HONG KONG CONSTRUCTION MATERIALS ASSOCIATION LIMITED

PRODUCING DURABLE CONCRETE IN CONCRETE INDUSTRY

26 APRIL 2017

Hong Kong Construction Materials Association
Technical Committee of Ready Mixed Concrete Committee
Presented by KW Leung and Kenny Sun

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Presented by Kenny Sun

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Presented by K. W. Leung

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Introduction

Definition of Durability of Concrete

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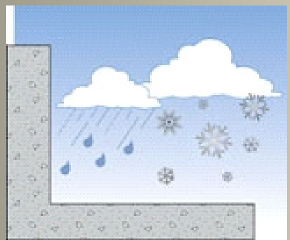
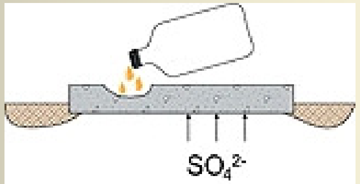
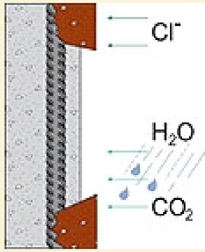
Ability to withstand its design service conditions for a design life without significant deterioration.”



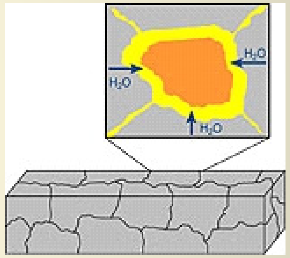
Resistance to weathering, including freezing and thawing



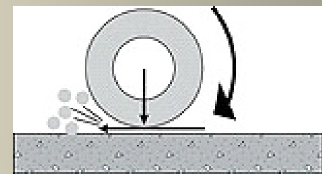
Chemical resistance



Corrosion resistance



Resistance to alkali-silica reaction (ASR)



Abrasion resistance

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Durable Concrete from Designers' Perspectives

Structure Types

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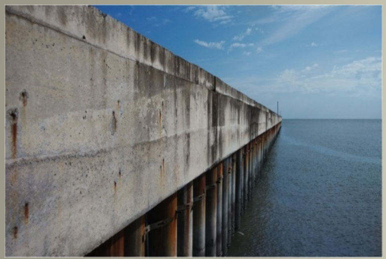
Particular structure types need special attention (Severe Exposure Condition)



Marine structure, e.g. bridge decks, bridge piers especially exposed to salt water

Structure under continuous abrasion, e.g. parking structure, pavements

Structure with potential exposure to chemical attack, e.g. waste treatment plant, chemical plant, nuclear power station, etc

Structure in region which undergo continuously freezing and thawing

Structure with long design life, e.g. 120 years design life

Exposure Conditions

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Class / Designation	Description of environment	Informative example where exposure classes may occur
1 No risk of corrosion or attack		
X0	For concrete without reinforcement or embedded metal: all exposures except where there is freeze/ thaw, abrasion or chemical attack	
	For concrete with reinforcement or embedded metal: very dry	Concrete inside buildings with very low air humidity
2 Corrosion induced by carbonation (Where concrete containing reinforcement or other embedded metal is exposed to air and moisture)		
XC1	Dry or permanently wet	Concrete inside buildings with low humidity. Concrete permanently submerged in water
XC2	Wet, rarely dry	Concrete subjected to long-term water contact. Many foundations
XC3	Moderate humidity	Concrete inside buildings with moderate or high air humidity. External concrete sheltered from rain.
XC4	Cyclic wet and dry	Concrete surfaces subject to water contact, not within exposure class XC2
3 Corrosion induced by chlorides other than from sea water (Where concrete containing reinforcement or other embedded metal is subject to contact with water containing chlorides, including deicing salts from sources other than sea water)		
XD1	Moderate humidity	Concrete surfaces exposed to airborne chlorides
XD2	Wet, rarely dry	Swimming pools. Concrete exposed to industrial waters containing chlorides
XD3	Moderate humidity	Parts of bridges exposed to spray containing chlorides. Pavements. Car park slabs
4 Corrosion induced by chlorides from sea water (Where concrete containing reinforcement or other embedded metal is subject to contact with chlorides from sea water or air carrying salt originating from sea water)		
XS1	Exposed to airborne salt but not in direct contact with sea water	Structures near to on the coast
XS2	Permanently submerged	Parts of marine structures
XS3	Tidal, splash and spray zones	Parts of marine structures
5 Freeze/thaw attack with or without de-icing salts (Where concrete is exposed to significant attack from freeze-thaw cycles whilst wet)		
XF1	Moderate water saturation, without de-icing agents	Vertical concrete surfaces exposed to rain and freezing
XF2	Moderate water saturation, with de-icing agents	Vertical concrete surfaces of road structures exposed to freezing and airborne de-icing agents
XF3	High water saturation, without de-icing agents	Horizontal concrete surfaces exposed to rain and freezing
XF4	High water saturation, with de-icing agent or sea water	Road and bridge decks exposed to de-icing agents. Concrete surfaces exposed to direct spray containing de-icing agents and freezing. Splash zones of marine structures exposed to freezing
6 Chemical attack		
XA1	Slightly aggressive chemical environment according to Table 2*	Vertical concrete surfaces exposed to rain and freezing
XA2	Moderately aggressive chemical environment according to Table 2*	Vertical concrete surfaces of road structures exposed to freezing and airborne de-icing agents
XA3	Highly aggressive environment according to Table 2*	Horizontal concrete surfaces exposed to rain and freezing

Exposure classes: EN 206-1:2000

Class / Designation	Description of environment	Informative example where exposure classes may occur
XS1	Exposed to airborne salt but not in direct contact	Structures near to on the coast

EN 206-1:2000 Table 4 - Exposure Classes

Exposure Conditions

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	Exposure classes																	
	No risk of corrosion or attack	Carbonation-induced corrosion				Chloride-induced corrosion						Freeze-thaw attack				Aggressive chemical environments		
						Sea Water			Chloride other than from sea water									
	XO	XC 1	XC2	XC3	XC4	XS1	XS2	XC3	XD1	XD2	XD3	XF1	XF2	XF3	XF4	XA1	XA2	XA3
Maximum w/c	-	0.65	0.60	0.55	0.50	0.50	0.45	0.45	0.55	0.55	0.45	0.55	0.55	0.50	0.45	0.55	0.50	0.45
Minimum strength class	C12/15	C20/25	C25/30	C30/37	C30/37	C30/37	C35/45	C35/45	C30/37	C30/37	C35/45	C30/37	C25/30	C30/37	C30/37	C30/37	C30/37	C35/45
Minimum cement content, kg/m3	-	260	280	280	300	300	320	340	300	300	320	300	300	320	340	300	320	360
Minimum air content, percent	-	-	-	-	-	-	-	-	-	-	-	-	4.0	4.0	4.0	-	-	-
Other requirement												Aggregate in accordance with EN12620 with sufficient freeze / thaw resistance					Sulfate-resisting cement	

Recommended limiting values for composition and properties of concrete in EN206

EN 206-1:2000 Table 5 - Recommended limiting values for composition and properties of concrete

	Exposure classes
	Chloride-induced corrosion
	Sea Water
	XS1
Maximum w/c	0.5
Minimum strength class	C30/37
Minimum cement content, kg/m^3	360
Minimum air content, percent	-

Designed Life

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HK-ZH-MO Bridge

Design Life: 120 Years

Tsing Ma Bridge

Design Life: 120 Years

Stonecutter Bridge

Design Life: 120 Years

Concrete durability is essential for the long design life of 120 years for major infrastructure projects.

Specification on Durability of Concrete

Major considerations base on different exposure conditions

- Minimum and/or maximum cementitious content
- Water to cementitious content ratios
- Placing temperature / in-situ peak temperature / temperature gradient of the structure
- Limit on reactive alkali, i.e. Alkali-aggregate reaction (AAR) control
- Addition of supplementary cementitious content, e.g. PFA, CSF, GGBS, etc.
- Addition of chemical, e.g. SRA, WP, Corrosion Inhibitor, etc.
- Chloride content in concrete mix

Specification on Durability of Concrete

Specification for marine concrete

Mix Parameter	Acceptable limits
Water/cementitious content ratio	Not exceeding 0.38
Cementitious content	380-450kg/m^3
Supplementary cementitious materials	Either PFA or GGBS, and CSF to be incorporated
If PFA added, PFA content	25-40%
If GGBS added, GGBS content	60-75% (normal application) Or 60-90% (low heat application)
CSF content	5-10%
Characteristic strength	45MPa

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- **DSD Project – Power Station Cooling Water System**

- Watertight admixture with HPI to reduce water absorption to 1% or below as measured by BS1881: Part 122: 1983

- SRA to reduce shrinkage by 30% or more at 28 days as measured by ASTM C157-93

Admixtures 16.10 Add the following sub-clause after GS Clause 16.10(2):

(3) Watertight admixture shall be a proprietary product approved by the Engineer. The watertight admixture shall be an approved hydrophobic, poreblocking ingredient at a rate of 30 litres per cubic metre of concrete such that the concrete shall have a corrected 30 minutes water absorption of not greater than 1.0% as measured by BS 1881: Part 122: 2983 except that the age at test shall be 7 days.

(4) Reinforced concrete for water retaining and watertight structures shall contain a Shrinkage Reducing Admixture (SRA). The SRA shall be a proprietary type approved by the Engineer and shall conform to the following properties and product performances:

(a) The SRA shall be a liquid Propylene Glycol based admixture suitable for coast environment, and suitable for accurate dispensing at the concrete ready mix plant.

(b) The usage of the SRA shall be strictly in compliance with the manufacturer's recommendations.

(c) The SRA shall achieve a minimum shrinkage reduction of 30% at 28 days of drying for laboratory cast specimens. Testing shall conform to ASTM C157-93.

- **DSD Project – Harbour Area Treatment**

- Limitation on cementitious content to 380-450kg/m3

- Incorporated of SCM, 25-40% of PFA & 5-10% of condensed silica fume

For concrete used in water retaining structures, add the following after Clause 16.14:-

Cementitious content 16.14A (1) For concrete used in water retaining structures, the cementitious content shall comply with Clause 16.14 and sub-clauses (2) to (6) mentioned below.

(2) Cementitious content is the combined mass of cement and the dry mass of Condensed Silica Fume (CSF) and the mass of Pulverised Fuel Ash (PFA) per cubic metre of compacted concrete.

(3) The cementitious content of the concrete mix shall be within the 380-450 kg/m^3.

(4) PFA shall be incorporated in the concrete as separate materials. The proportion of PFA replacement shall be within the 25-40% range by mass of the cementitious content for normal applications.

(5) The proportion of the dry mass of CSF replacement shall be within the 5-10% range by mass of the cementitious content.

(6) For concrete for water retaining structures, the water/cement ratio shall not exceed 0.38. For the purposes of this calculations, the water shall be the total water in the mix inclusive of non-solid components of liquid admixtures, and the cement shall be the total cementitious content.

(7) Grade 45 concrete must contain 6% of micro-silica (also known as condensed silica fume, to CSA-A23.5-M86, Canadian Standard) by weight of cementitious material.

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- **BD Project – Residential Development At Tai Po Town**

- Watertight admixture with HPI to reduce water absorption to 1% or below as measured by BS1881: Part 122: 1983

- Superplasticizer is to be included

3.2 PERFORMANCE SPECIFICATION FOR HYDROPHOBIC PORE BLOCKING INGREDIENT (HPI) CONCRETE

Corrosion-proof and waterproof concrete shall comply with the conditions and requirements as set of out in Section 3.2.

All concrete in the designated areas shall conform with all specified requirements and also the following:

a) The cement content of the concrete shall be no less than 350 kilograms per cubic metre.

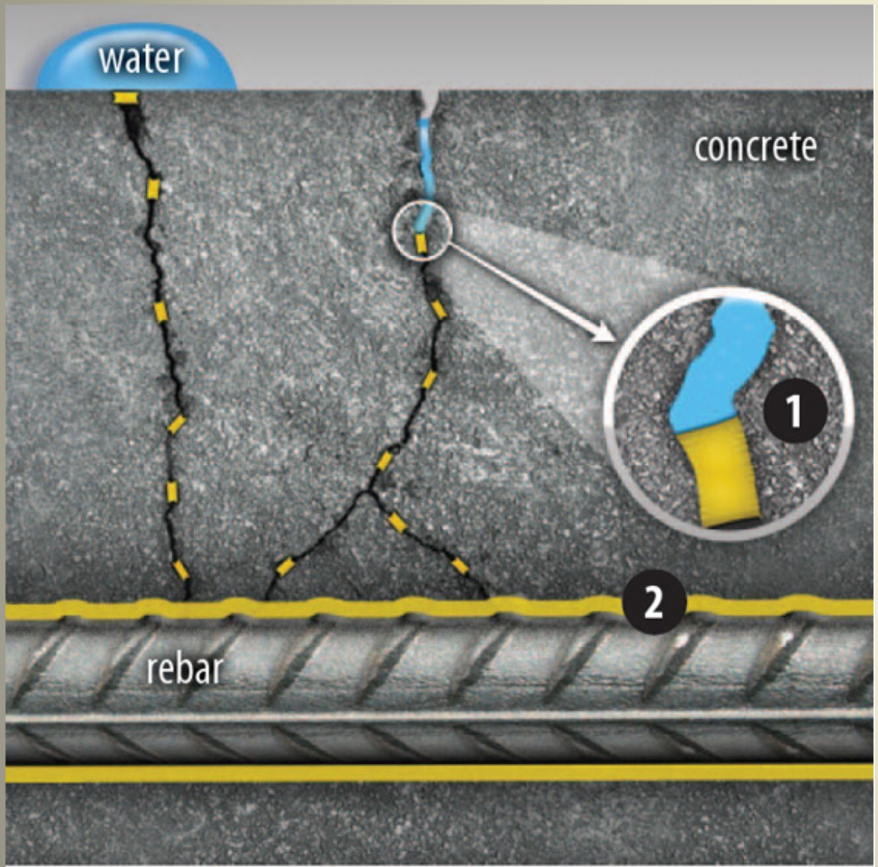
b) The concrete shall contain a time-proven effective Hydrophobic Pore Blocking Ingredient (HPI) or proven equal and approved in writing, strictly in accordance with Manufacturers' Detailed Technical Specifications, producing concrete with a Hydrophobic Matrix throughout as well as dispersed polymer particles suitable for use as a pore-blocking agent.

c) The concrete shall further contain an approved High Range Water Reducing admixture or superplasticiser such that the free (water + HPI): cement ratio shall not exceed 0.45 and the concrete will be of adequate workability for void-free placement and compaction.

d) The Hydrophobic Pore Blocking Ingredient (HPI) concrete shall conform to all specified requirements and shall further be shown to produce concrete with a corrected 30 minute absorption of not greater than 1% (one percent), as measured by BS 1881: Part 122: 1983, except that the age at test shall be 7 days.

Intended Use – e.g. Water-Retaining Structure

Hydrophobic Pore-blocking Ingredient (HPI)



1. Hydrophobic pore blocking 2. Corrosion-inhibiting surface coating

- Materials developing polymer barriers inside pores during the hydration process.
- The nature of the polymers can cause water to form a water drop on the surface of the concrete.
- The surface tension of the water itself keeps it from being able to penetrate the wall.

Intended Use – e.g. Water-Retaining Structure

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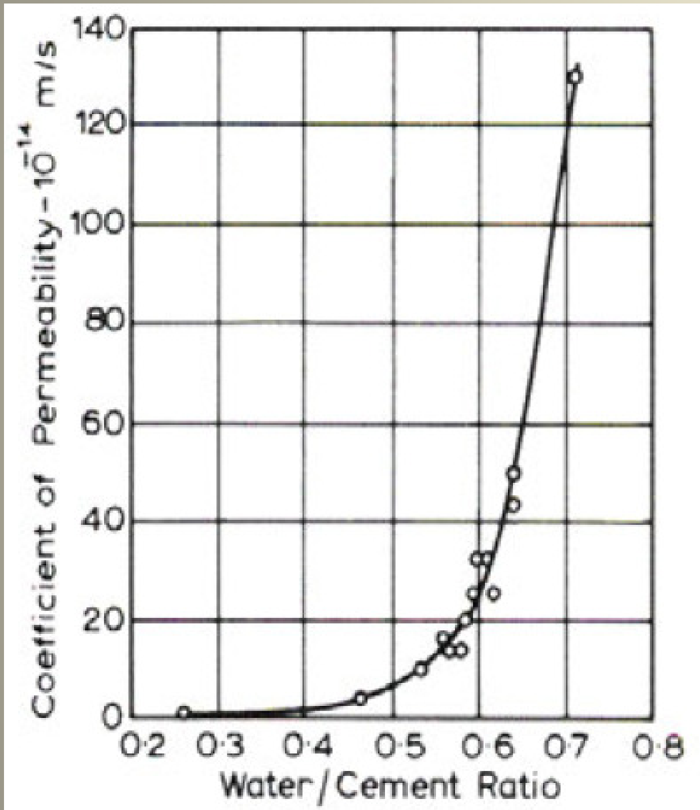

Effect of w/c ratio on permeability
(Powers et al, 1954)

- Low water/cementitious ratio w/c ≤ 0.38
- High workability e.g. Slump≥175MM
- Use of superplasticizer
  - enhance workability
  - reduce the amount of pores
  - better dispersion of cement particles
  - increase concrete density
  - reduce permeability
- Use of waterproof admixture
  - further improve permeability properties

Intended Use – e.g. basement below water level

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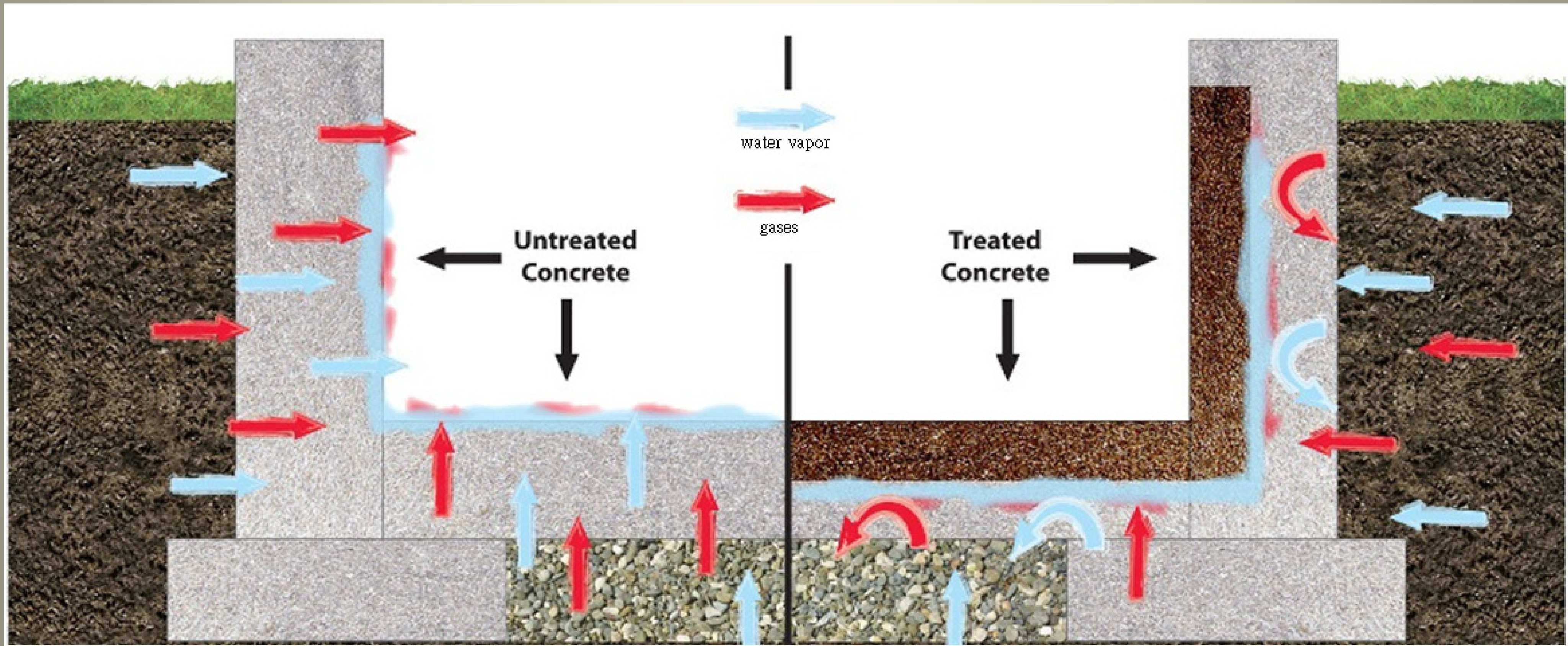
Treated and Non-treated concrete



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Durable Concrete from Construction Sites' Perspectives

Placing and Compaction

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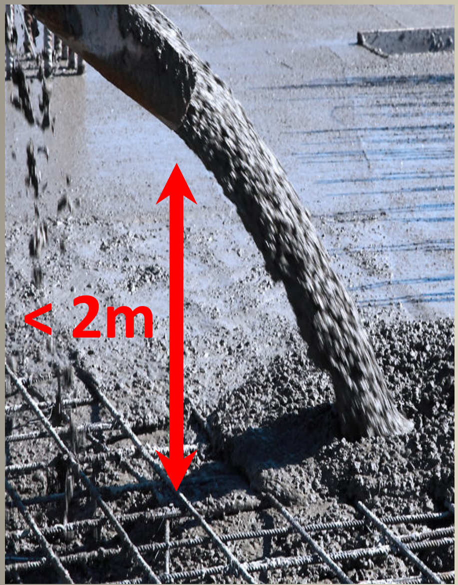

Excessive free fall may lead to concrete segregation

Long pumping distance may reduce air content and workability

Over-vibration may lead to segregation
Under-vibration may lead to inadequate compaction thus homey combing

Placing and Compaction

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Inadequate Vibration - Honeycombing

Curing and Concrete Cover

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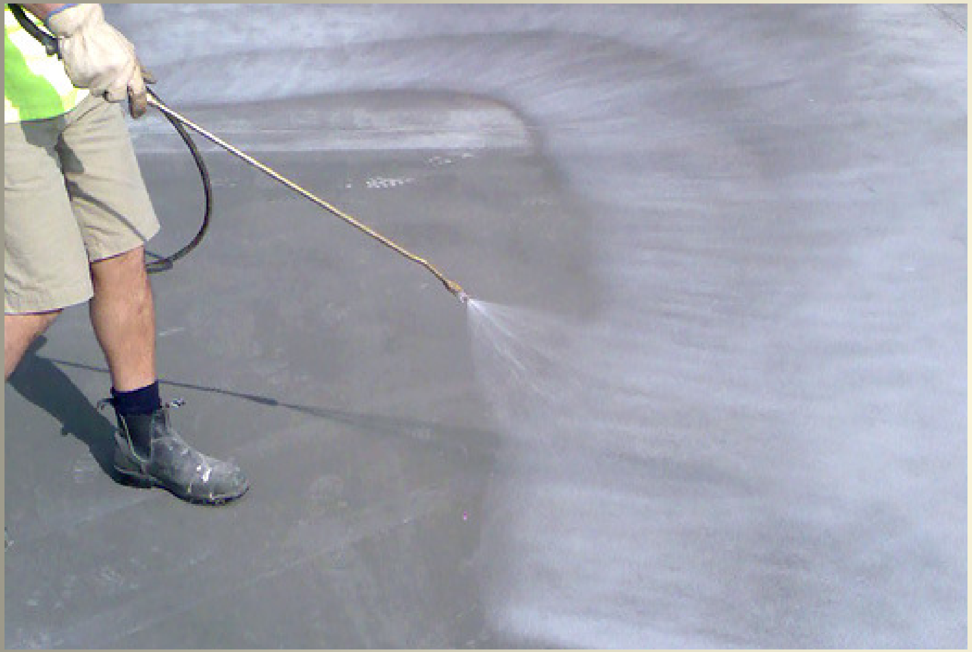

Curing at different stages

- Moisture retention / Reduce plastic shrinkage crack
- Enhance hydration process
- Proper strength development
- Reduce chemical attack

Concrete cover

- Determine the ease of ingress of aggressive agents and corrosion rate of reinforcement.

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Durable Concrete from Concrete Producers' Perspectives

Durable Concrete From Concrete Producers’ Perspectives

- **Permeability of concrete affected by:**
  - Surface tension in capillary pores
  - Hydrostatic pressure
  - External factors such as inadequate compaction and curing

Durable Concrete From Concrete Producers' Perspectives

- **Shrinkage of concrete affected by:**
  - Plastic Shrinkage
  - Autogenous Shrinkage
  - Drying Shrinkage
  - Intrinsic tensile stresses to cause shrinkage cracking due to drying shrinkage / autogenous shrinkage if concrete is restrained, thus adversely affecting durability.

Durable Concrete From Concrete Producers' Perspectives

- **Common Performance parameters of Concrete in HK**
  - Permeability
  - Water Absorption
  - Rapid Chloride Permeability
  - Permeability Coefficient
  - Water Penetration Depth
  - Sorptivity
  - Shrinkage
  - Temperature

Durable Concrete From Concrete Producers' Perspectives

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Example on Specification Requirements

CEDD Specification

Table 16.15: Compliance criteria for sorptivity and chloride diffusion

Test	Type		Compliance Criteria
Sorptivity	Plant Trial	-	Equal to or less than 0.07 mm/min$^{0.5}$ at 28 days.
	Shaft, lining	-	Equal to or less than 0.07 mm/min$^{0.5}$ at 28 days.
Chloride Diffusion	Plant Trial	-	Equal to or less than 1000 coulombs at 28 days.
	Shaft, lining	-	Equal to or less than 1000 coulombs.

MTRC Specification

For Category A concrete the results of the RCPT shall be average 35 day electrical resistance less than 1500 Coulombs.

For Category A concrete the results of the absorption tests shall be average absorption value at 28 days of less than 1.5%.

Durable Concrete From Concrete Producers' Perspectives

Example on Specification Requirements

Private Project Specification

- Water absorption at 7 days shall not be greater than 1.0%

The integral waterproofing concrete shall contain a time-proven hydrophobic pore-blocking ingredient or proven equal and approved in strict accordance with the Waterproofing Materials Manufacturer's detailed technical specifications. Once the approval has been given, the Contractor shall not change the approved ingredients with out the Engineer's approval.

Durable Concrete From Concrete Producers' Perspectives

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Example on Specification Requirements

<u>Requirements for Stormwater Storage Structure</u>

- With Shrinkage Reducing Admixture
- Min. cement content: 360kg/m^3
- Max. cementitious content: 410kg/m^3
- With 25% PFA replacement
- Max. water/cementitious ratio: 0.45
- Min. shrinkage reduction of 30% to control mix at 28days is required

Durable Concrete From Concrete Producers' Perspectives

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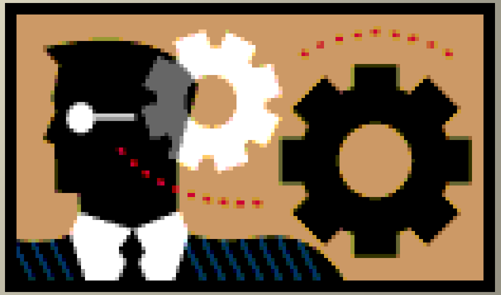
- **Reduce Permeability of Concrete Mix by:**
  - Lower Water/Cementitious ratio
  - Incorporating SCMs (e.g. PFA, GGBS & CSF)
  - Use of chemical admixtures

- **Reduce Drying Shrinkage of Concrete Mix by:**
  - Lower water / cementitious ratio
  - Increasing aggregate content (i.e. Reduce paste volume)
  - Use of chemical admixtures



Durable Concrete From Concrete Producers' Perspectives

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- **Type of Admixtures**
  - Air-entraining
  - Retarding
  - Accelerating
  - Water reducing
  - ***High range water reducing***
  - ***Shrinkage reducing***
  - ***Waterproofing***
  - Viscosity modifying
  - Etc…

Durable Concrete From Concrete Producers’ Perspectives

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Report on Chemical admixtures for concrete

ACI 212.3R-10 VS ACI 212.3R-16

ACI 212.3R-10

18 Admixture Types

→

ACI 212.3R-16

23 Admixture Types

Durable Concrete From Concrete Producers' Perspectives

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Trial mix results – Example of Using SCMS and Superplasticiser

Grade	Designed Slump	OPC	PFA	CSF	Superplasticiser (PC)	W/C ratio
45/20	175mm	314 kg/m^3	114 kg/m^3	23 kg/m^3	5.5 lit/m^3	0.38
			(25%)	(5%)		

Durable Concrete From Concrete Producers' Perspectives

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Trial mix results – Example of Using SCMS and Superplasticiser

	7 days	28 days	58 days
Average Compressive Strength (MPa)	56.3	78.6	88.2

	Sample One	Sample Two	Average
Chloride Diffusion at 28 days (Coulombs)	433	418	423

	Sample One	Sample Two	Average
Sorptivity at 28 days ($mm/min^{0.5}$)	0.06	0.06	0.06

Durable Concrete From Concrete Producers' Perspectives

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- **Concrete with Hydrophobic Pore-Blocking Ingredient (HPI)**
  - **Hydrophobic Pore-blocking Admixture**
    - Produce hydrophobic water repelling properties
    - Improve water repellency
    - Reducing water absorption of concrete
    - Reduce the permeability of concrete to enhance the durability of concrete
  - **Application**
    - Water retaining structures
    - Water tank
    - Swimming pool, etc.

Durable Concrete From Concrete Producers' Perspectives

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Trial mix results – Example of Using Hydrophobic Pore-blocking Admixture

Grade	Designed Slump	OPC	PFA	Superplasticser (PC)	HPI	W/C ratio
45/20	175mm	340 kg/m^3	110 kg/m^3	4.5 lit/m^3	4.5 lit/m^3	0.38
			(24.4%)			

Durable Concrete From Concrete Producers' Perspectives

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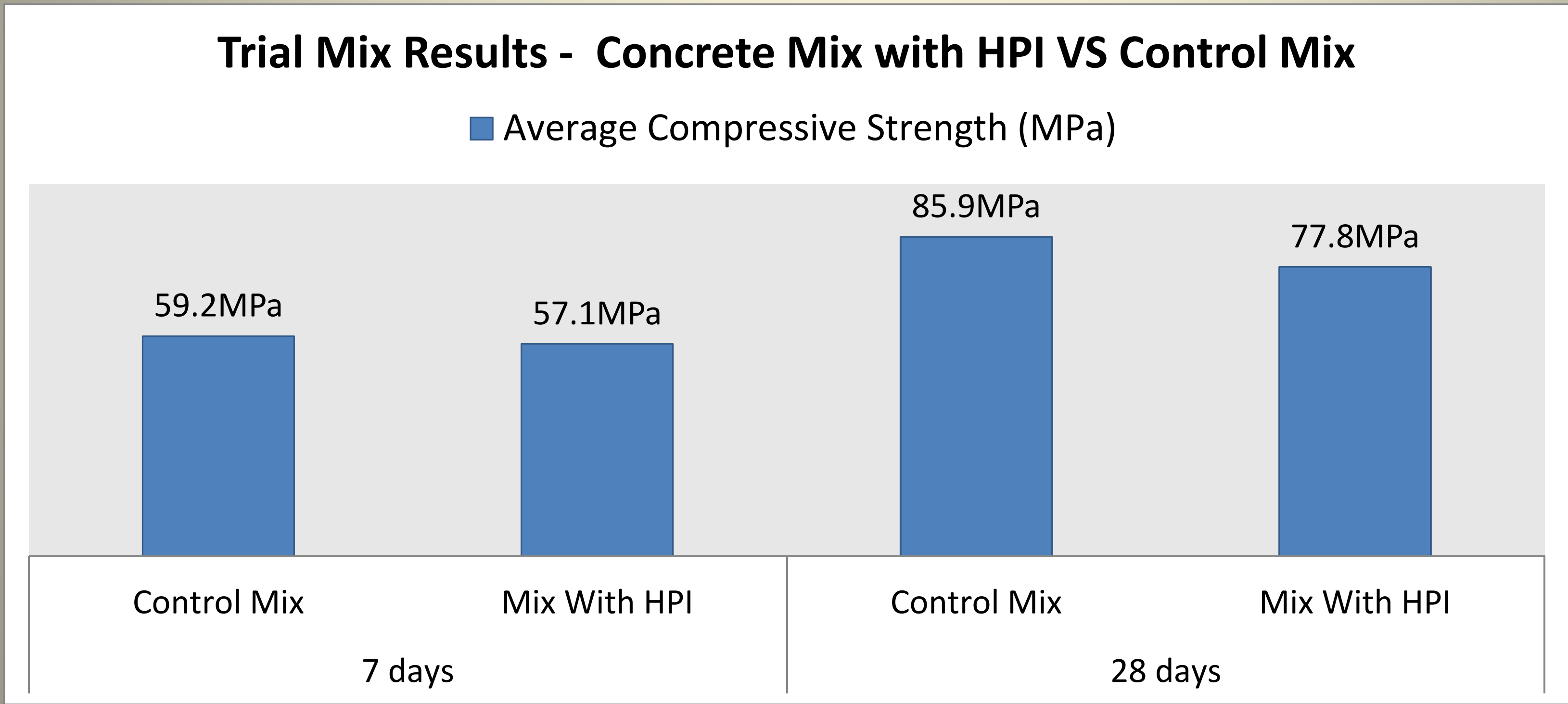
Trial mix results – Example of Using Hydrophobic Pore-blocking Admixture



Durable Concrete From Concrete Producers' Perspectives

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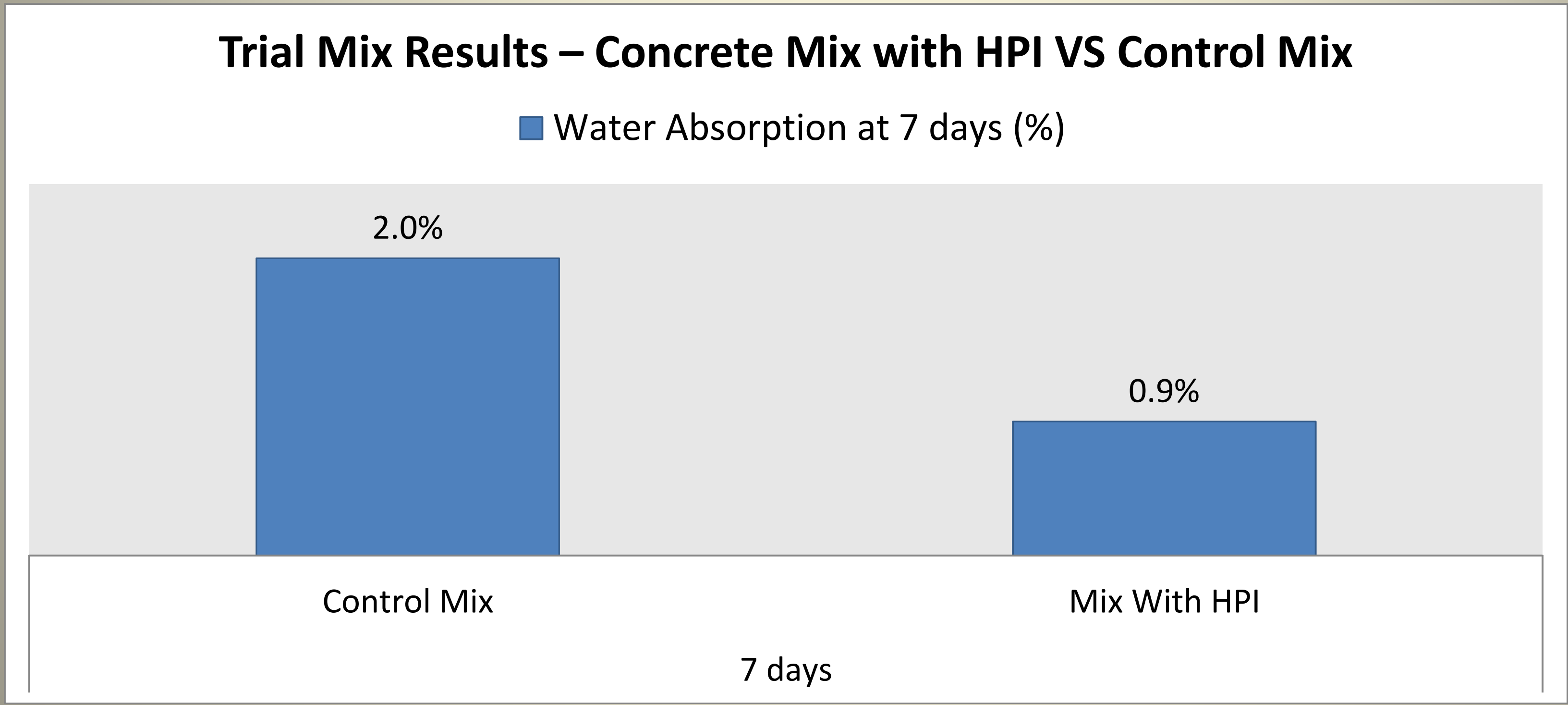
Trial mix results – Example of Using Hydrophobic Pore-blocking Admixture



Durable Concrete From Concrete Producers' Perspectives

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Findings Based on Trial of Concrete Using Hydrophobic Pore-blocking Admixture

- By using HPI in concrete, the water absorption at 7 days was reduced by 55.0% and compressive strength of 7 days and 28 days were reduced by 3.5% and 9.4% respectively.

Water absorption at 7 days	**↓ 55.0%**
Compressive Strength at 7 days	**↓ 3.5%**
Compressive Strength at 28 days	**↓ 9.4%**

Durable Concrete From Concrete Producers' Perspectives

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- **Application of Shrinkage Reducing Admixture**
  - Water retaining structure
  - Large area concrete Slab
  - Minimizing cracking by using SRA which allowing reduction of joints (i.e. Water Storage Tank)

Durable Concrete From Concrete Producers' Perspectives

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Trial mix results – Example of Using Shrinkage Reducing Admixture

Grade	Designed Slump	OPC	PFA	Superplasticser (PC)	SRA	W/C ratio
45/20	175mm	298 kg/m^3	112 kg/m^3	7.0 lit/m^3	5.5 lit/m^3	0.38
			(27.3%)			

Durable Concrete From Concrete Producers' Perspectives

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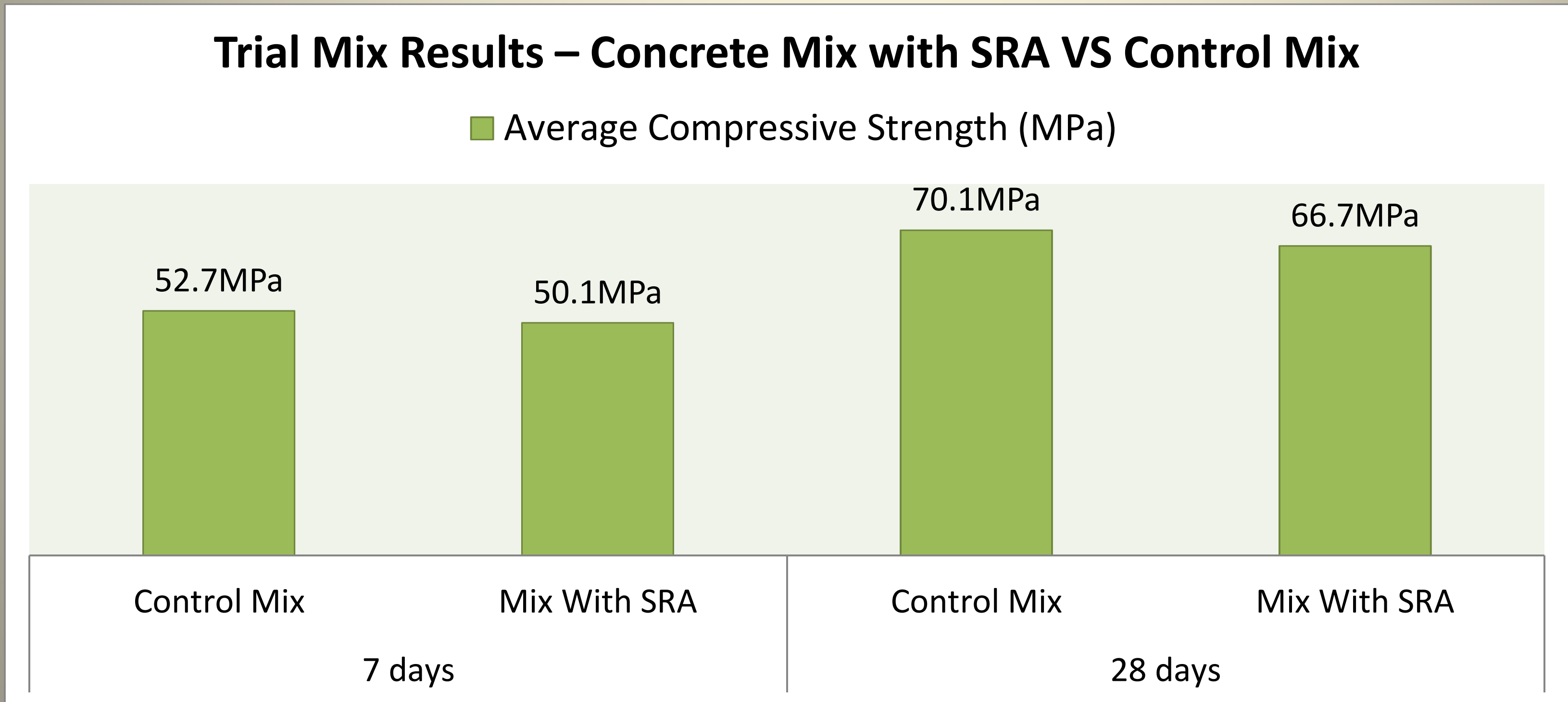
Trial mix results – Example of Using Shrinkage Reducing Admixture



Durable Concrete From Concrete Producers’ Perspectives

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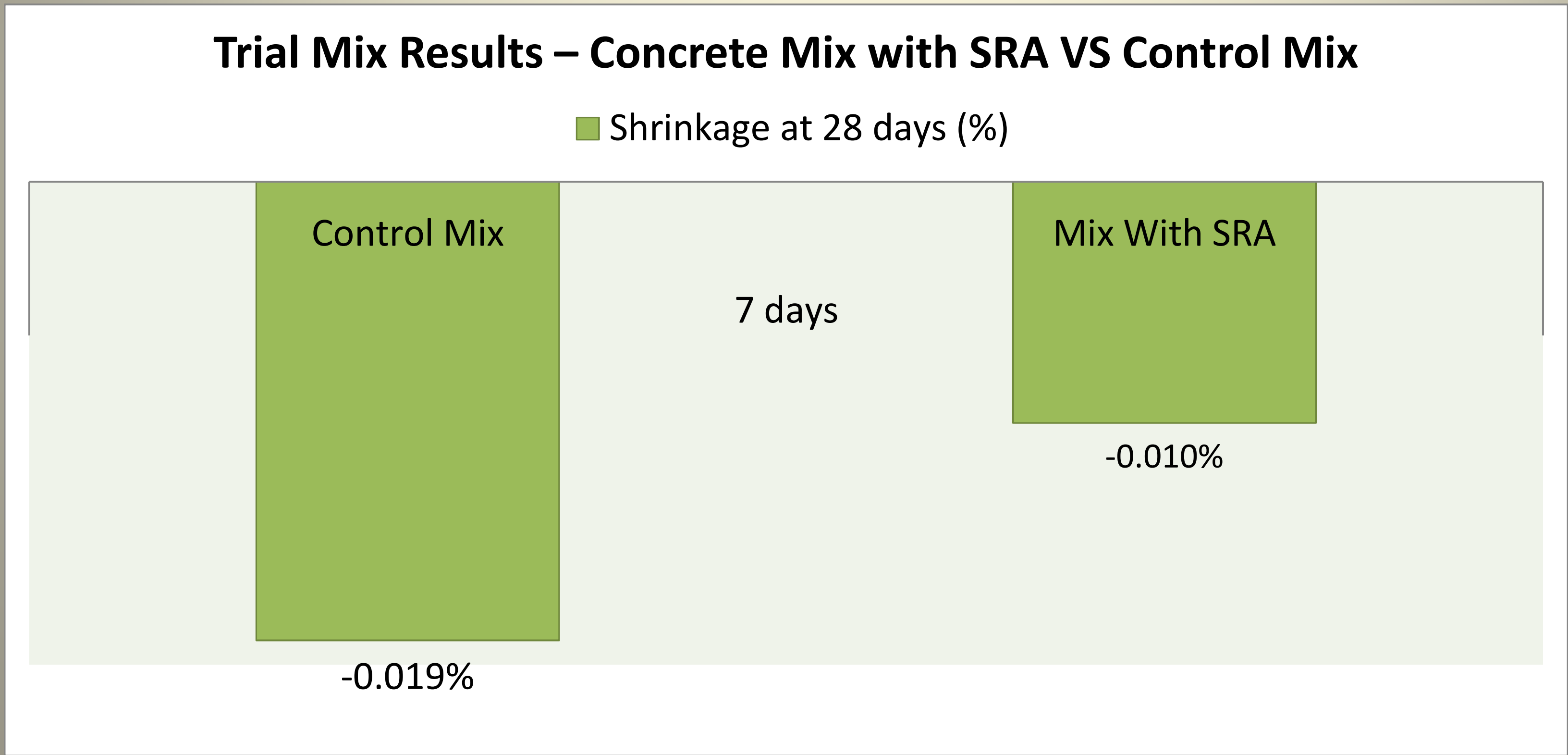
Trial mix results – Example of Using Shrinkage Reducing Admixture



Durable Concrete From Concrete Producers' Perspectives

Findings Based on Trial Using Shrinkage Reducing Admixture

- By using SRA in concrete, the shrinkage at 28 days was reduced by 47.4% and compressive strength of both 7 days and 28 days were reduced 4.9%.

Shrinkage at 28 days	47.4%
Compressive Strength at 7 days	4.9%
Compressive Strength at 28 days	4.9%

- Base on ACI 212.3R-10, adding some SRA to concrete at a 2% dosage by mass of cement can reduce the strength as much as 15% at 28 days.

Durable Concrete From Concrete Producers' Perspectives

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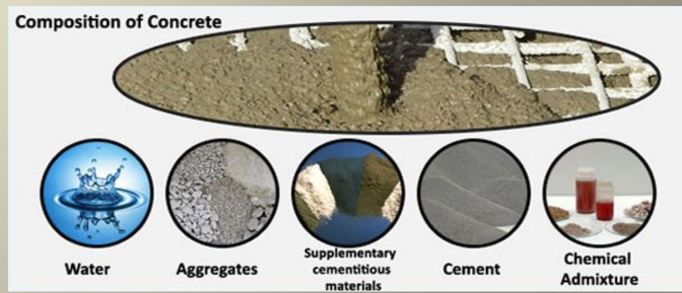
- **Measures & Concerns (1)**
  - **Proportioning of Concrete Mix**
    - – Optimal proportion to meet the desired performance.
    - – Compatibility of different types of admixtures and their dosage
    - – The effects on fresh & hardened concrete properties



Durable Concrete From Concrete Producers' Perspectives

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- **Measures & Concerns (2)**
  - **Concrete Production**
    - Mixing time and batching sequence
    - Stringent quality control measures
    - Supervision by competent person / well-trained staff
    - Proper storage

Durable Concrete From Concrete Producers' Perspectives

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Conclusion

Concrete durability is enhanced by:

- Using well proportioning concrete mix
- Use of SCMs or advance chemical admixtures
- Proper workmanship (i.e. placing, compacting & curing of concrete)
- Close supervision

SUSTAINABLE, CONSISTENT AND DURABLE CONCRETE