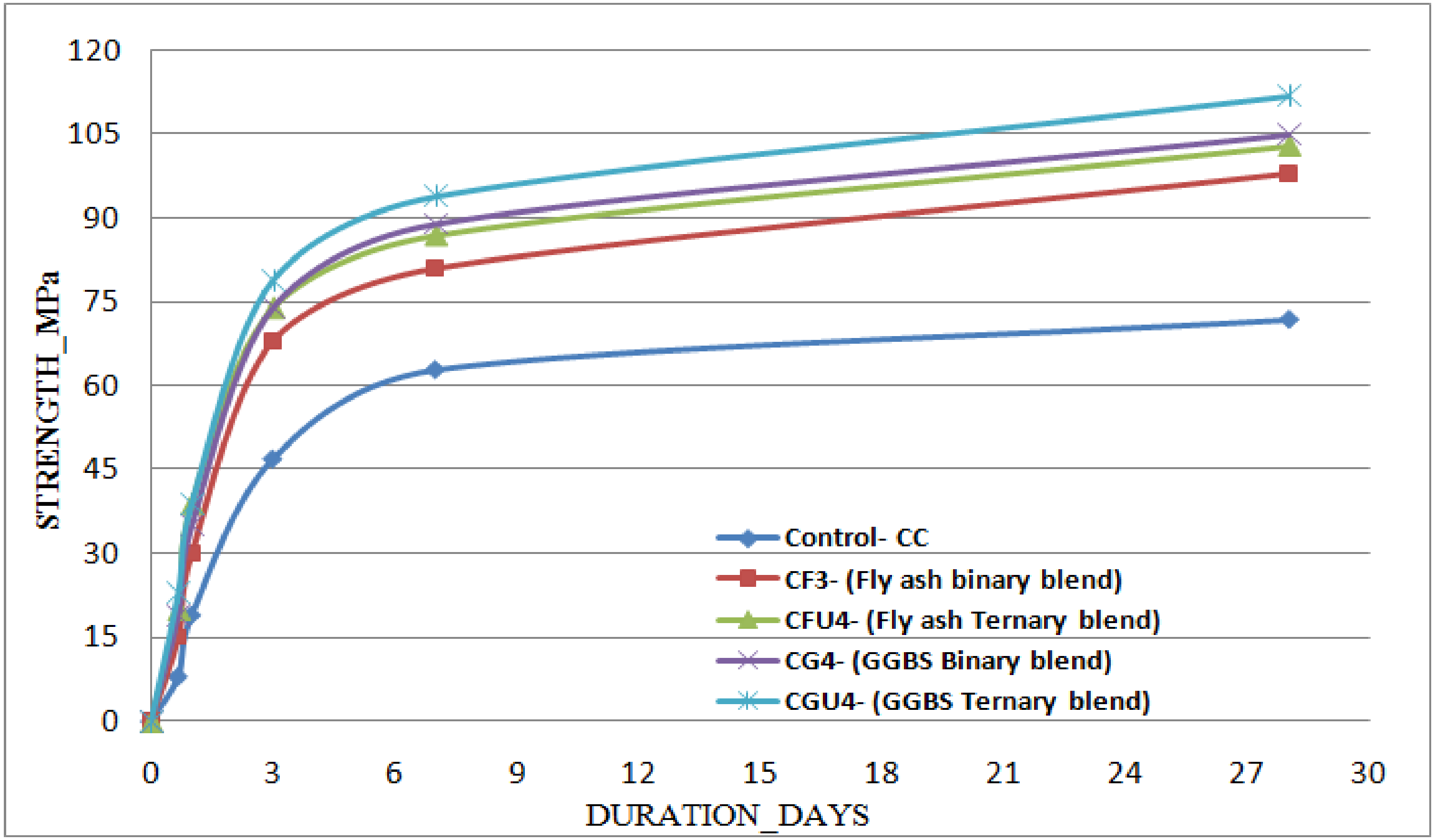
Compressive strength of mixes containing nS.

Mix	% nS	Compressive Strength, MPa				
		Curing Age				
		16 hours	24 hours	3 days	7 days	28 days
CSD-1	0.25	24.7	40.7	72.1	82.9	101.1
CSD-2	0.5	31.0	42.7	76.0	87.9	105.8
CSD-3	**1**	**29.9**	**42.3**	**76.9**	**93.2**	**105.8**
CSD-4	1.5	28.7	38.3	81.8	87.2	111.5
CSP-1	0.25	22.5	43.1	81.6	91.8	110.2
CSP-2	0.5	30.9	50.7	83.7	94.2	105.4
CSP-3	**1**	**30.3**	**51.1**	**85.1**	**95.1**	**107.2**
CSP-4	1.5	34.6	47.2	86.9	96.0	109.0



Compressive strength variation of optimal concrete mixes.

Strength comparison of HSC



For Fly ash and GGBS blended Concrete specimen- BMSCE, Bengaluru

Limitations

- Mix optimization requires technical knowledge and related skills for achieving repeatability.
- Risk of excessive shrinkage if the cementitious materials are not well proportioned.
- Demand for high quality control.
- High quality material selection, costly than medium quality materials.
- Requirement of special mixing and curing methods in most cases.
- Considerable testing and evaluation required to mitigate risks of strength reduction in Field produced HSC.

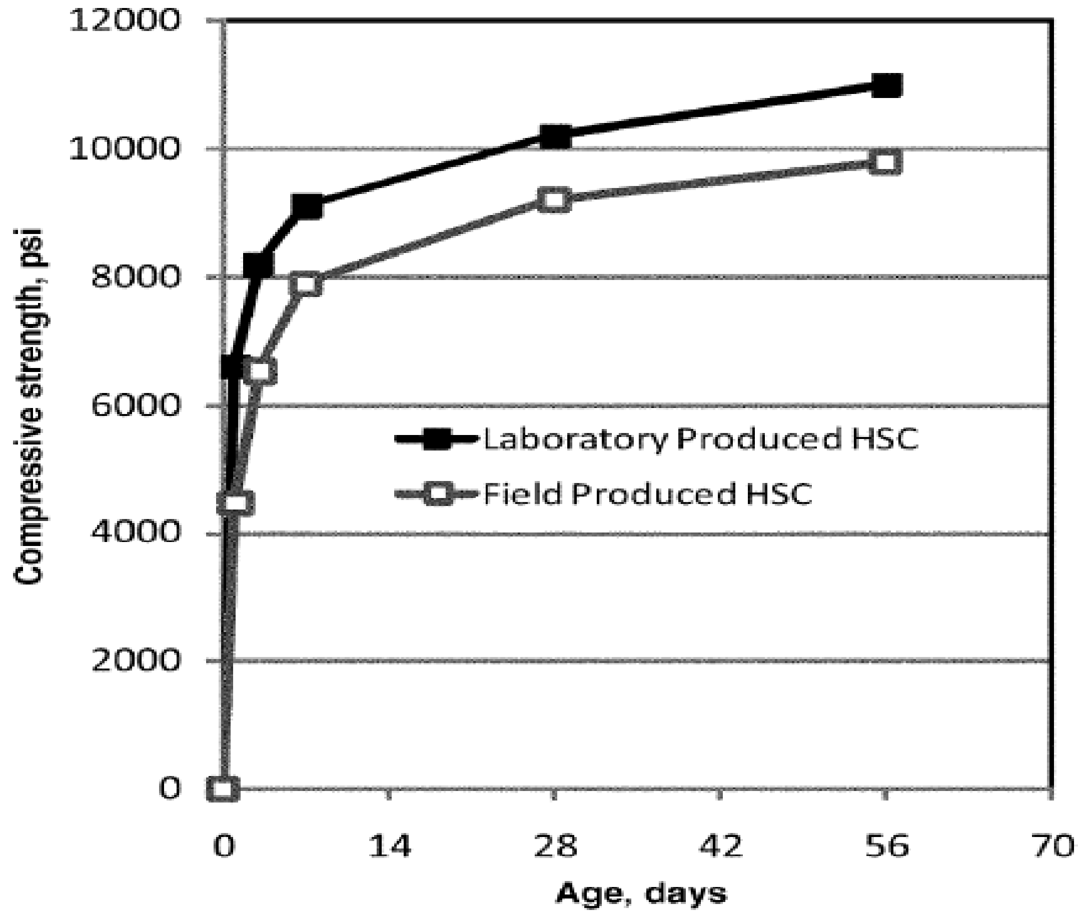


Fig. 4.3—Laboratory-molded concrete strengths versus ready mixed field-molded concrete strengths for 9000 psi (62 MPa) concrete (adapted from Myers [1999]).

Challenges in Implementation

Technological	*Lack of Reproducibility of HSC at commericial scale due to variability in material sourcing/equipment/competency*

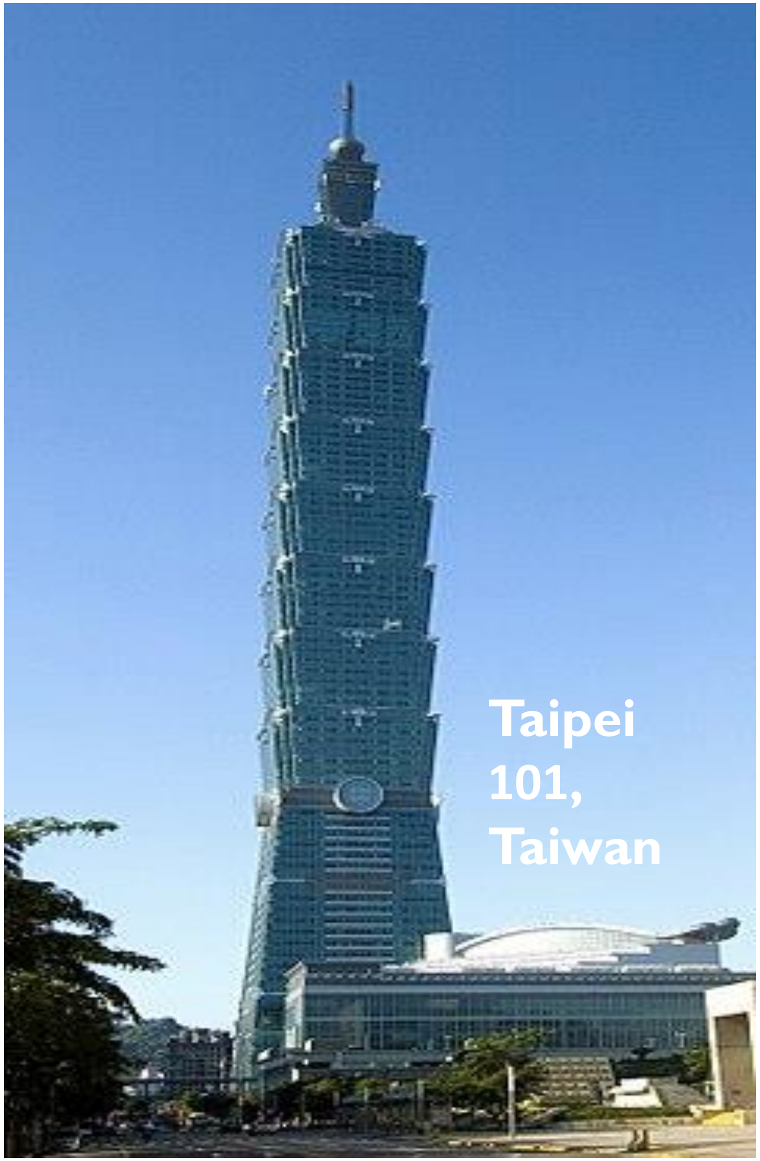
Economical	*Less concern on long term economic benefits* *High initial investment in material and manufacturing facility*

Social	*Lack of demand for Advanced concrete technology* *Lack of support from financial and regulatory authorities.*

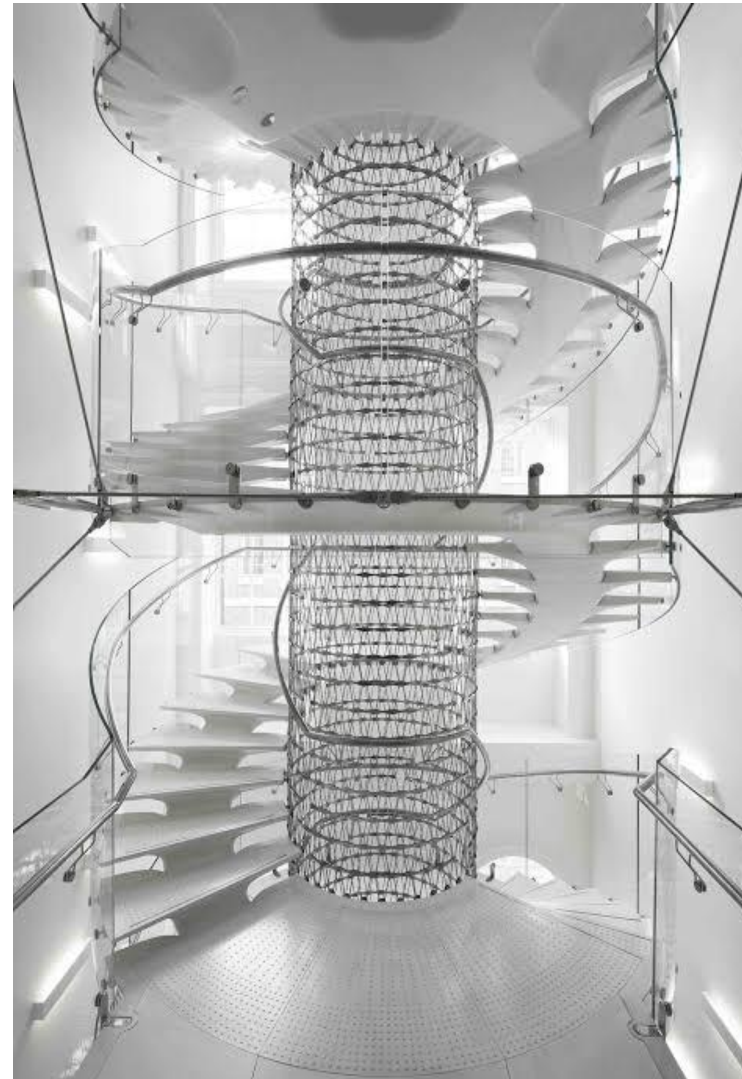
Few prominent structures realized by HSC/ HPC

Footbridge of Peace, Seoul, South Korea.

High rise buildings



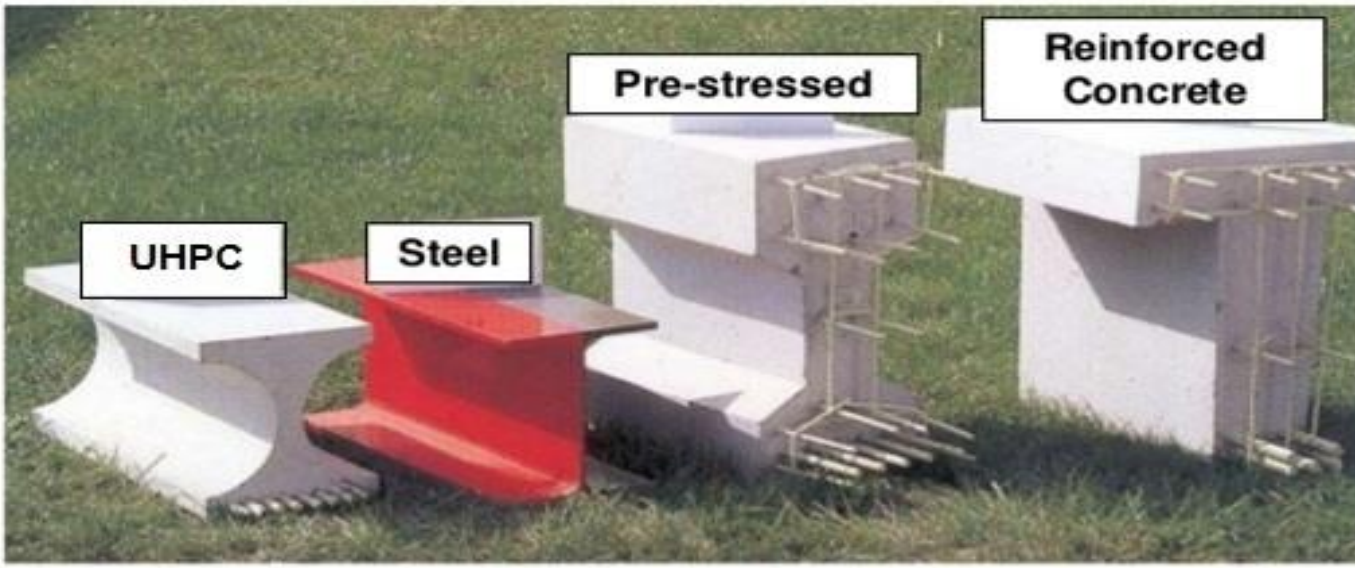
Staircase units



Precast beam sections

Ultra-High Strength

Beams of Equal Load Carrying Capacity



Mass (weight) of Beams

kg/lineal meter	140	112	467	530
lbs/lineal ft.	94	75	313	355

J. J. Fly over, Mumbai.

Recent Pride…Statue of Unity

Thank you…