Effective Use of Admixtures for More Sustainable Concrete Technology

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Sustainability

+ve Impact of Concrete

- Concrete h
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- Raw mater
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- *Both the ab
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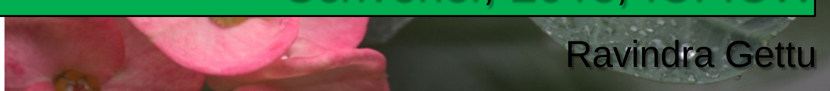
Material	Embodied Energy (MJ/kg)	CO_2 (Kg CO_2/kg)
Normal concrete	0.95	0.130
Fired clay bricks	3.00	0.22
Road & pavement	2.41	0.14
Glass	15.00	0.85
Wood (plain timber)	8.5	0.46
Wood (multilayer board)	15	0.81
Steel (from ore)	35.3	2.83
Steel (recycled)	9.5	0.43

Scrivener, 2013, ICI-ICW



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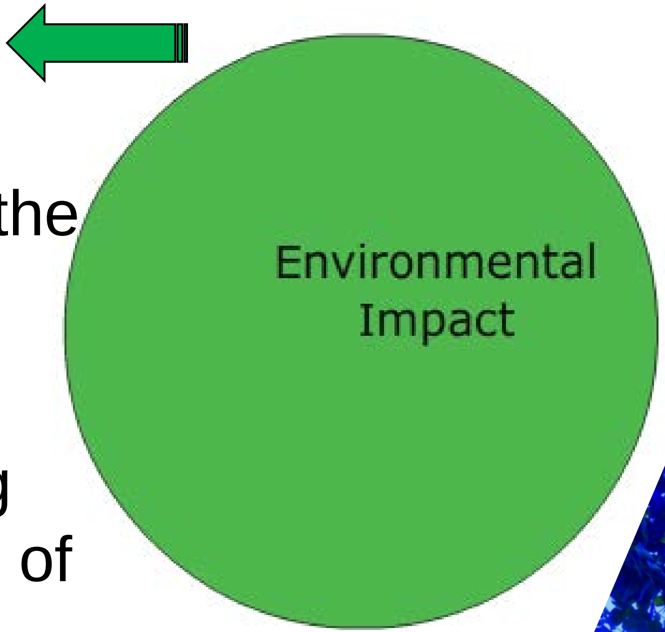
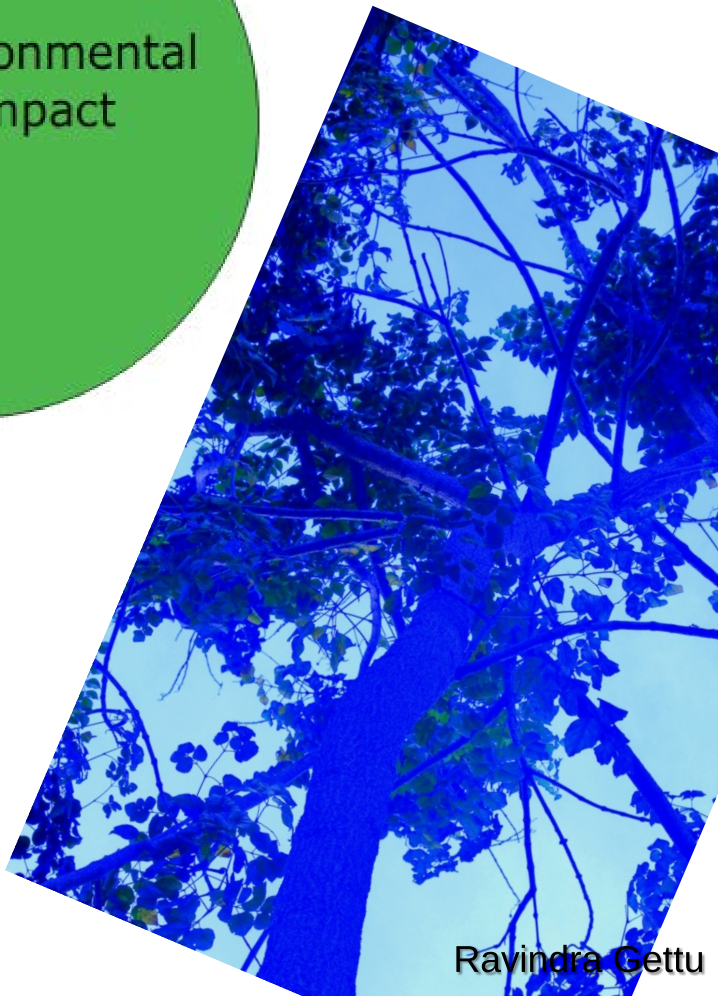
-ve Impact of Concrete



- Cement production in the world is about 3 billion tonnes
- Cement manufacturing accounts for about 5% of CO_2 emissions in the world
- Concrete usage estimates vary from 10 to 30 billion tonnes; Reinforced concrete about 17 billion tonnes



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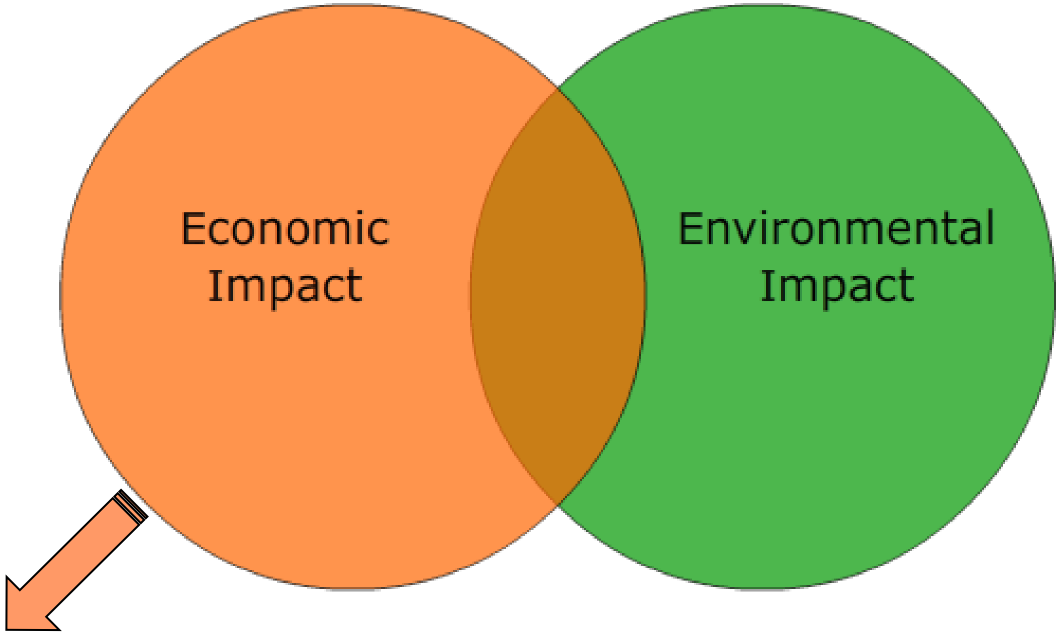

+ve Impact of Concrete

- Construction provides livelihood to a large percentage of the population
- Construction spending continues to increase at the rate of 3-4%

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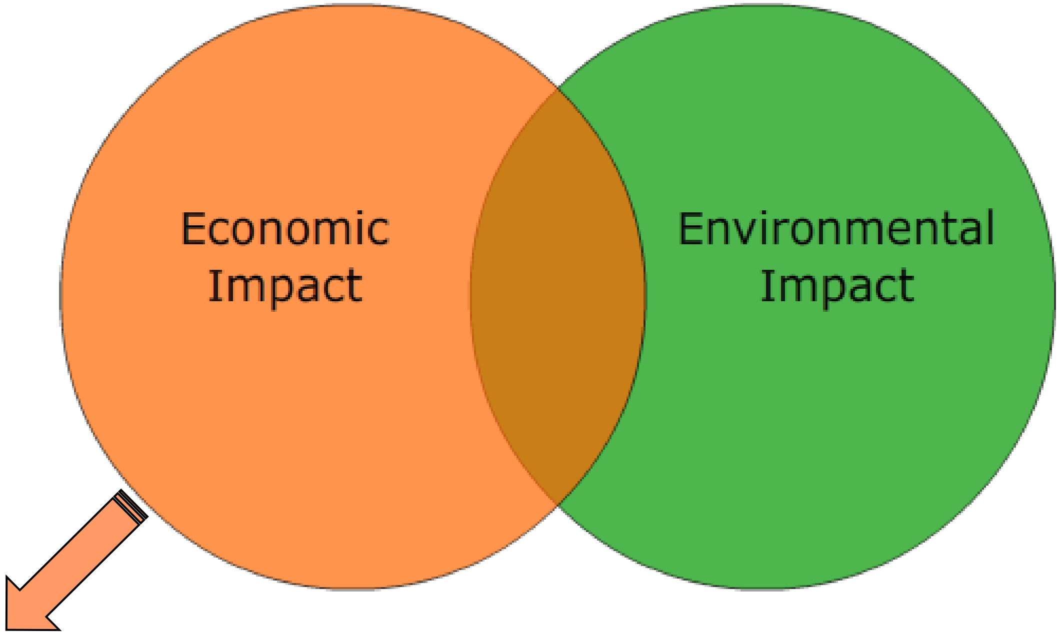

-ve Impact of Concrete

- Poor construction with concrete can lead to high repair and rehabilitation costs
- Cost cutting often results in bad quality

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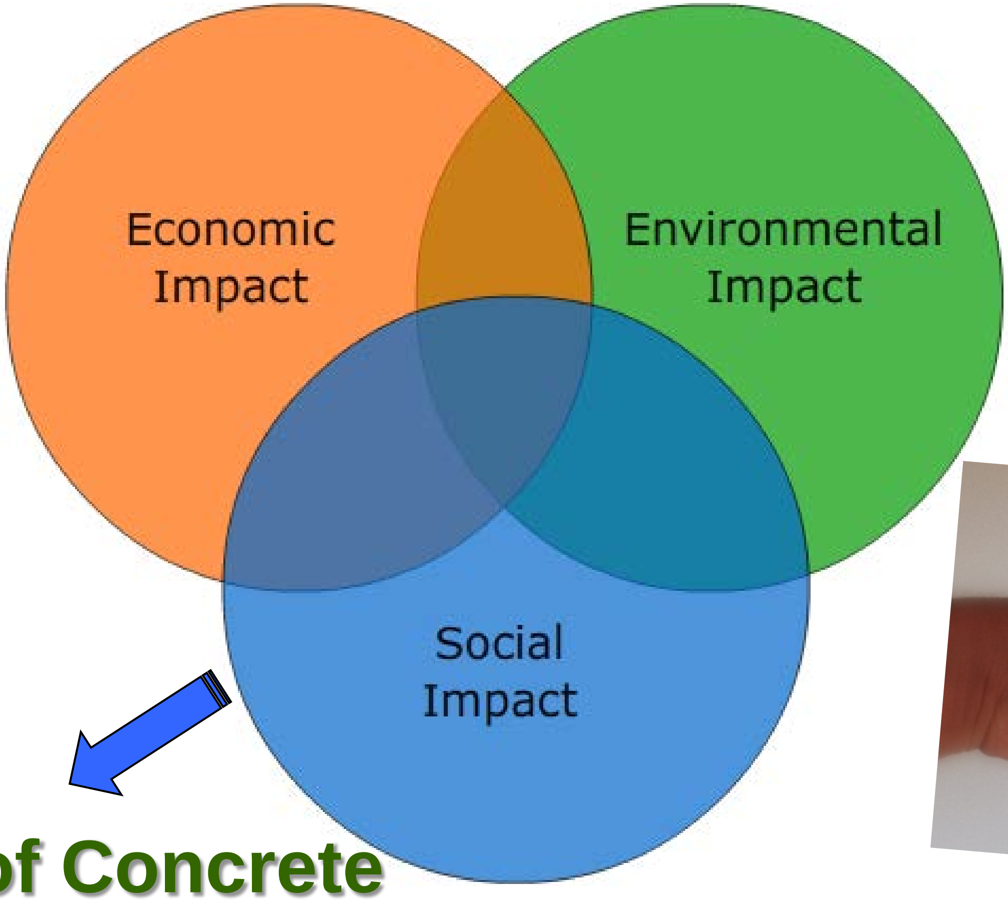

+ve Impact of Concrete

- Concrete is a long term investment that is within reach for most
- Can provide security to the user

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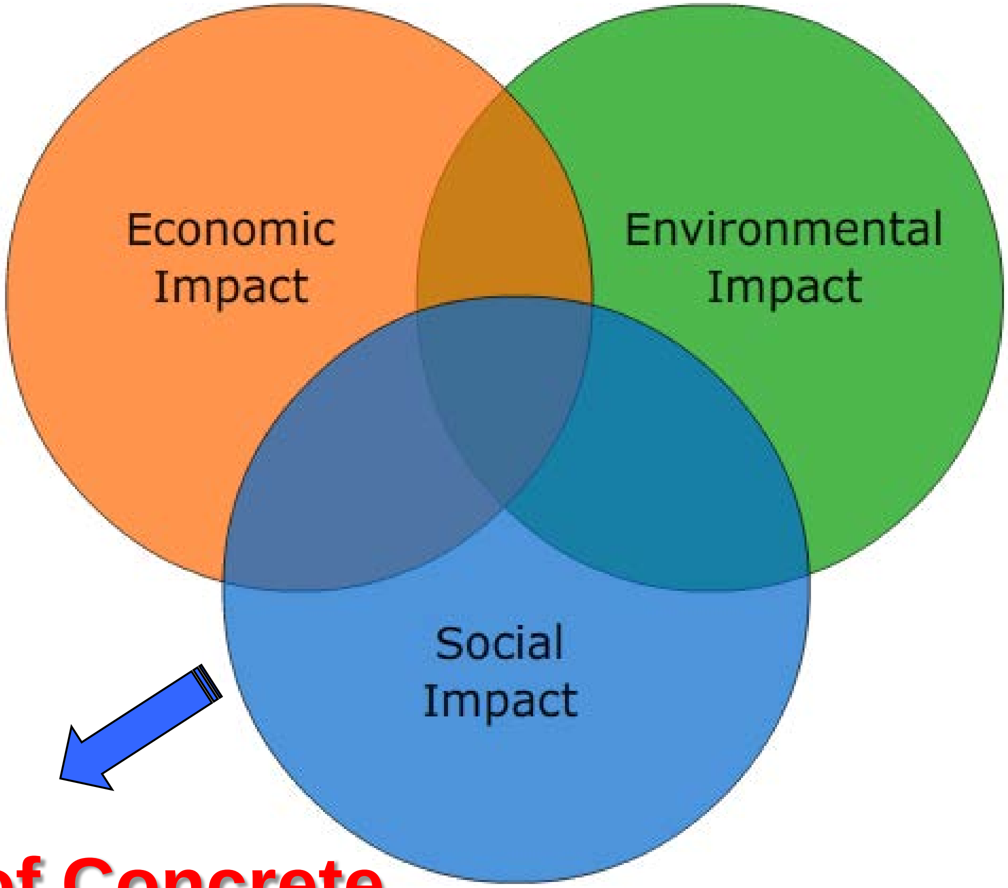

-ve Impact of Concrete

- Cities are becoming concrete jungles
- Quality of concrete is not assured for the user

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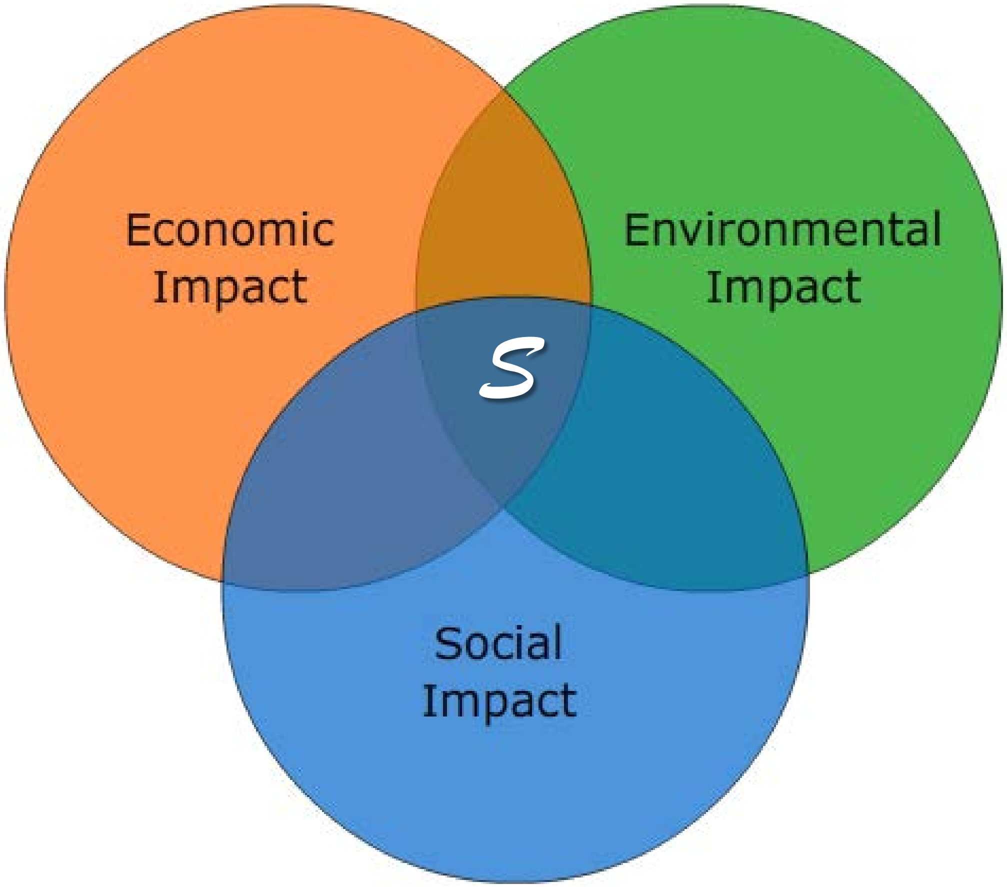

Sustainability Success requires maximum positive economic, environmental and social impacts

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Sustainability

"Simple" Principles for Concrete Construction

- Use less raw materials and energy *over the whole life*
- Reduce the emissions and waste *over the whole life*
- Analyse cost effectiveness *over the whole life*
- Analyse the social impact *over the whole life*

Sustainability

“Simple” Principles for Concrete Construction

- Use less clinker and water, and more waste material
- Increase the useful life of the project
- Increase overall cost-effectiveness
- Improve defect tolerance (i.e., lower sensitivity to defects)

Superplasticizers for Sustainability

How can the superplasticizer help?

- More uniform and homogenous mix
- Better performance (properties, constructability)
- Improves durability (life, maintenance)
- Aids in the use of waste as mineral admixtures
- Increases tolerance of non-ideal aggregates
- Improves working conditions at the construction site

Superplasticizers for Sustainability

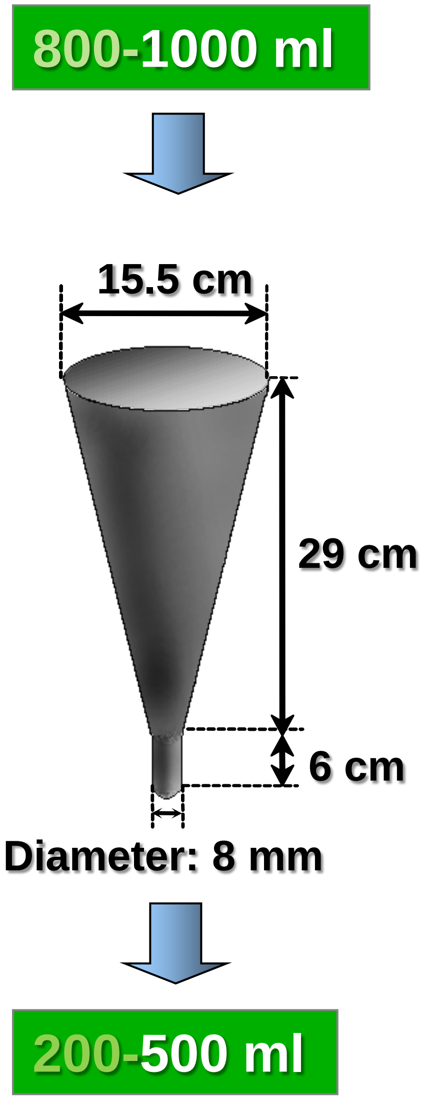
Issues addressed here regarding the use of a superplasticizer

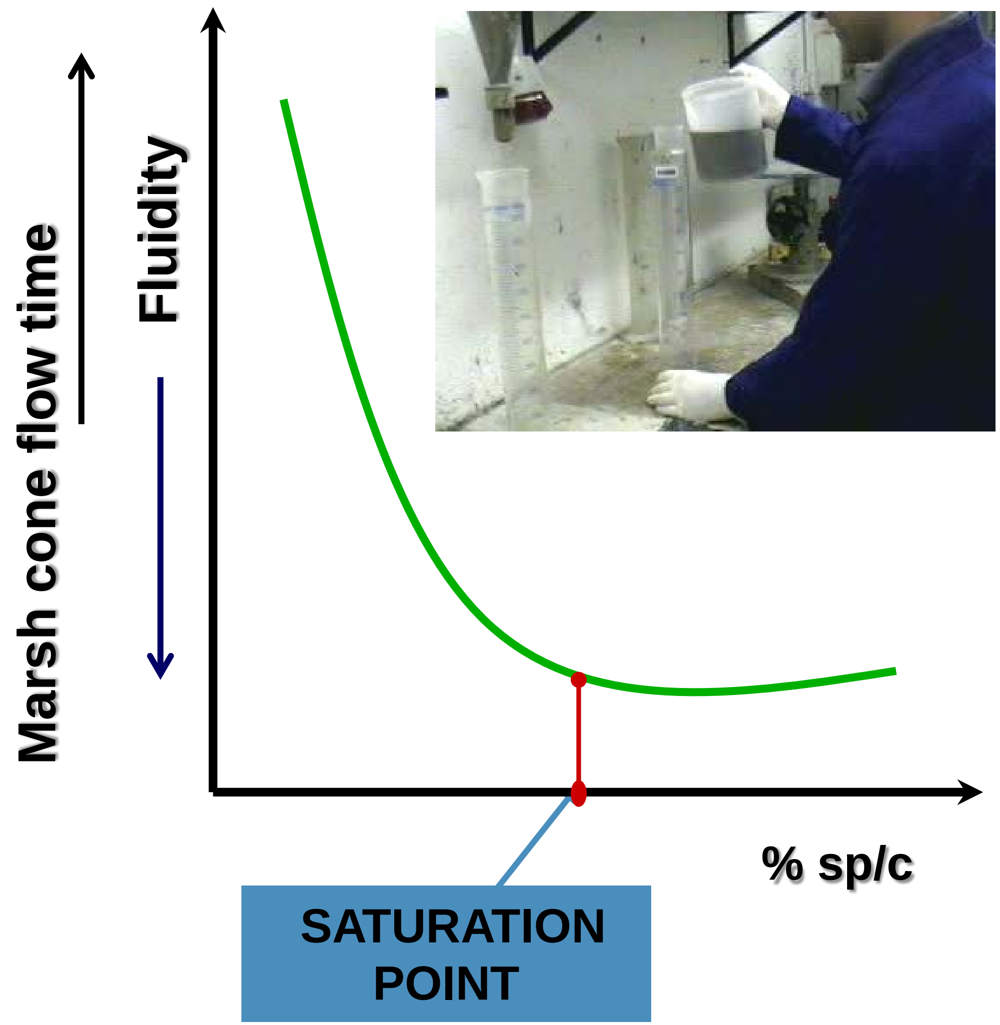
- Choice of the product and dosage
- Mixture proportioning for high fluidity concrete

How to Choose the Superplasticizer and Its Dosage?

- Ideally, the incorporation of the superplasticizer should make the cement paste system behave in a linearly viscous manner.
- The superplasticizer should help maintain the flowability of fresh concrete over the necessary time period
- The superplasticizer should not excessively affect the setting time and early strength gain of concrete

Marsh Cone Test: Evaluation of the compatibility and dosage





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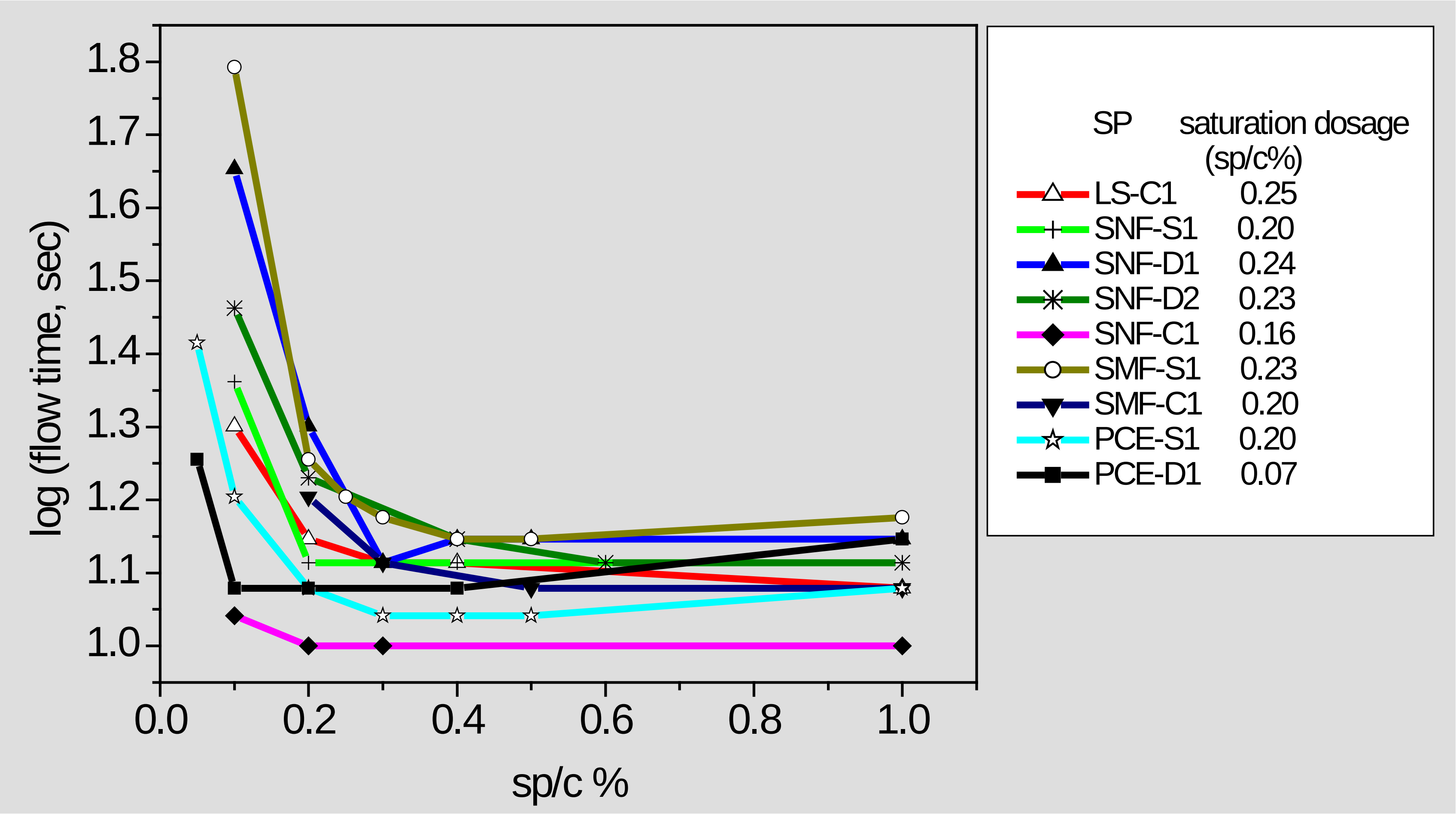
Marsh Cone Flow Time



- **Applicable to all types of superplasticizers.**
- **Saturation dosage varies with the type (and brand) of superplasticizer.**

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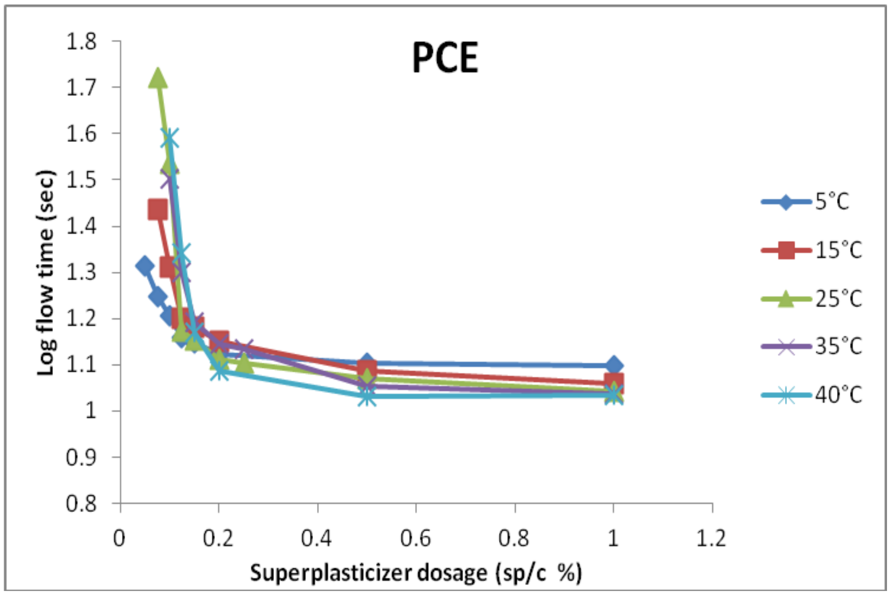
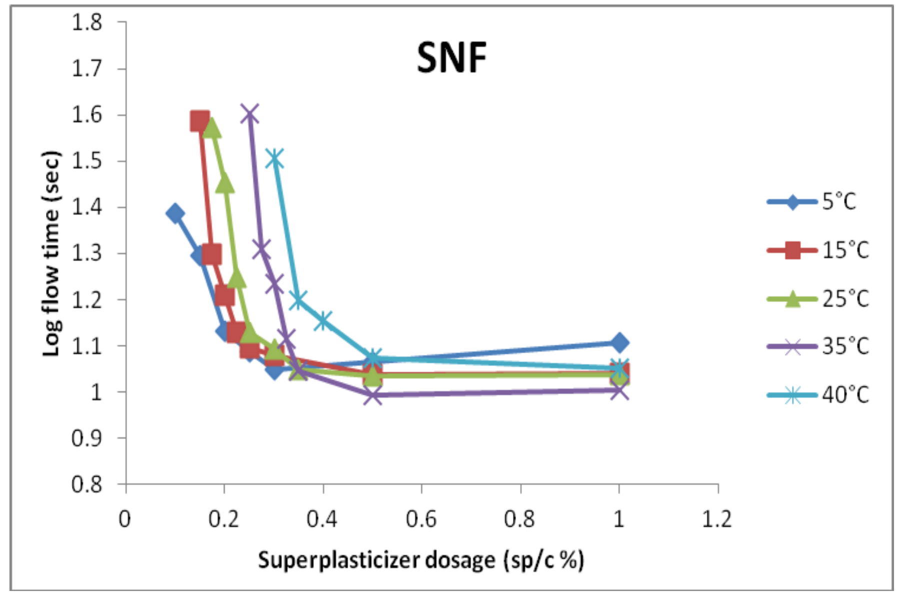
EFFECT OF TEMPERATURE ON THE FLUIDITY OF SUPERPLASTICIZED CEMENT PASTE

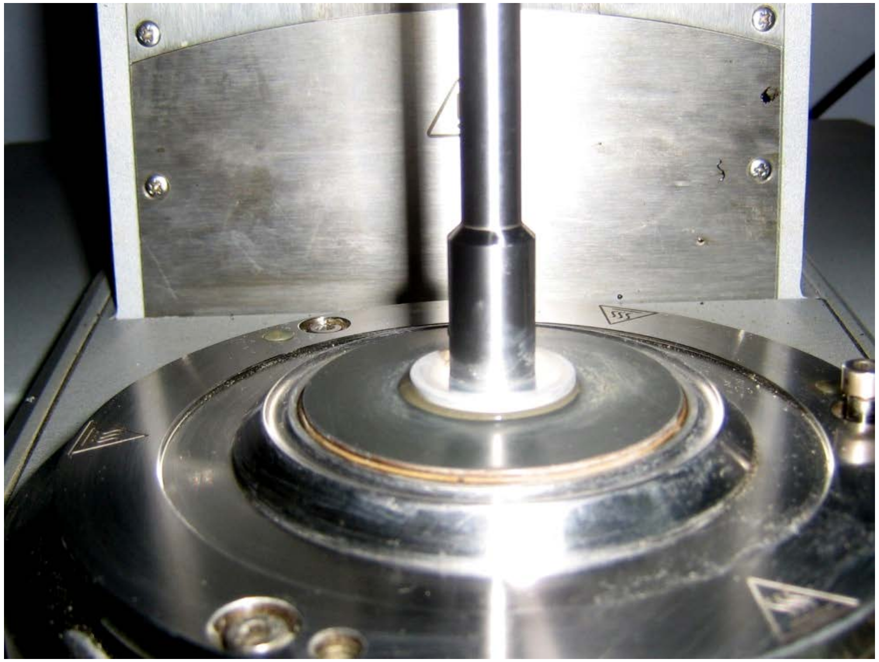




The PCE based superplasticizer is less sensitive to changes in the ambient temperature, especially when the dosage is close to the saturation dosage

Transition Studies with a Dynamic Shear Rheometer

Anton Paar Rheometer



Shearing of cement paste with parallel plate attachment

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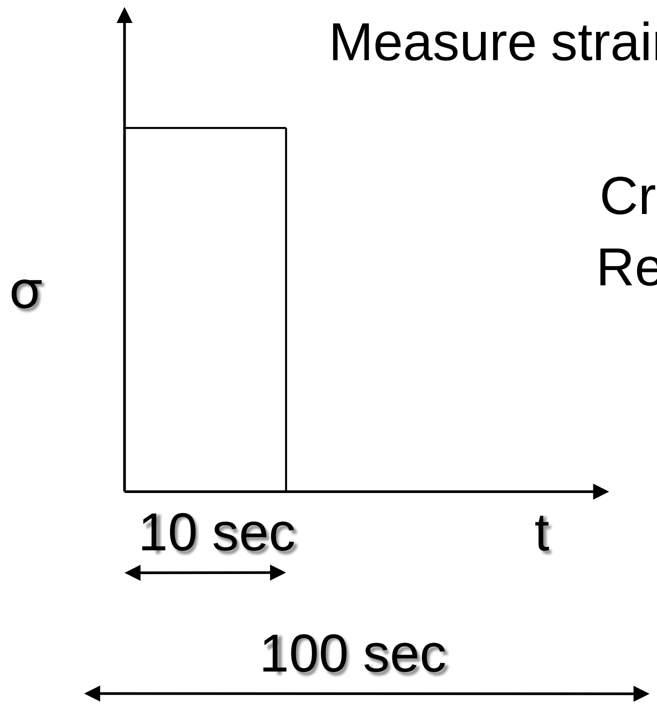
Creep and Recovery

To understand the viscoelastic nature of the superplasticized paste.

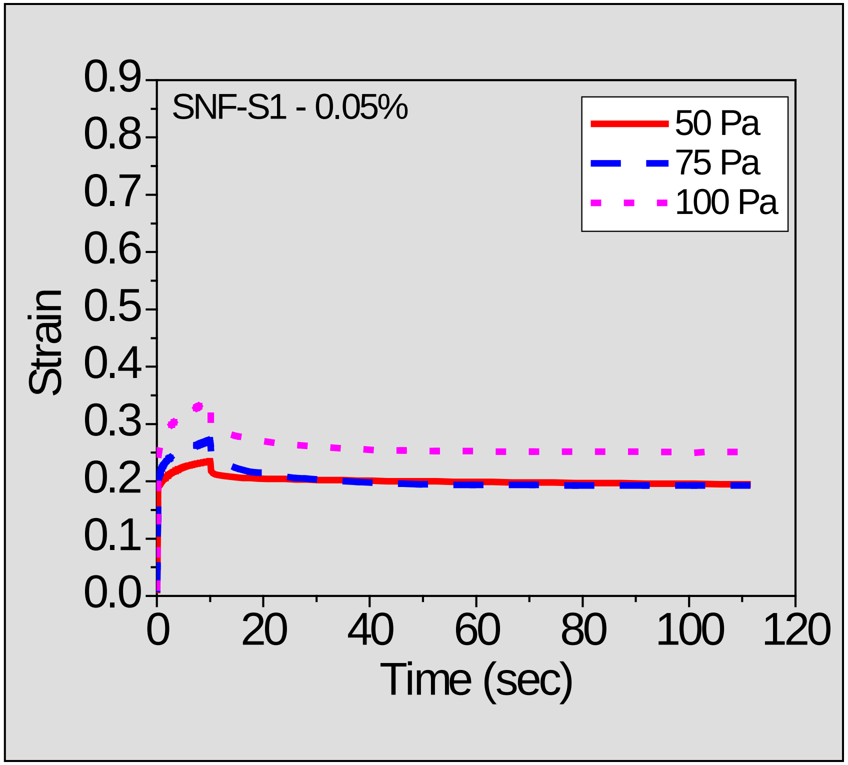
Measure strain v_s t

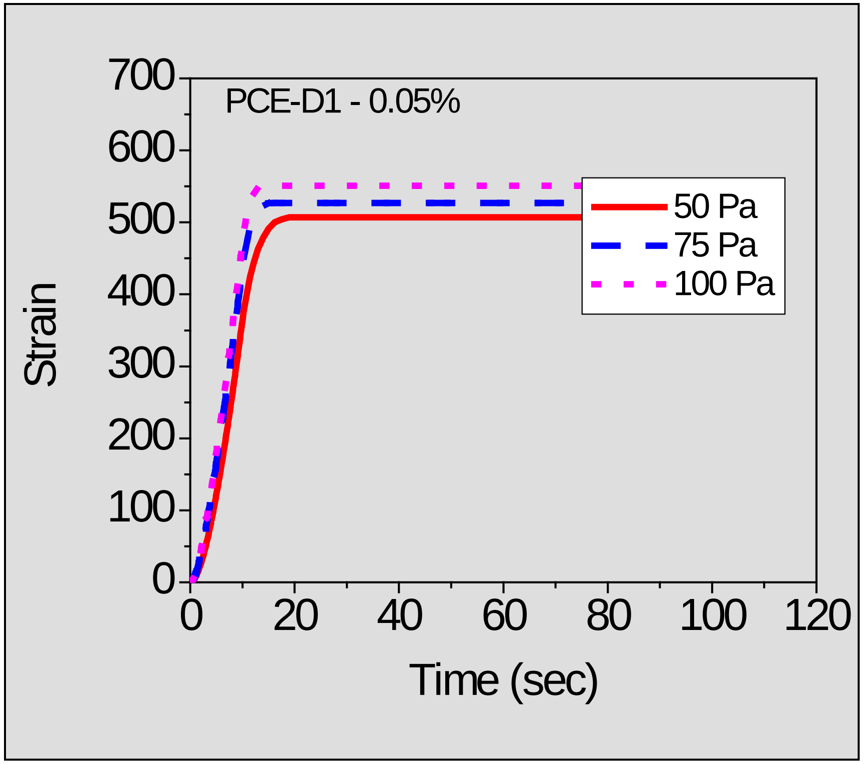


Creep (10 sec)

Recovery (100 sec)

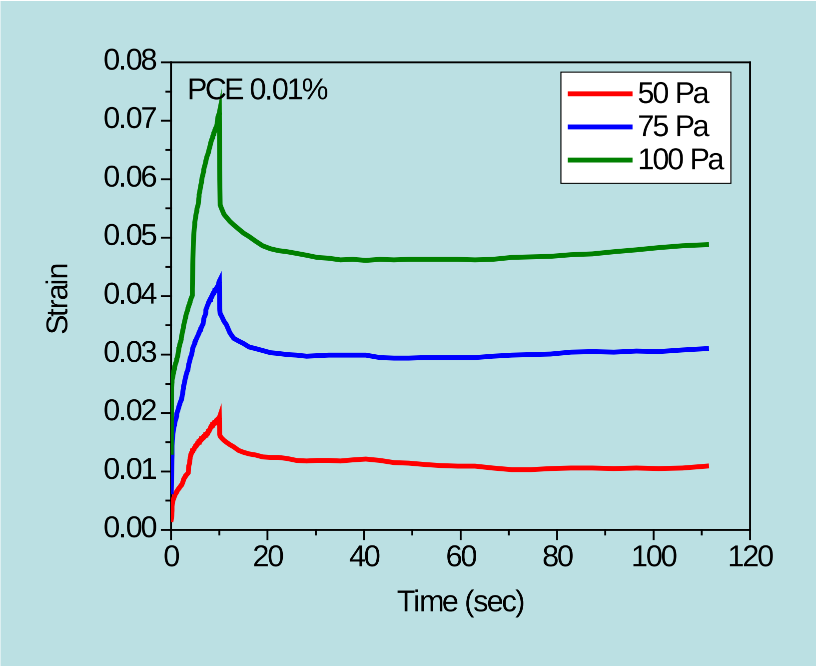
Creep and Recovery of Superplasticized Paste





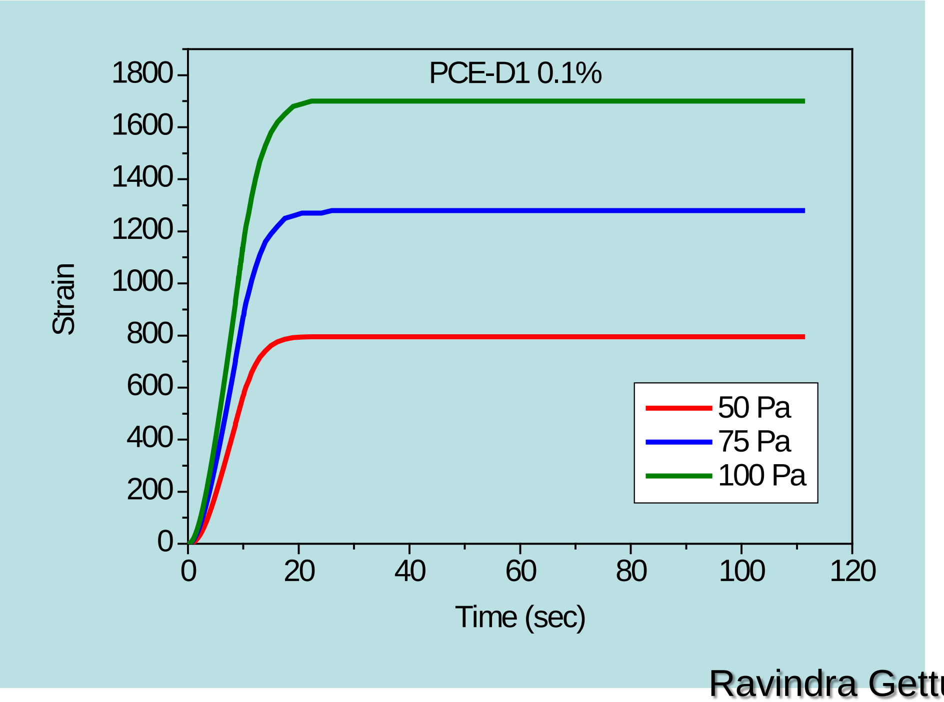
- **Strain recovery is less compared to pure cement paste, with more fluid-like behaviour for superplasticized paste.**
- **Paste with the PCE shows linearly viscous nature at the same dosage (0.05%) where SNF gives viscoelastic response.**

Viscoelastic Characterisation of Superplasticized Cement Paste



The creep and recovery test shows viscoelastic behaviour at low dosage of SP and viscous nature at saturation dosage

At saturation SP dosage the paste shows linear increase in strain with an increase in stress, without any recovery



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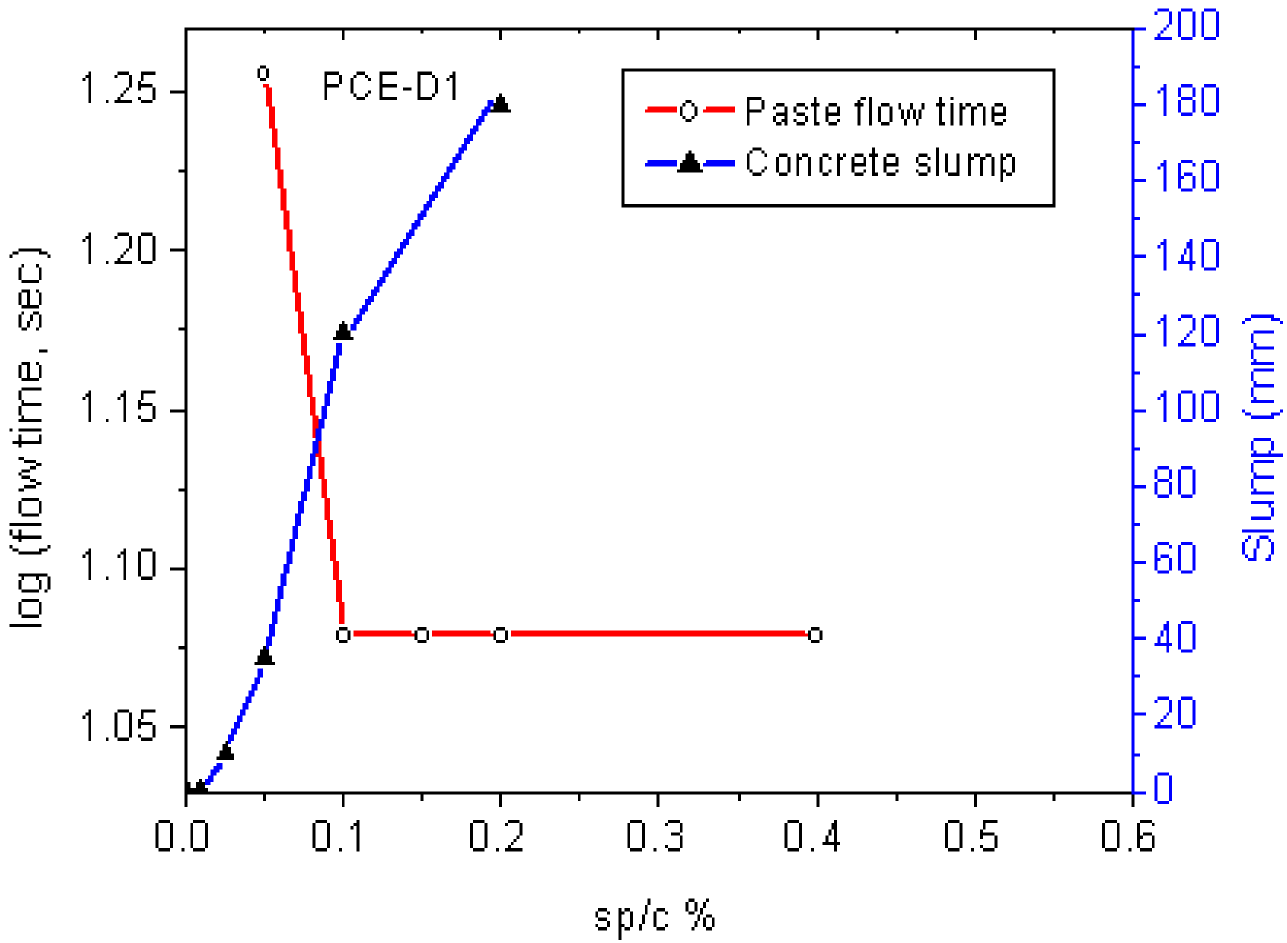
Paste-Concrete Correlation

Can the flow behaviour of paste and concrete be correlated?

Can the paste be used to optimise the concrete mix?

Paste-Concrete Comparison

- **In general, there is good correlation between the behaviour of paste and concrete.**
- **However, aggregates with high absorption can increase the superplasticizer demand in concrete.**

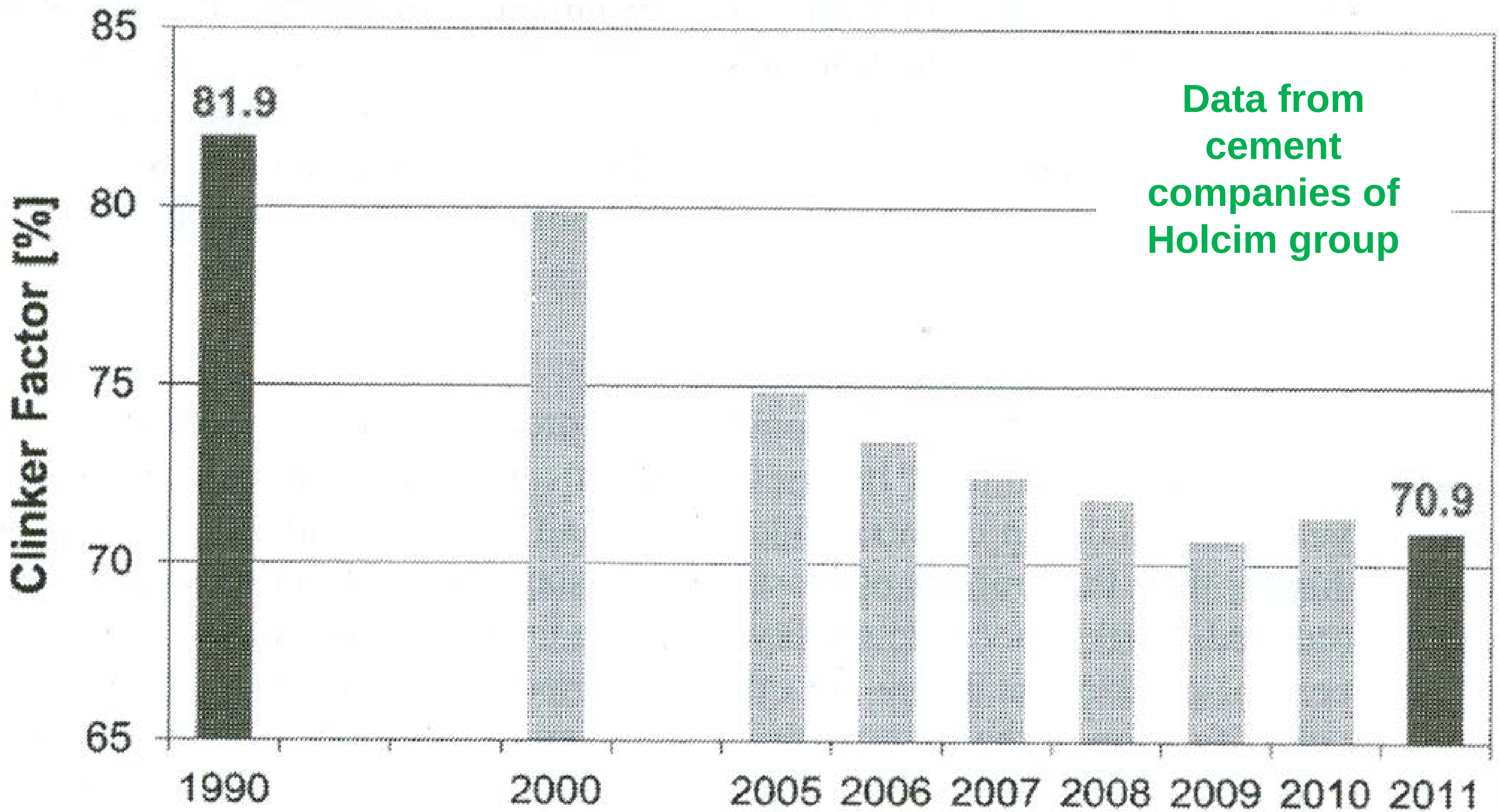


Mineral Admixtures for Sustainability

How can fly ash and slag help?

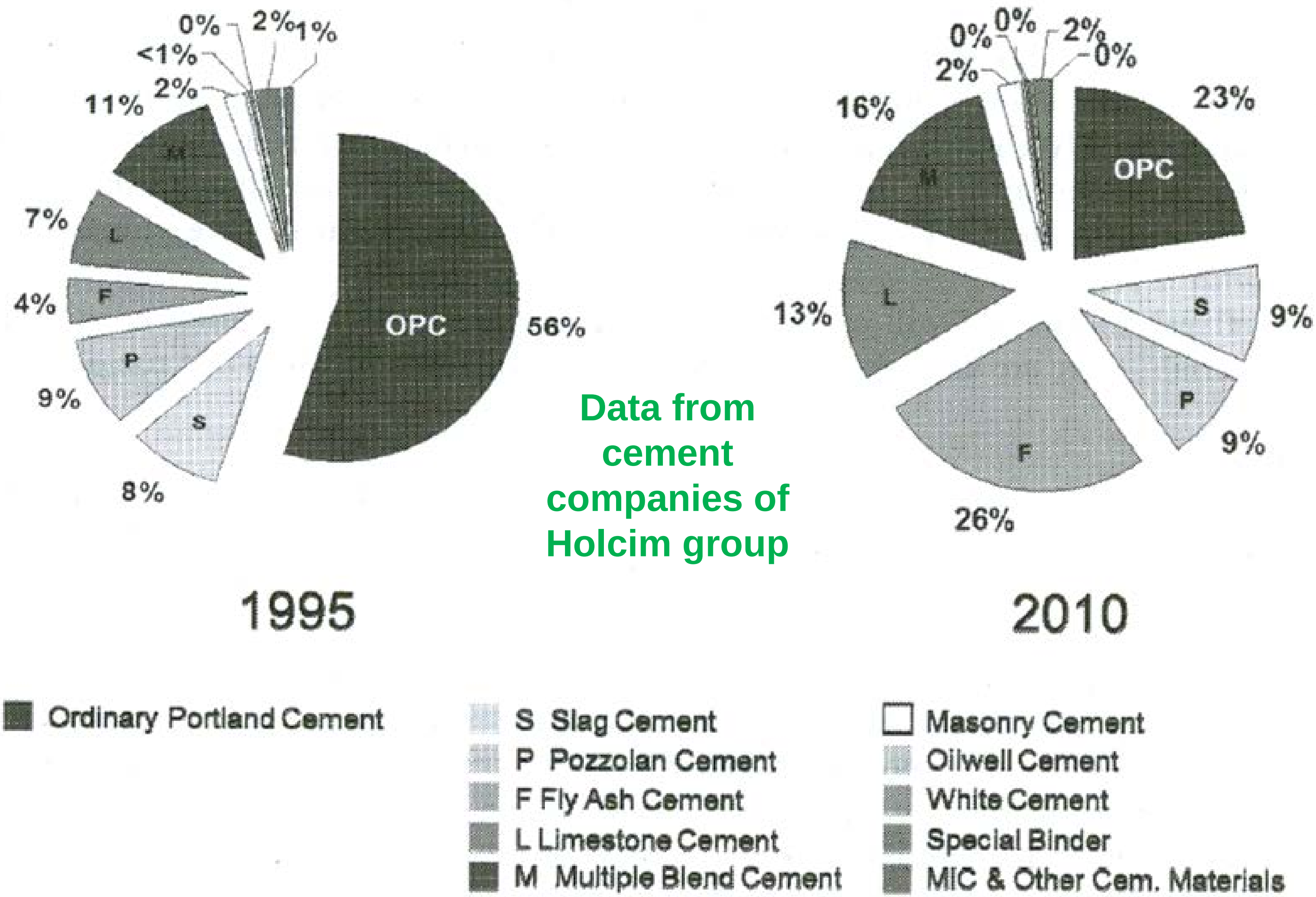
- They are waste materials, abundant in many countries.
- As supplementary cementitious materials, they can reduce the clinker demand.
- Durability parameters could improve.

Reduction of Clinker in Cement



Scrivener, 2013, ICI-ICW

Reduction of Clinker in Cement



Data from cement companies of Holcim group

Scrivener, 2013, ICI-ICW

Fly ash in Brazil

- Coal reserves of 11 billion tonnes, can yield energy for 500 years.
- Fly ash production is about 4 million tonnes; 30% used in concrete production.
- In general, the SiO_2 content is about 50-60%.

Izidoro et al., 2012

On-going research at IIT Madras on concrete durability with different mineral admixtures

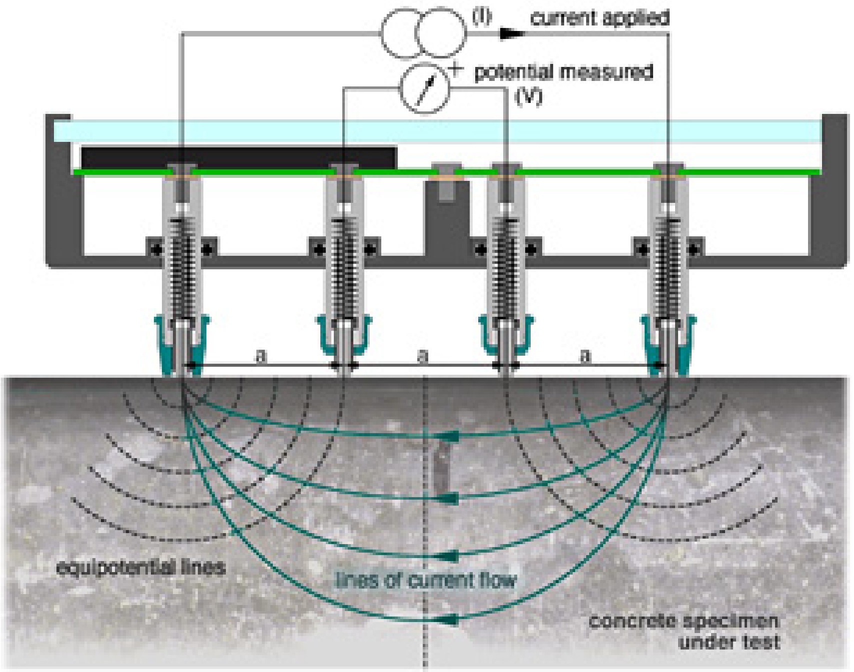
Durability tests

Category	*Test method*	*Parameter*
Chloride penetration	Rapid Chloride Permeability	Total charge passed
	Accelerated Chloride Migration	Non-steady state diffusion coefficient
	Chloride Conductivity	Chloride conductivity
	Bulk Diffusion	Chloride concentration
Gas permeability	Oxygen Permeability	Oxygen permeability index
	Torrent Air Permeability	Permeability
	Accelerated Carbonation	Carbonation depth
Water permeability	Sorptivity	Sorptivity index
	Germann Water Permeability	Surface permeability
	German Water Permeability	Water penetration
Concrete resistivity	Wenner 4 Probe Resistivity	Surface resistivity

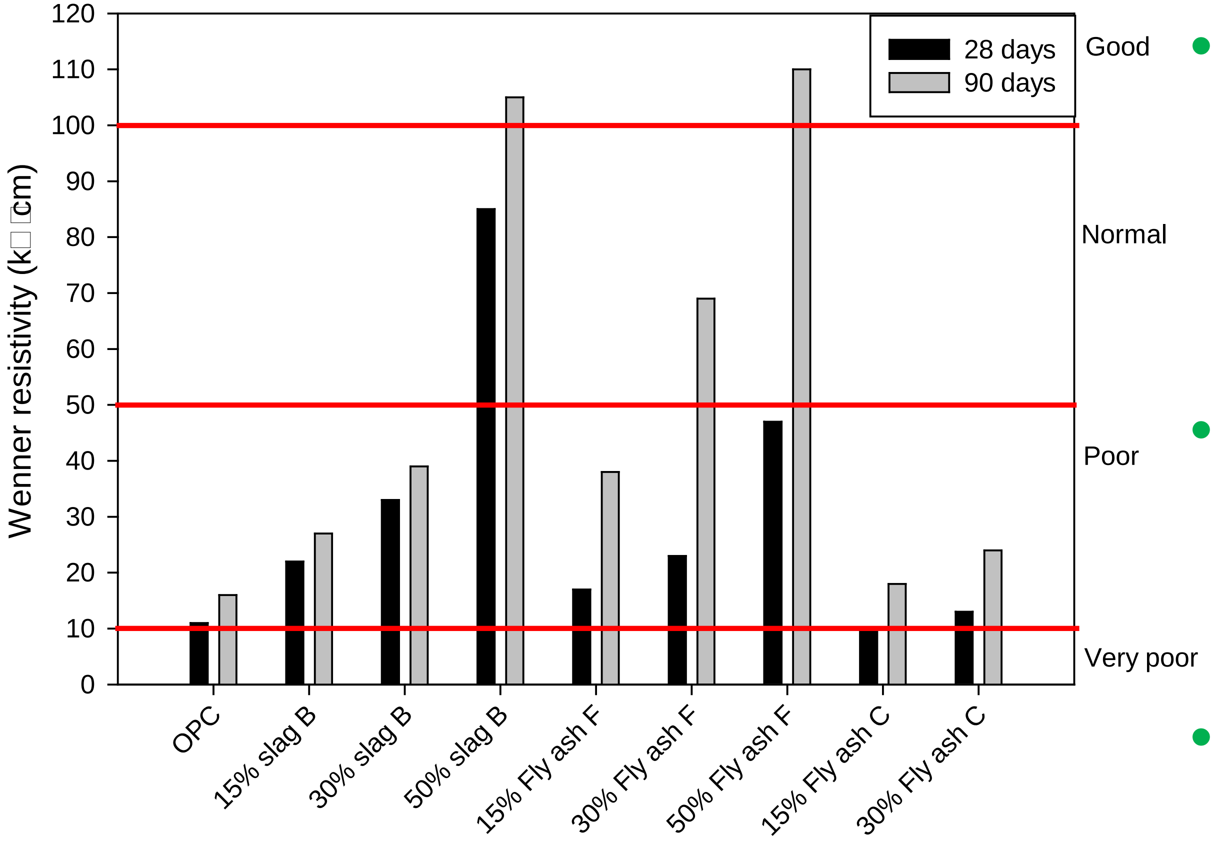
Wenner 4 Probe Resistivity Test

Resistivity, kΩ.cm	Concrete quality
> 100	Good
50 - 100	Normal
10 – 50	Poor
< 10	Very poor

(RILEM TC 230)



Effect of mineral admixtures on concrete resistivity



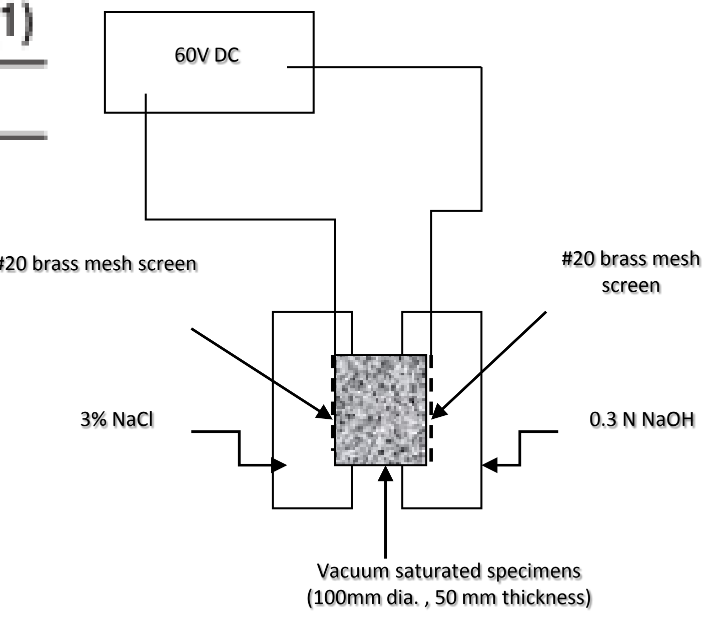
Wenner resistivity test results on mixes with total binder content of 310 kg/m^3 and w/b 0.5

- **Mineral admixture mixes are showing better resistivity than OPC mixes**
- **Slag and Class F fly ash yield the highest resistivity**
- **Performance of Class C fly ash is close to OPC**

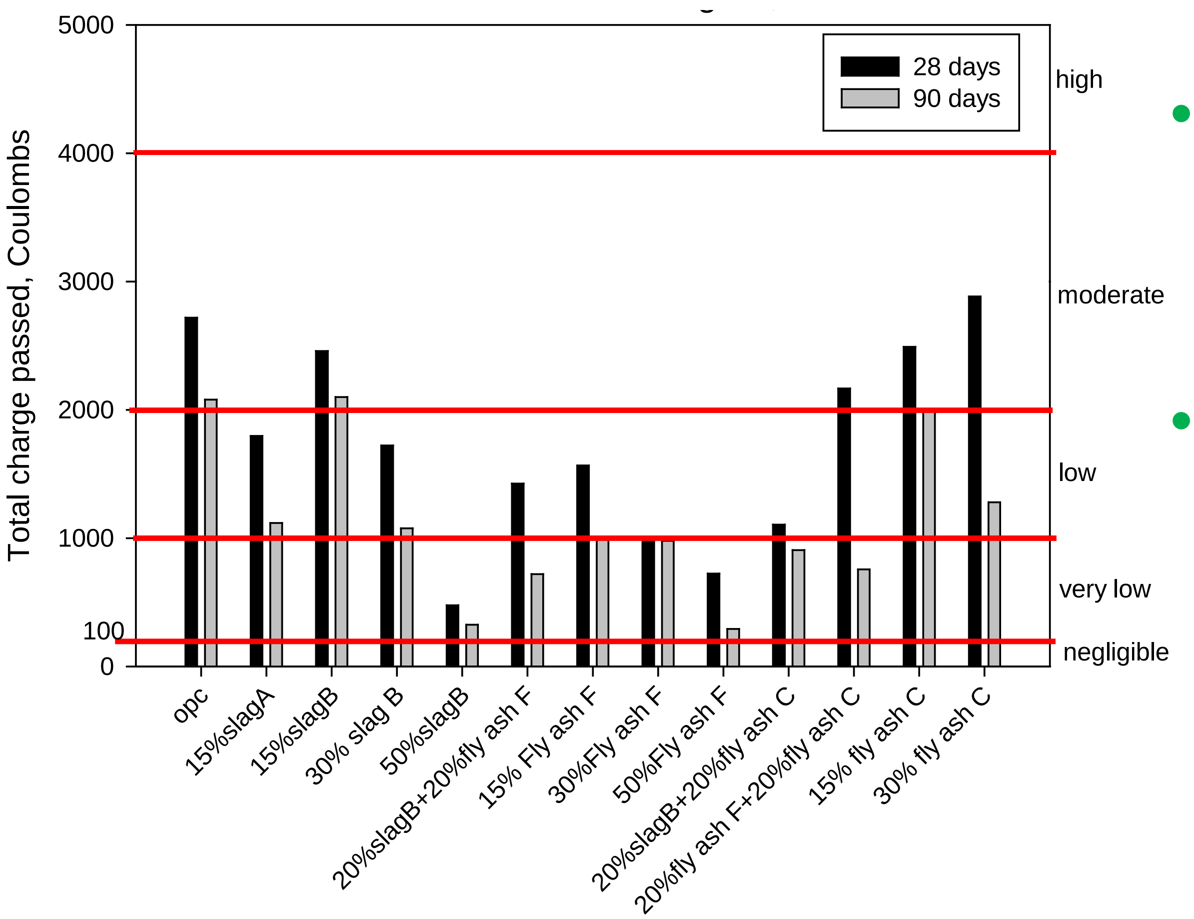
Rapid Chloride Permeability Test - RCPT (ASTM C 1202)

TABLE 1 Chloride Ion Penetrability Based on Charge Passed (1)

Charge Passed (coulombs)	Chloride Ion Penetrability
>4,000	High
2,000–4,000	Moderate
1,000–2,000	Low
100–1,000	Very Low
<100	Negligible



Effect of mineral admixtures on chloride ion penetrability



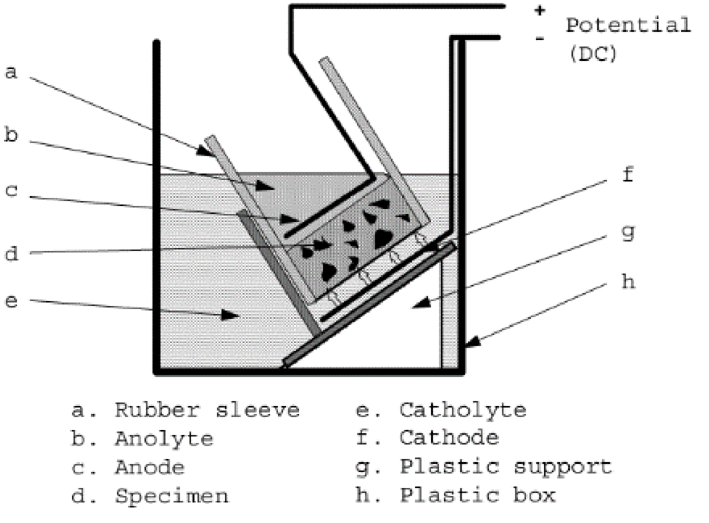
RCPT results on mixes with total binder content of 310 kg/m^3 and w/b 0.5

- **Slag and Class F fly ash yield lowest chloride penetration**
- **Class C fly ash performs similar to OPC at 28 days but improves at 90 days**

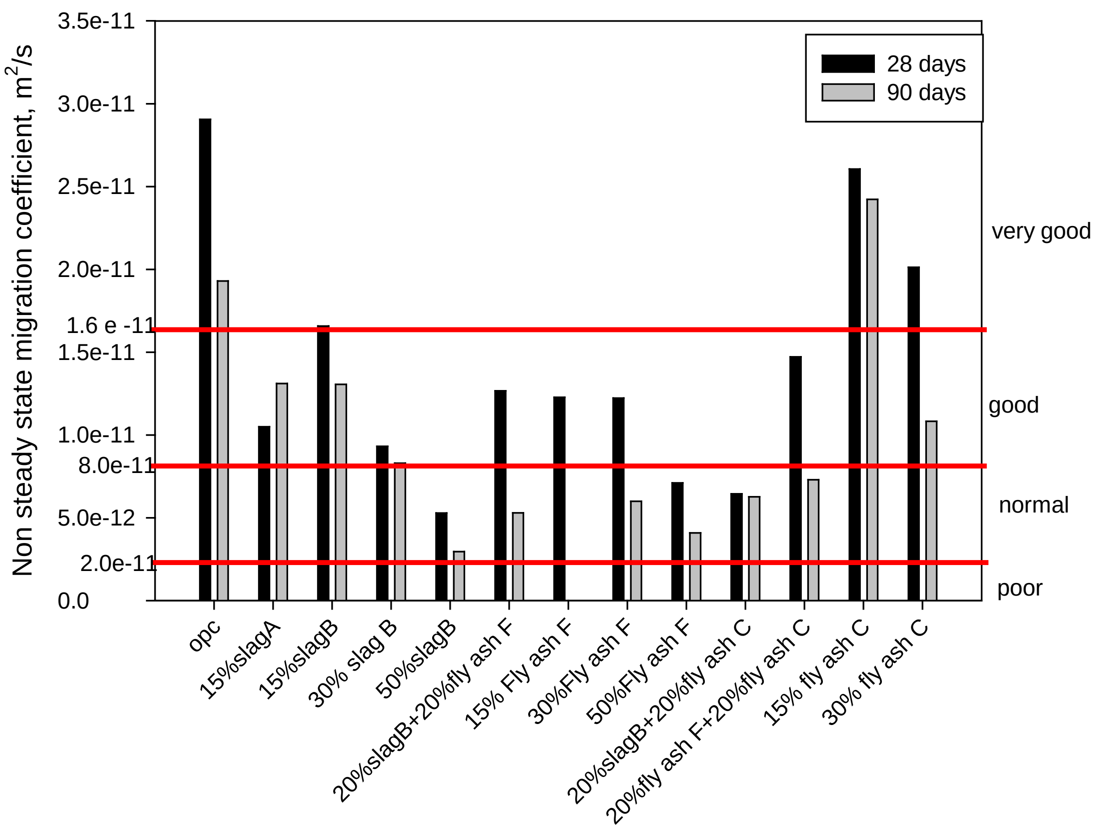
Accelerated Chloride Migration Test (NT Build 492)

Nordtest Method BUILD 492, Migration coefficient (m^2/s)	**Concrete quality**
$< 2 \times 10^{-12}$	Very good
$2 – 8 \times 10^{-12}$	Good
$8 – 16 \times 10^{-12}$	Normal
$> 16 \times 10^{-12}$	Poor

(RILEM TC 230)



Effect of mineral admixtures on chloride ion migration

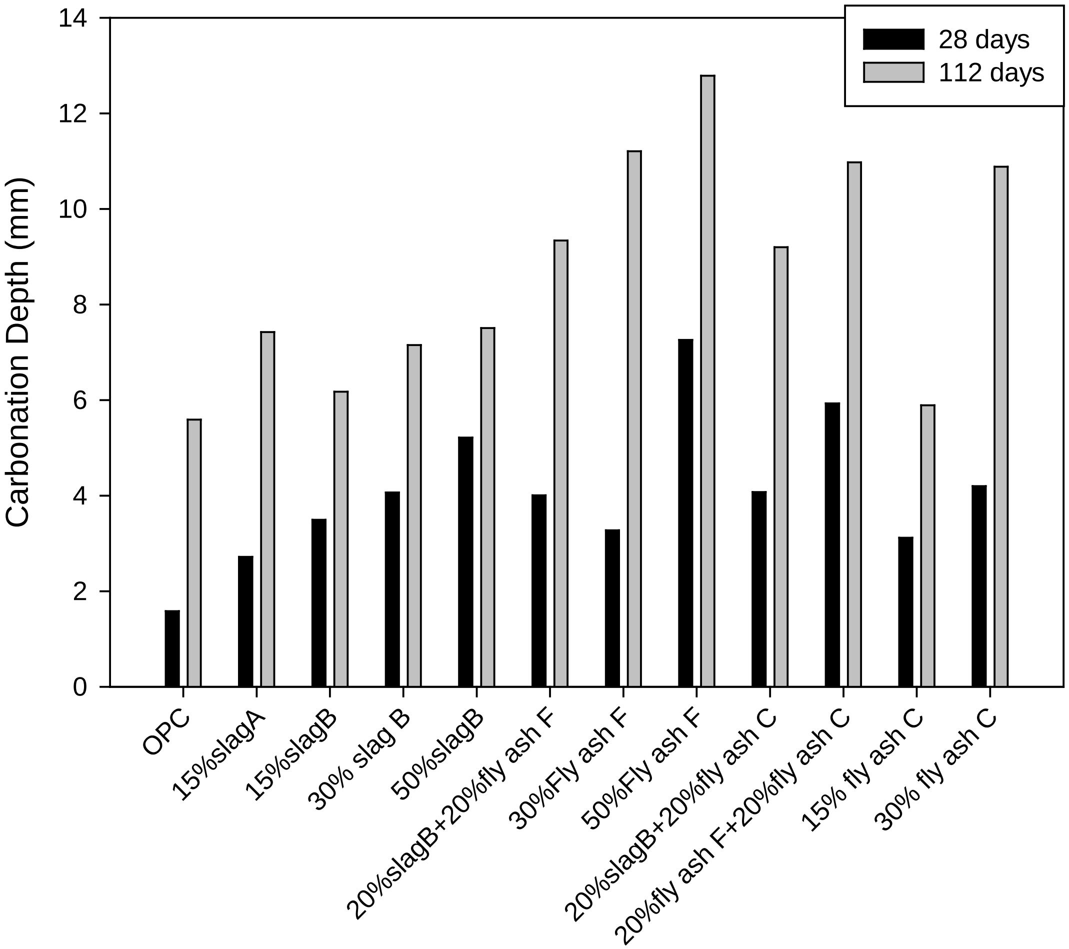


ACMT results on mixes with total binder content of 310 kg/m³ and w/b 0.5

- **Mineral admixture mixes generally have lower chloride migration than OPC mixes**
- **Slag and Class F fly ash at 50% replacement yield the lowest non-steady state migration coefficient**
- **Fly ash C improves at 90 days**

Accelerated Carbonation Test

Effect of mineral admixtures in accelerated carbonation



Depth of Carbonation Data
(Exposure period 28 days and 112 days;
1% CO_2, 65% RH, 25^{o}C)
Mixes with total binder content 310 kg/m^3; w/b 0.5

- **Depth of carbonation is more in the case of mixes with mineral admixtures**
- **Mixes with high fly ash dosages show greater depth of carbonation**
- **OPC performs better in the case of accelerated carbonation test**

BENEFITS OF USING BLENDED CEMENT HAVING FLY ASH AND SUPERPLASTICIZER ON CHLORIDE INDUCED CORROSION IN CRACKED CONCRETE

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Materials and Parameters Studied

- ✓ Cements: OPC and PPC (blended cement with about 25% fly ash F)
- ✓ Polycarboxylic ether superplasticizer (PCE SP)
- ✓ Water to cement ratio (w/c): 0.57, 0.47, 0.37
- ✓ Crack width: 0 mm (uncracked), 0.2 mm, 0.4 mm
- ✓ Slump: Concrete without SP: 25-50 mm & with PCE SP: 125-150 mm

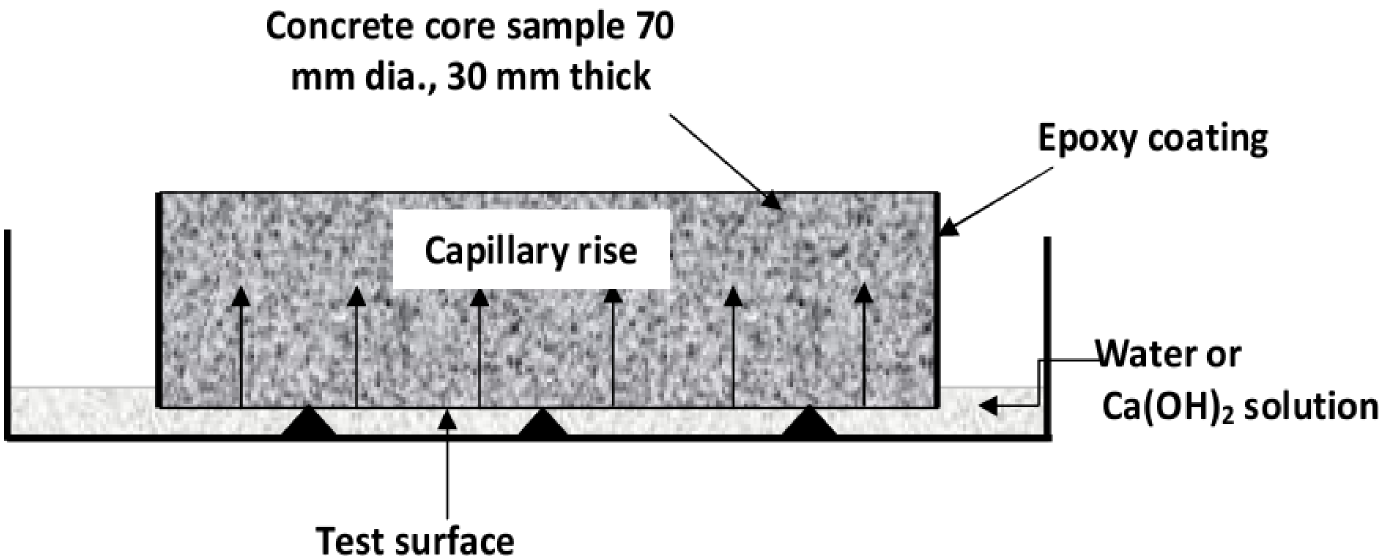
Tests Carried out

- ✓ Mechanical and Durability tests of the Concrete
  Compressive, Split tensile,
  Flexural strengths
  RCPT, diffusivity, sorptivity
  | using standard test specimens
- ✓ Impressed Voltage Accelerated Corrosion Test
- ✓ Half-cell potential and Resistivity Measurements
- ✓ Gravimetric Weight loss Measurements

Sorptivity Test (DI Manual, SA)

Water sorptivity test, mm/√h	Concrete quality
< 6	Very good
6 - 10	Good
10 - 15	Poor
> 15	Very poor

(RILEM TC 230)



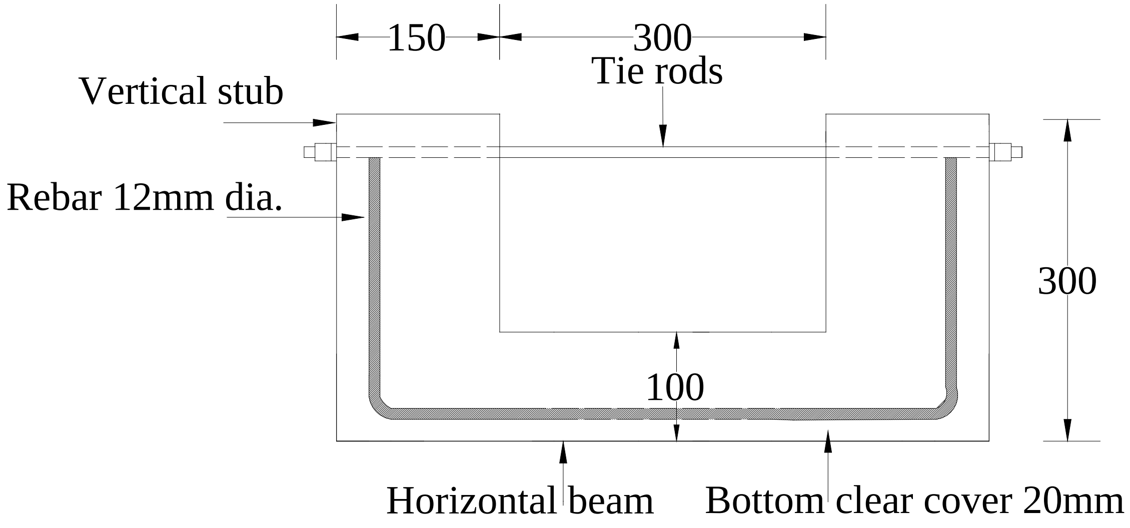
U Shaped Specimen Developed at SERC

- U-shaped specimen: horizontal beam -100x100x600 mm

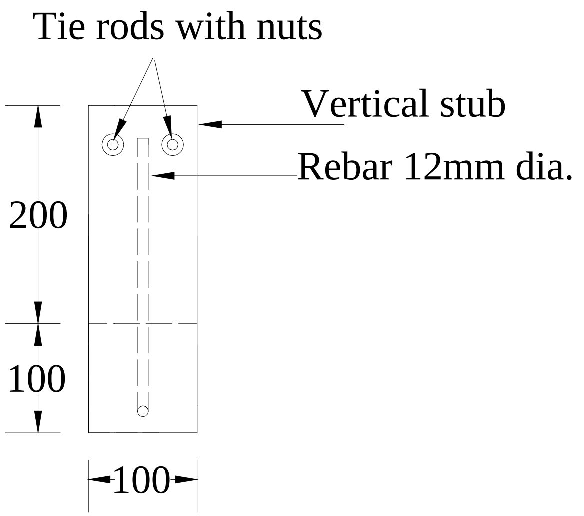
  two integral vertical stubs -100x150x200

- Holes provided in the stub portion to insert two tie rods for inducing cracks in the beam portion

- After 28 days of water curing and 30 days of air curing, tie rods inserted in the beam and tightened to apply a pure bending moment in the beam portion (induced flexural cracks)



Sectional elevation



Side view

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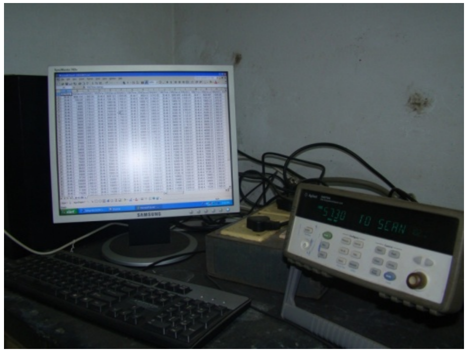
Impressed Voltage Test (Accelerated Corrosion)

- U Shaped specimens were put in 3.5% NaCl solution for 24 hours to ensure full saturation of the test specimen
- A potential of 10V is applied. The high impressed voltage was used to accelerate the corrosion process and shorten the test period. Current passed was recorded for every one hour using Auto Data-logger
- Specimens were exposed for the specified durations (22 days) to attain a weight loss of about 20% in the rebars of the uncracked specimens with w/c = 0.57 (Holm 1987; Liu and Weyers 1996)



Mechanical and Durability Test Results (28 Days)

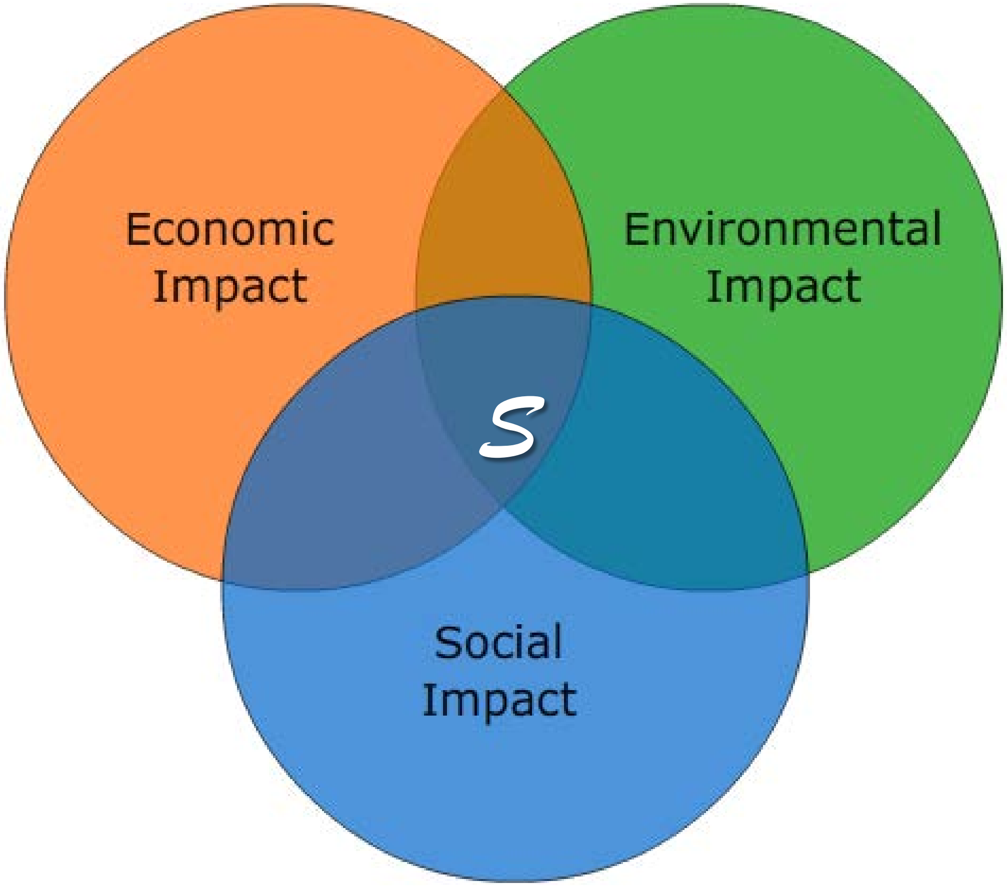
OPC (Control) and PPC+SP Concretes

w/c	0.57	0.47	0.37
OPC Concrete			
Cube comp. strength (MPa)	33.2	44.7	53.7
Bulk resistivity (kΩ.cm)	14	15	15
Diffusivity (10^{-7} m^2/s)	7.7	n.a.	n.a.
RCPT (Coulombs)	2600	2100	1900
Sorptivity ($mm/min.^{1/2}$)	0.097	0.092	0.087
PPC+SP Concrete			
Cube comp. strength (MPa)	32.5	44.8	54.0
Bulk resistivity (kΩ.cm)	26	26	30
Diffusivity (10^{-7} m^2/s)	3	1	0.5
RCPT (Coulombs)	860	760	525
Sorptivity ($mm/min.^{1/2}$)	0.055	0.044	0.041

Gravimetric Weight Loss in Rebar (% reduction)

w/c	0.57	0.47	0.37
OPC			
Uncracked	18.5	14.0	11.9
0.2 mm-crack	30.2	23.1	18.2
0.4 mm-crack	33.4	25.2	22.4
PPC-SP			
Uncracked	5.5	4.9	4.1
0.2 mm-crack	13.7	12.2	11.1
0.4 mm-crack	16.8	15.7	12.3

CONCLUDING REMARKS



Judicious use of admixtures can contribute significantly in making sustainable concrete

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