Moving Towards Net Zero in Concrete Constructions – Opportunities & Challenges

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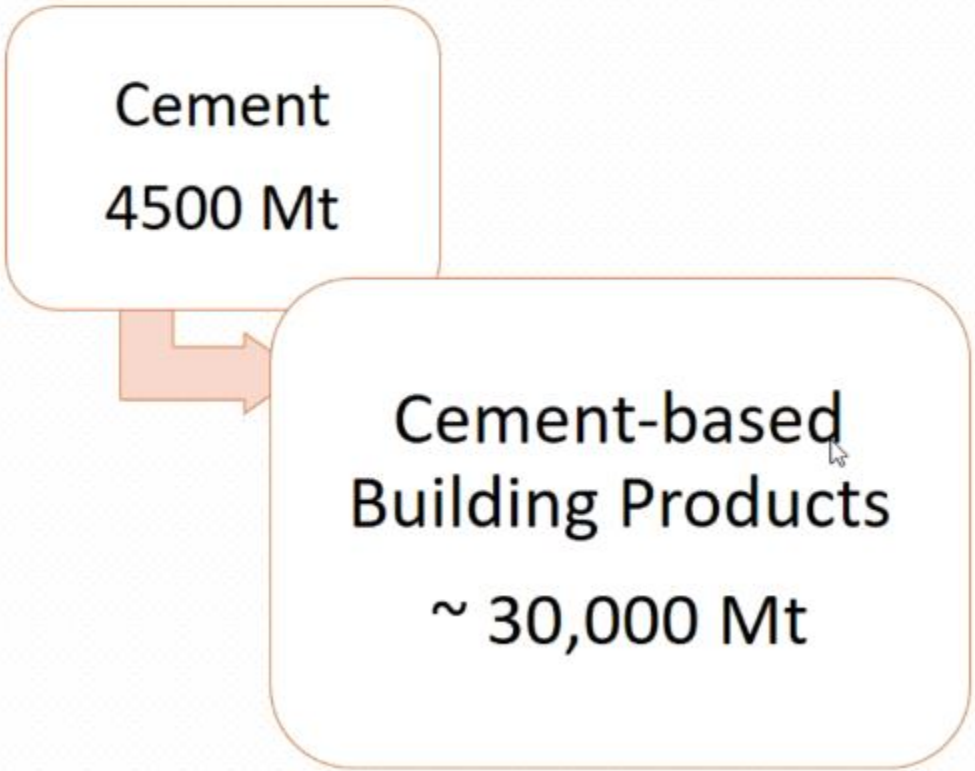
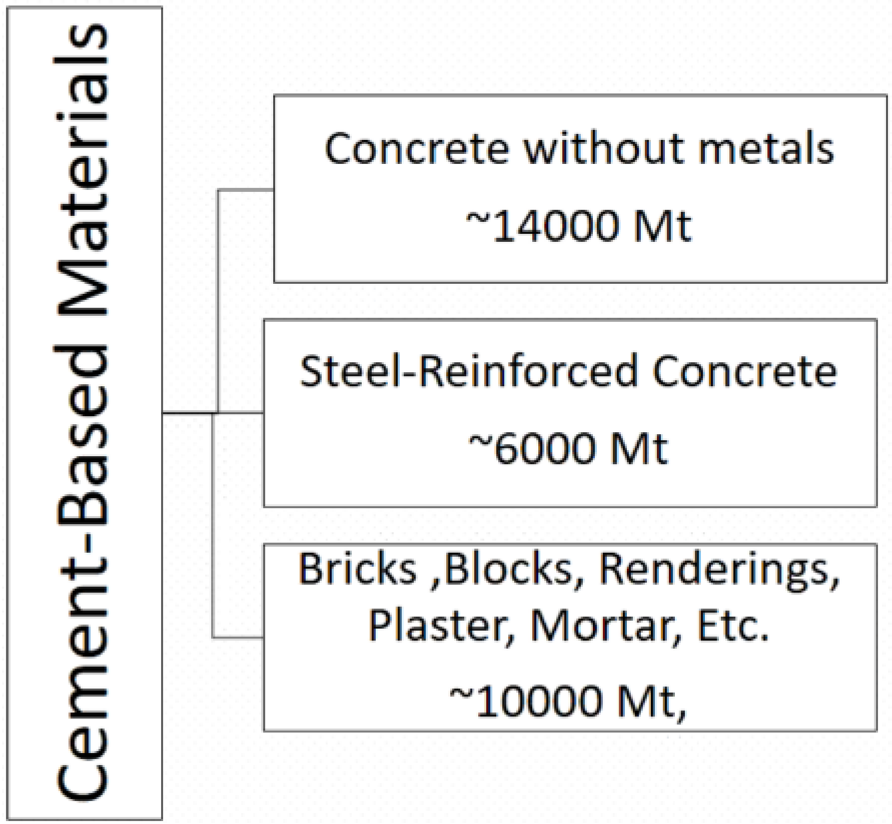
Approximate Volume Expansion of Cement Based Building Materials From The Global Cement Production Base



Broad Groups of Cement-Based Building Materials



Cement & Concrete Scenario in the Coming Decade in India

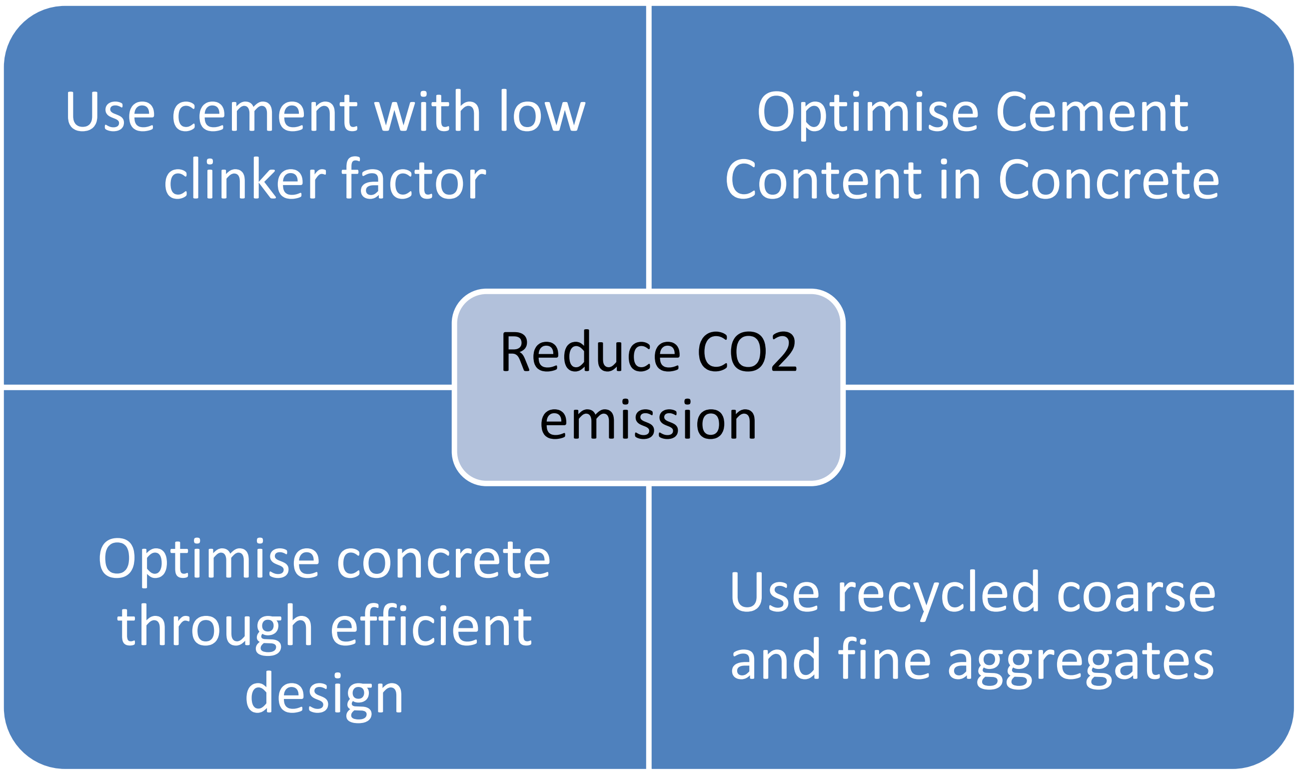
Parameters, Mt/Year	2019	2027
Cement capacity	550	600
Cement production	335	510
Cement-based building products	2200	3400
Structural concrete	1450	2250
Reinforced cement concrete	380	585

Sustainability – The Urgency!

- **Net Zero CO_2 target for Cement – 2070**
- **Net Zero CO_2 target for Concrete - 2050**

- Investors are now questioning
  - WB, Indian Banks – Govt & Private Sector
  - What's your Green House Gas emission
  - Carbon footprint and steps to reduce it on a timeline
- Carbon Border Adjustment Mechanism (CBAM)
  - $ 20 per MT or 30% additional tax
  - Cement, Aluminium, Steel
- Carbon Capture, Utilisation & Storage (CCUS)

Strategies for CO_2 Emission Reduction in Concrete



CO_2 Emissions from Cement Industry

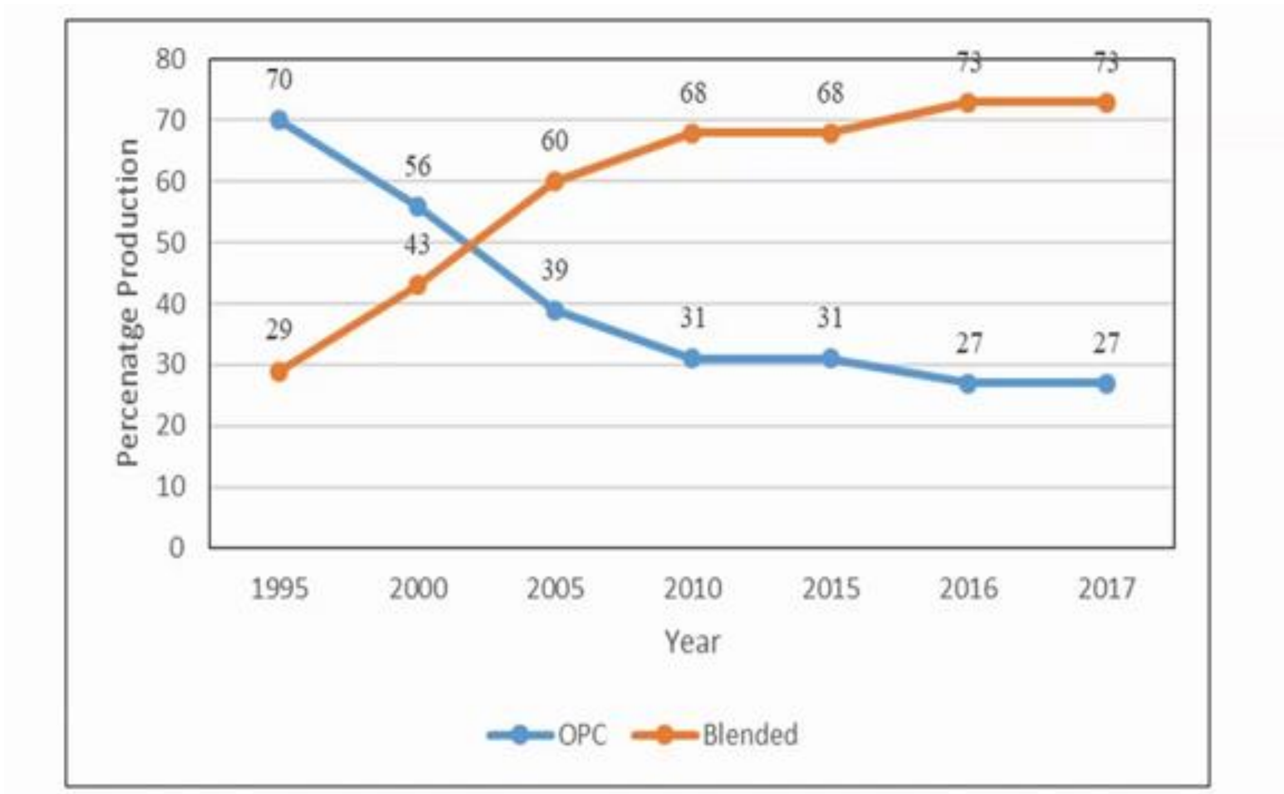
- *Global Cement Sector generates 2.8 b MT of CO2 – equivalent to 7 % of total emissions*

- *Indian Cement industry is working on GHG emissions*
  - *1996 – Emission factor – 1.12 T of CO2*
  - *2017 – Emission factor – 0.67 T of CO2*
  - *2032 – (target) – 0.462 T of CO2*
  - *2050 – (target) – 0.35 T of CO2*

Low Carbon technology roadmap for the Indian Cement Industry

- *Clinker Substitution / reduction*
- *Alternate Fuel and Raw materials*
- *Improving Energy Efficiency / Renewable energy / Waste Heat Recovery (WHR)*
- *Newer Technologies – Novel Cements, Carbon capture & Storage / Utilisation*

Trend of Cement Production - India

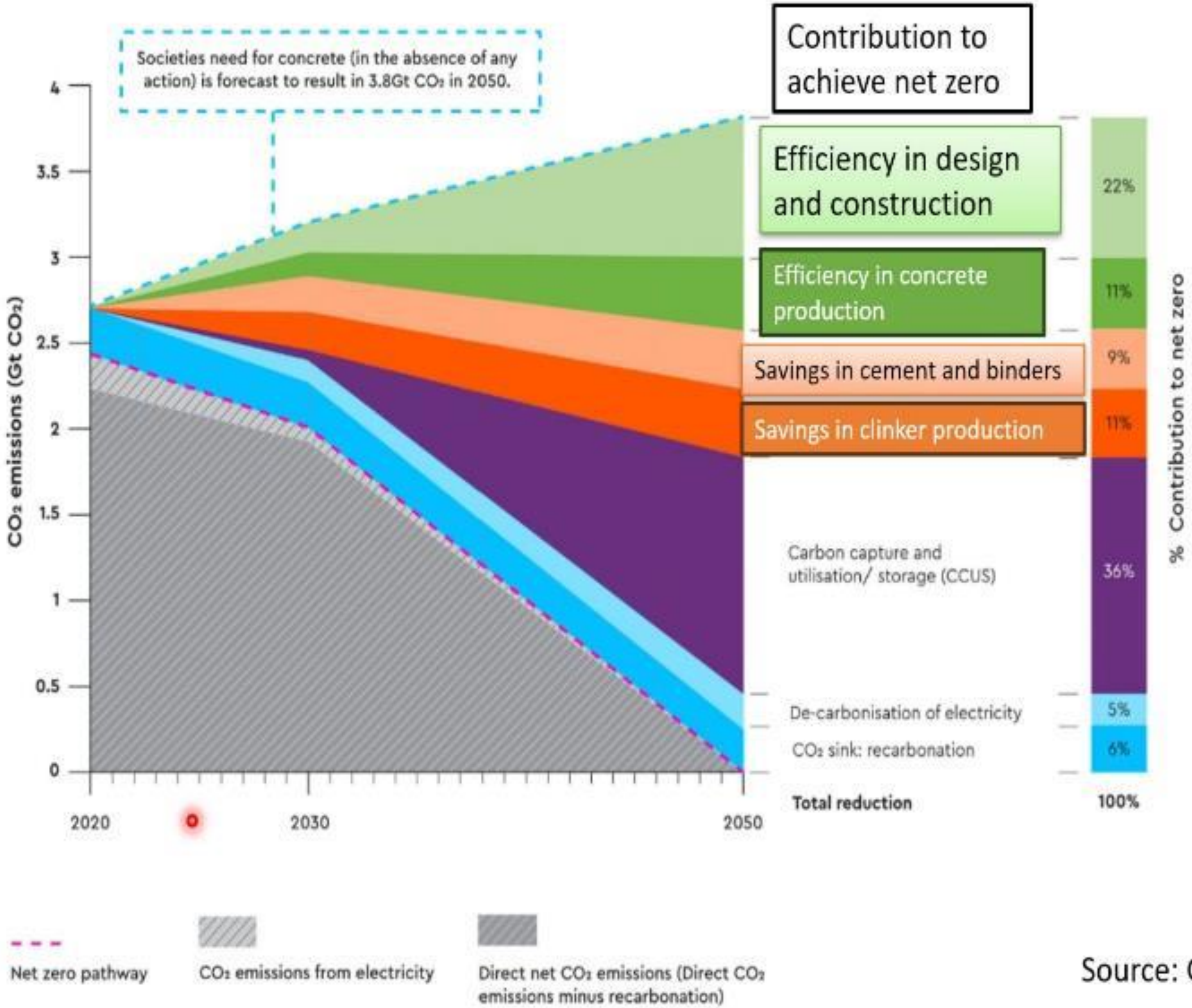


Global Status: Clinker-Cement Ratio

- China – 0.58
- Europe – 0.74
- USA – 0.72
- Germany – 0.71
- Ireland and Denmark – 0.90
- Netherlands – 0.46
- Japan / Korea/ Australia/ NZ – 0.79
- Russia – 0.88
- India – 0.74 (estimated to be 0.58 by 2050)

GETTING TO NET ZERO

Committed target – Net Zero by 2050

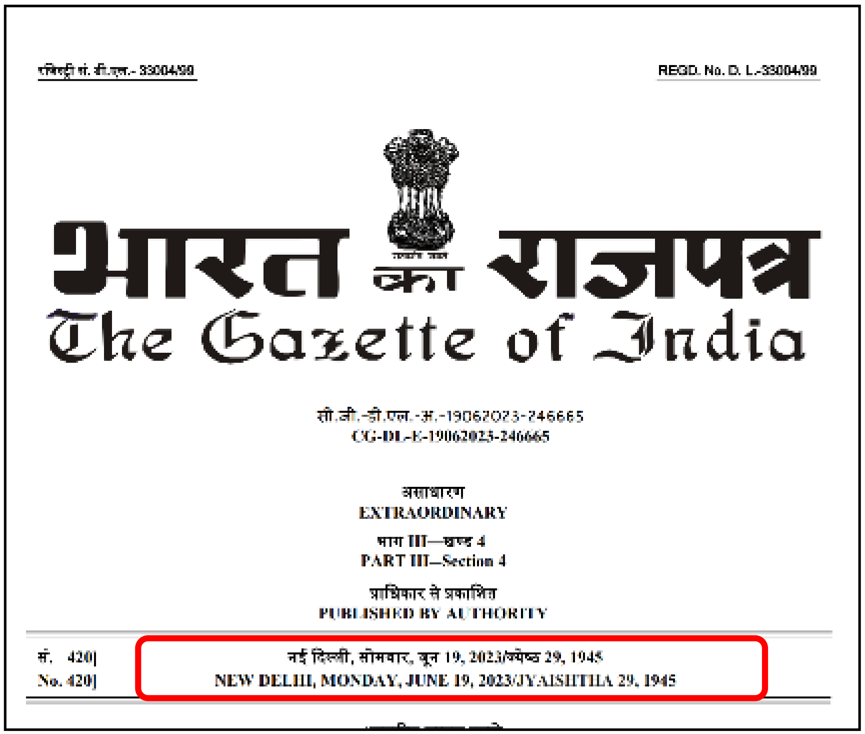


Source: GCCA

Composite Cement – IS:16415:2015 (Amended in 2023)

- *Portland cement clinker 45% (or OPC 50%)*
- *Fly ash : 10-25%*
- *Granulated slag : 25-40%*
- *Cement strength: 43 Mpa (equivalent to OPC 43)*

Limestone Calcined Clay Cement (LC_3)
IS:18189 - 2023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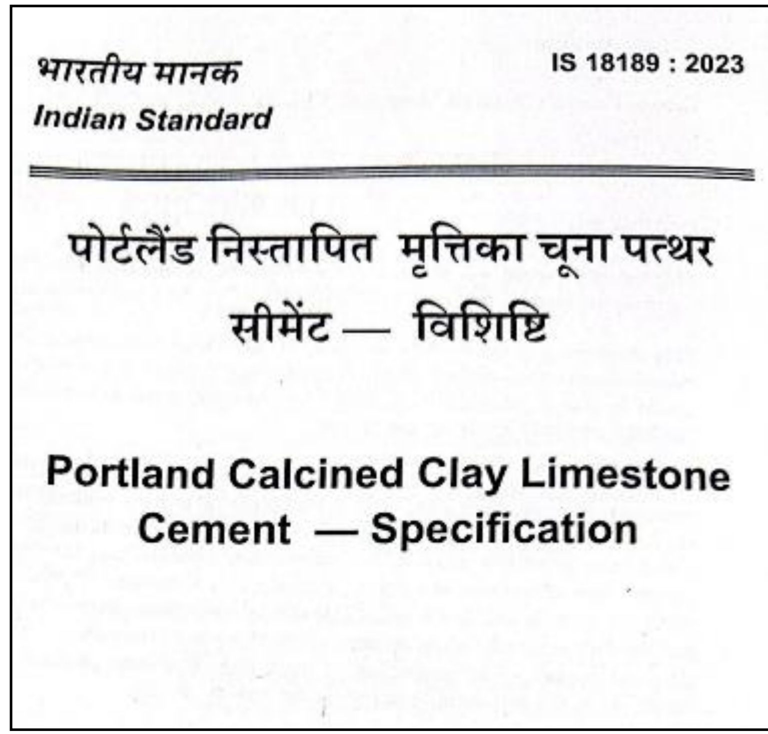
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IS 18189 : 2023

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Portland Calcined Clay Limestone Cement — Specification

Limestone Calcined Clay Cement (LC_3)
IS:18189 - 2023

Material composition:

- **Clinker min. 50 or OPC: 55%**
- **Calcined Clay: 10-35%**
- **Limestone: 5-20%**
- **Gypsum as per requirement**

Compressive Strength:

- **3 days: 23MPa**
- **7 days: 33MPa**
- **28 days: 43MPa**

(Strength is equivalent to OPC43 grade)

Raw Clay : min 40% Kaolinite
Calcined Clay: Lime Reactivity: min 8MPa.

Illustrative Comparison of Embodied CO2-e in M 30 Concrete

Parameter	No SCM	30% Fly ash	50% GGBS
Total cm	320	360	330
OPC	320	250	165
Fly ash	-	110	-
GGBS	-	-	165
CO2-e	292	228	161

Figures in (kg/m3)

Sustainable materials for Pavements
- Two Case Studies

HVFAC Pavement – Miyapur, Hyderabad

UltraTech Ready Mix Concrete Plant, Miyapur - Hyderabad

High Volume Fly Ash Concrete Road

High Volume Fly Ash Concrete Road

HVFAC Road Construction (UltraTech Experience)

Trial Mixes with High Volume Fly Ash

- 4 trial Mixes (2 with 40 mm MSA and 2 with 20 mm MSA) are highlighted

Trial No.	Cement kg	Fly ash kg	Sand kg	10 mm kg	20 mm kg	40 mm kg	Water lit	W/C	Admixtures lit	Slump mm	Compressive Strength (MPa)	
											7 day	28 day
1	250	150	650	325	275	600	155	0.39	1.8	90	32	45
2	225	225	708	265	265	530	120	0.27	4.0	80	36	47
3	225	225	708	530	530	-	158	0.35	2.0	120	28	43
4	225	225	708	636	424	-	132	0.29	4.0	100	32	46

Admixture – Sulphonated Naphthalene Condonsate (SNF) with Solid Content 42% and relative density 1.23 was used.

Test Results of Hardened concrete

Mix Type	Compressive Strength, Mpa					Flexural strength, Mpa	Split tensile strength, MPa	Water permeability m/sec
	Lab. Specimens				Cores	Lab. Specimens		
	7-d	28-d	56-d	74-d	74-d	56-d	56-d	56-d
OPC	40.0	53.0	56.0	58.0	51.0	6.2	1.9	3×10^{-10}
HVFA 20-mm (MSA)	35.0	51.0	58.0	62.7	58.5	6.9	2.4	2×10^{-11}
HVFA 40-mm (MSA)	34.0	49.0	56.0	61.3	54.0	6.4	2.1	3×10^{-11}

Concrete Road using LC3 Cement
- Dhar Cement Works, MP – Oct 2018

Concrete Road using LC3

- ***Limestone Calcined Clay Cement – LC3***
  - **50 % clinker**
  - **35 % calcined clay**
  - **15 % limestone**
- ***Low heat of hydration; green material***
- ***High early strength***
  - **3 days – 70 % of 28 day strength**
  - **7 days – 90 % of 28 day strength**

Laying – Manual Method

- **12 hrs – of concrete curing**

Performance Comparison: OPC vs. LC3

- *LC3 has lower Setting Times – Initial and Final*
- *It gains High early Strength – hence, faster curing is required*
- *Stickiness of LC3 is higher as compared to OPC*
- *To achieve desired workability (50 to 60 mm), LC3 needs higher w/c ratio and higher dosage of admixtures*
- *Early cutting of grooves is essential*
- *Colour of LC3 is darker*
- *Abrasion resistance is higher in LC3 (compared with OPC)*

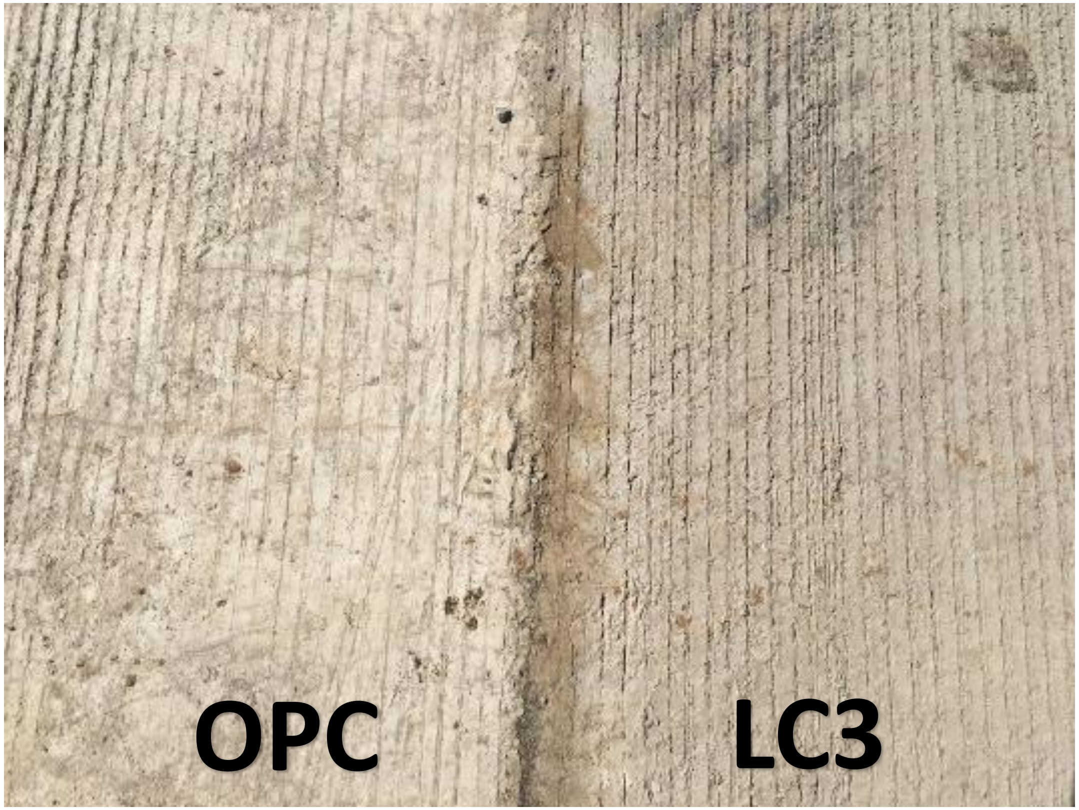
Mix Design: Concrete with LC3

Sample Taken for 1 Cum					
Cement	CA-II	CA-I	M- Sand	Water	Admixture
450 Kg	784 Kg	400 Kg	726 Kg	156 L (0.35%)	1.3%

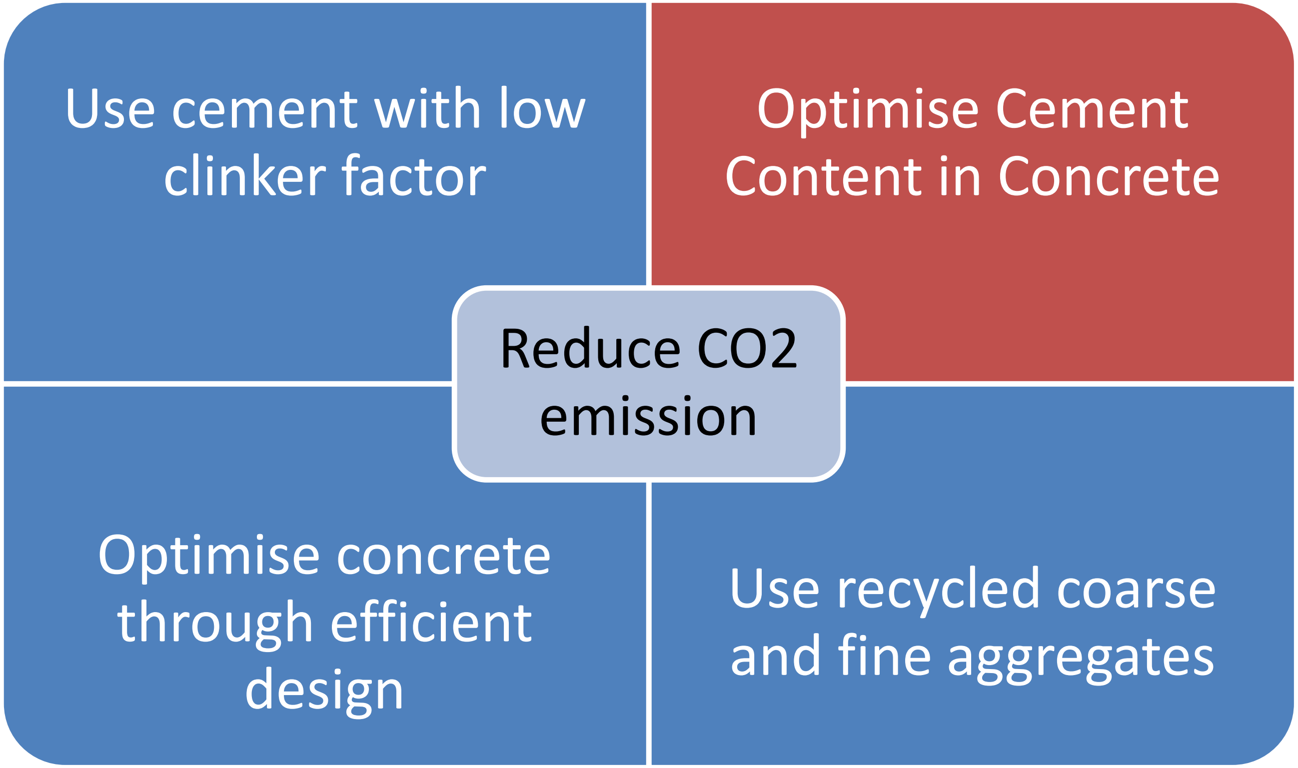
Results						
Date of Casting	**Trail No**	**Grade of Concrete**	**Admixture Dose**	**Avg Strength (Mpa)**		
				1 Day	**3 Day**	**7 Day**
10-10-2018	1st	M-45	1.05%	20.6	36.17 (80%)	49.07
10-10-2018	2nd	M-45	1.30%	18.68	37.12	49.73
10-10-2018	3rd	M-45	1.30%	18.91	36.29	52.04
10-10-2018	4th	M-45	1.30%	18.73	36.17	51.29

Comparison OPC vs LC3

- LC3 has a darker colour
- Higher Abrasion Resistance
- High Early Strength
- Faster Setting Time



Strategies for CO_2 Emission Reduction in Concrete



Optimum Cement Content – Present Approach

- ***Cement Content, Low w/Cm ratio, SCMs, more fines***
- ***Some examples:***

➢ **Normal concrete - Cement content 350 kg/m3; w/c ratio 0.4 - 0.6 yielding 25-30 MPa at 28 days**

➢ **HPC - Cement content 450+ kg/m3; Silica fume; w/cm ratio 0.32-0.35 yielding 60 MPa at 28 days**

➢ **UHPC - Cement content 650-700 kg/m3; Silica fume & other selected fines with w/cm ratio below 0.2 yielding 200 Mpa**

- **Does this approach take care of the space-filling character of the hydrates?**

Optimum-Cement-for-Better-Concrete Strategy

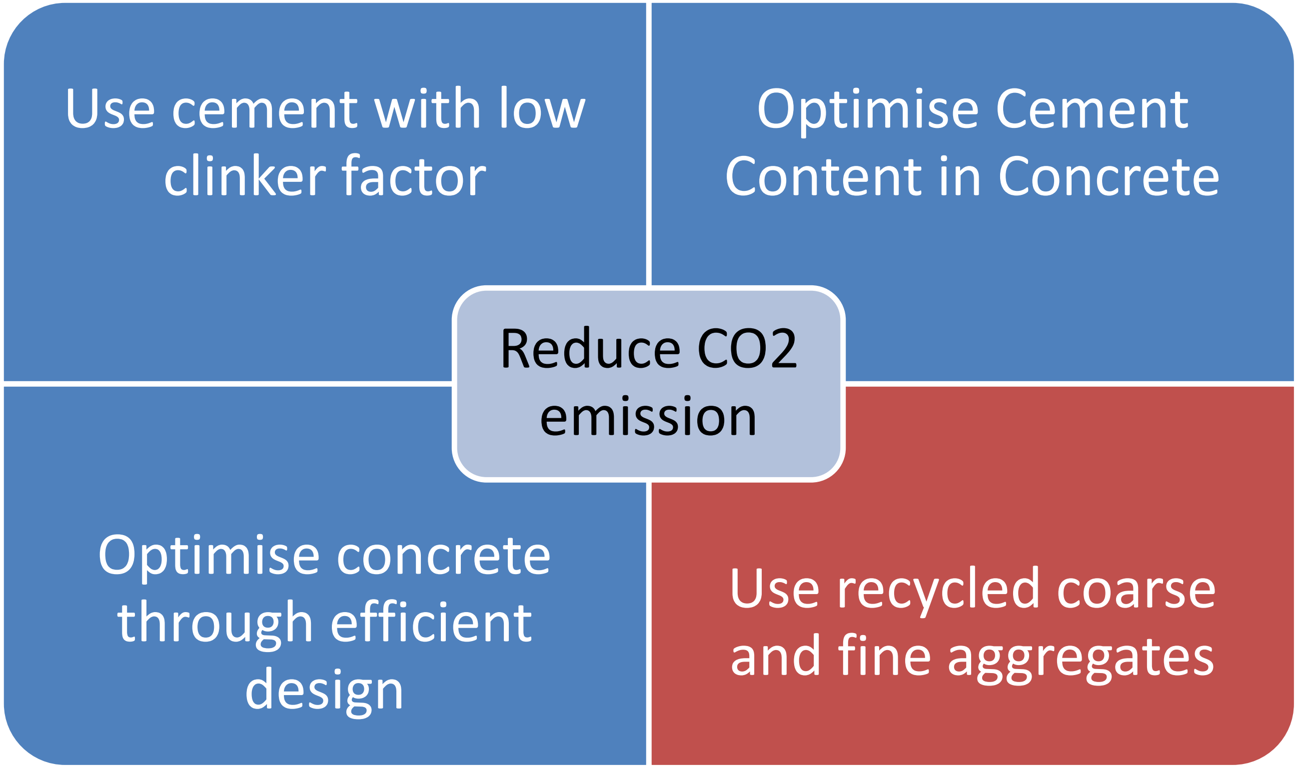
Fresh concrete

- PSD
- Particle dispersion
- Particle packing
- Rheology

Set & hardened concrete

- Gel space ratio
- Binder intensity index
- Particle packing density
- Age-strength optimization

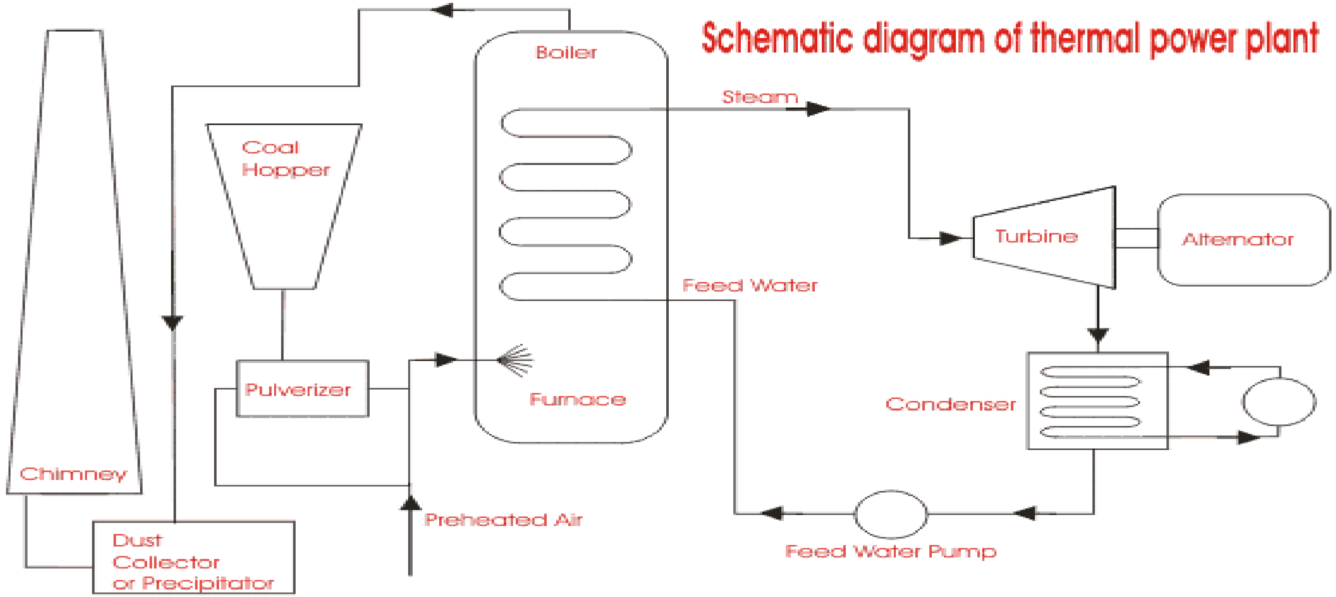
Strategies for CO_2 Emission Reduction in Concrete



Green Concrete Pavements

Use of Alternatives to Aggregates

Bottom ash from Thermal Power Stations



A 1000 MW Power Station;

- Consumes 12,000 t coal per day,
- Generates 4,200 t ash per day,
- 20 % is bottom ash.

- 69 percent of electricity generated in India is from coal-fired thermal power plants.
- 170 – 200 millions tonnes of coal combustion residues generated per year.
- 35- 40 million tonnes of bottom ash/year.

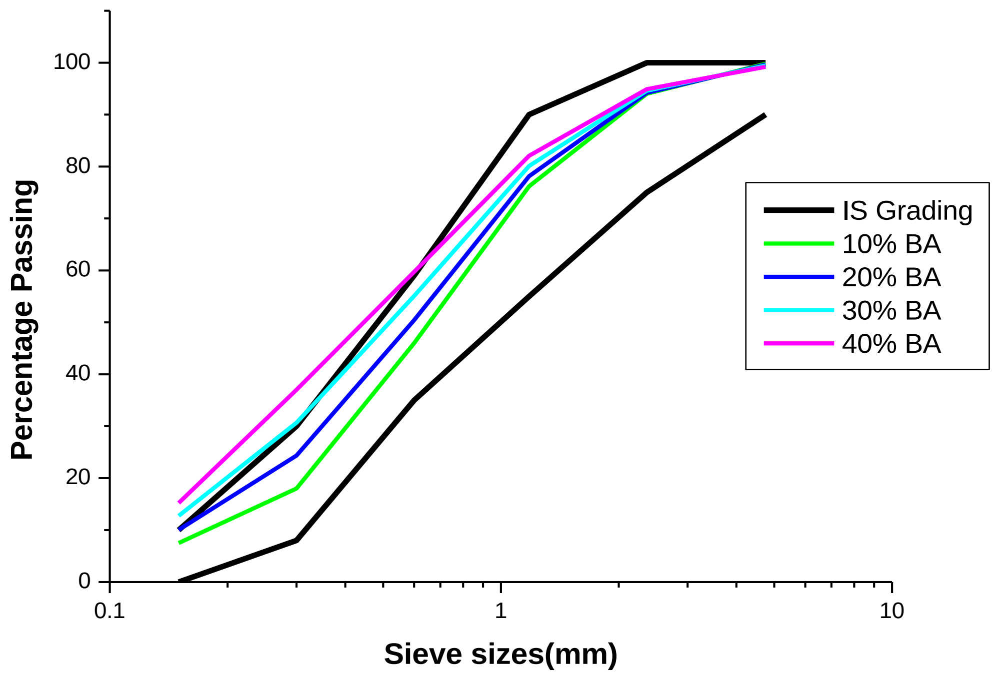
Replacement of sand in Concrete by bottom ash

Bottom ash as obtained from thermal power stations is much coarser than fly ash and similar in size to sand used as fine aggregate. It has a porous structure, lower specific gravity and high water absorption.

Physical properties of natural sand and as-received bottom ash

S. No	Property	Natural sand	Bottom ash
1	Specific gravity	2.60	1.57
2	Bulk density kg/m^3	1460	811
3	Fineness modulus	2.7	2.08
4	Zone	II	-
5	Water Absorption (%)	0.16	26

Mullick *et al*., Seoul, Korea, Sept. 2014



Combined grading of mixes of bottom ash and natural sand

Mullick *et al*., Seoul, Korea, Sept. 2014

Results of concrete mixes with 20% bottom ash as fine aggregate

Series	Cement Content, kg/m3	w/c	Sand,%	Bottom ash, %	Slump, mm	Comp. strength, MPa	
						7-d	28-d
I	500	0.37	100	0	89	46.9	65.1
			80	20	73	45.3	67.3
II	450	0.40	100	0	94	40.8	59.4
			80	20	81	40.2	62.1
III	400	0.43	100	0	86	30.5	52.9
			80	20	78	29.4	55.0

✓For constant water content, replacement by bottom ash lowered the slump and may require higher dosage of superplasticiser.

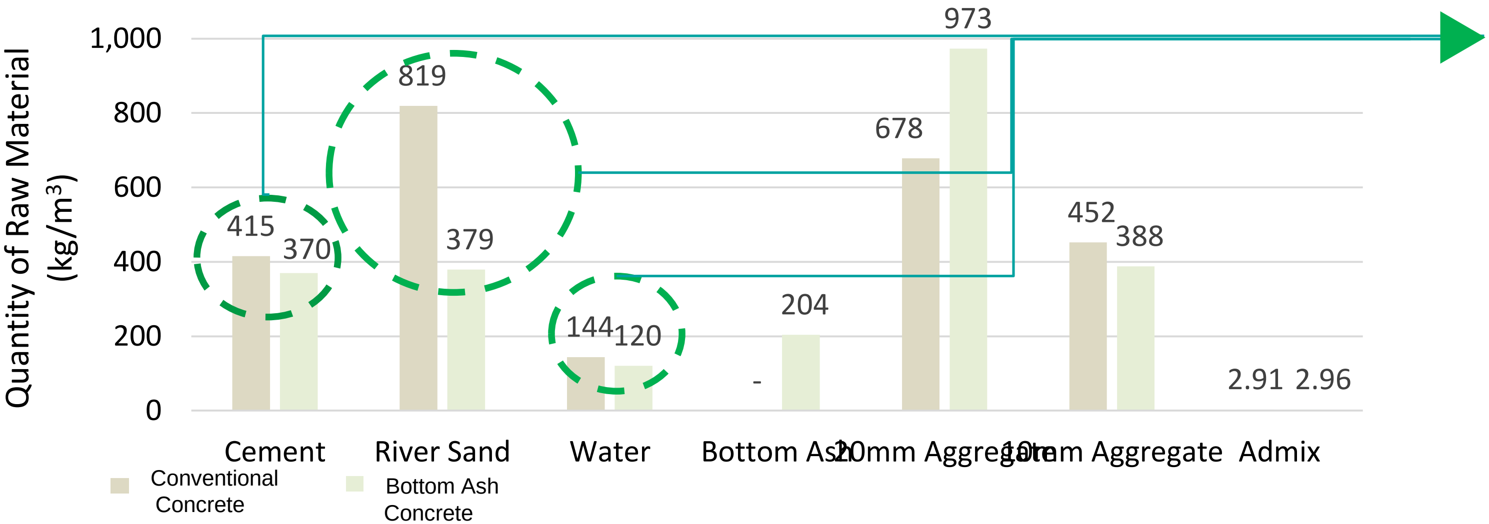
✓28-days compressive strength of concrete was higher with replacement of sand by bottom ash.

✓Structural grade concrete (55 – 65 MPa) can be obtained with part replacement of sand by bottom ash.

Mullick *et al,* Seoul, Korea, Sept. 2014

Bottom Ash - Concrete is also more economical compared to conventional concrete

Representative estimates of quantity and costs for construction of M-40 grade concrete road in Chandrapur, Maharashtra. Quantum of savings varies with location, grade of concrete and quality of raw materials



Typical savings with BA Concrete

54% River sand

11% Cement

16% Water

Bottom ash concrete reduces input cost by **INR 500 per cubic meter** (>10% savings)

~ INR 45 lakh* savings for constructing 1 km stretch of 8-lane highway

As this is a novel tech. lifecycle costs are not currently available. However, software-based simulation shows:

- BA concrete has **~20% more life** compared to conventional concrete, indicating reduced lifecycle costs

*Volume of concrete considered 9000 cubic meters for 8-lane highway (2X4 lanes, 30m wide, 1000m long, 0.3m deep)

Real time results to be collected

First trial stretch in country of jointed pavement using cost effective design with bottom ash
The mix is virtually self compact concrete and hence efforts required for compactions are much less
Even fixed form paver can suffice the need

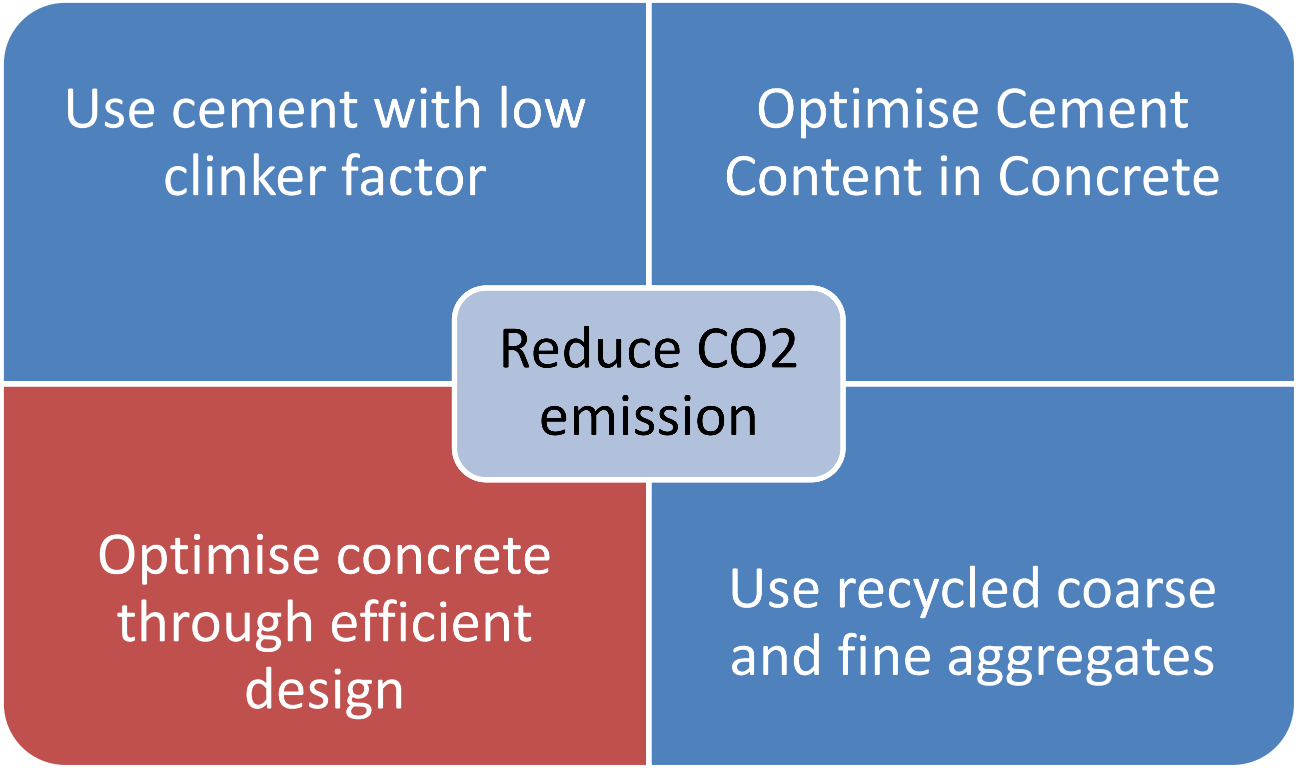
Typical Self compact Concrete

Use of Recycled Aggregates (RCA) – A good substitute for natural aggregates

Unprocessed aggregate

Processed aggregate

Strategies for CO_2 Emission Reduction in Concrete



Green Concrete Pavements

Through Efficient Design Innovations

Innovative pavement designs

- *Whitetopping – as a Composite Pavement*
- *Use of Fibre reinforced Concrete*
- *Two Lift Concrete Pavement*
- *Roller Compacted Concrete*
- *Precast Concrete*
- *ICPB (Interlocking Concrete Paver Blocks)*
- *Cell Filled concrete – for Rural Roads*
- *Short Panelled Concrete Roads*

High Performance Concrete Specification and Performance Requirement

Specifications

less than 236 kg of cement per m^3 of concrete

Columns:
Up to 40 floors: 80-95 MPa concrete
Upper floors with 60 – 70 MPa mix

56-day strength

Performance Requirements

- Slump flow: 600 – 710 mm
- Ability to pump at least 15 floors for 95 MPa mix
- Ability to pump at least 40 floors for 80 MPa mix
- Maximum heat of hydration: 70º C

superstructure of One World Trade Center

High Performance Concrete: Rheology Control of Formation

- **Engineered stiff mixes** for continuous rapid construction (Slip Form)

Performance Requirements:

- Shape retention

Fly ash for rheology control

Concluding Remarks

- Concrete has incredible design versatility and flexibility
- Concrete Pavements are ***Green and Sustainable***
- Optimisation towards Sustainability is an ongoing process
- Final target is to achieve ***Net-Zero carbon emission***
- Need to guard concrete construction so that concrete is neither misused nor abused
- Concrete Technology & Optimisation is all the more important for Pavement engineers.


Thank You
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