20.04.2016

Standing Committee on Concrete Technology

Annual Concrete Seminar 2016
"Green Concrete"

Green Technologies of Concrete
Concrete without OPC

Research on Materials Innovation

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MEng, CEng, MICE, MIM, MICT, FHKCI, FHKIE, RPE, BEAM Pro

Technical Director

OPTIMIX Group Limited

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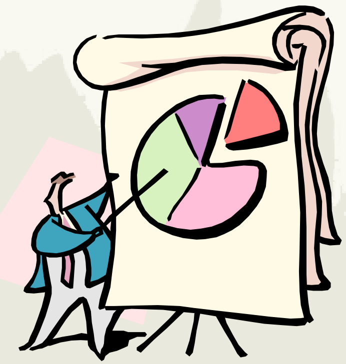
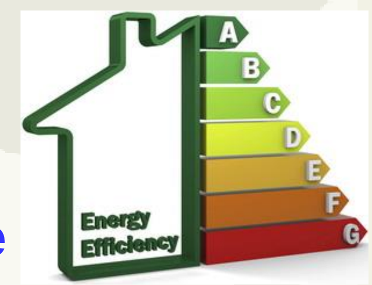
Outline

- Demand on Green Construction
- Green Targets & Green Construction Products
- Carbon Footprint of Ordinary Portland Cement
- Green Concretes without OPC
- Standardisation and Guidelines
- Potential Applications of OPC-Free Binder
- Remarks & Ongoing Works

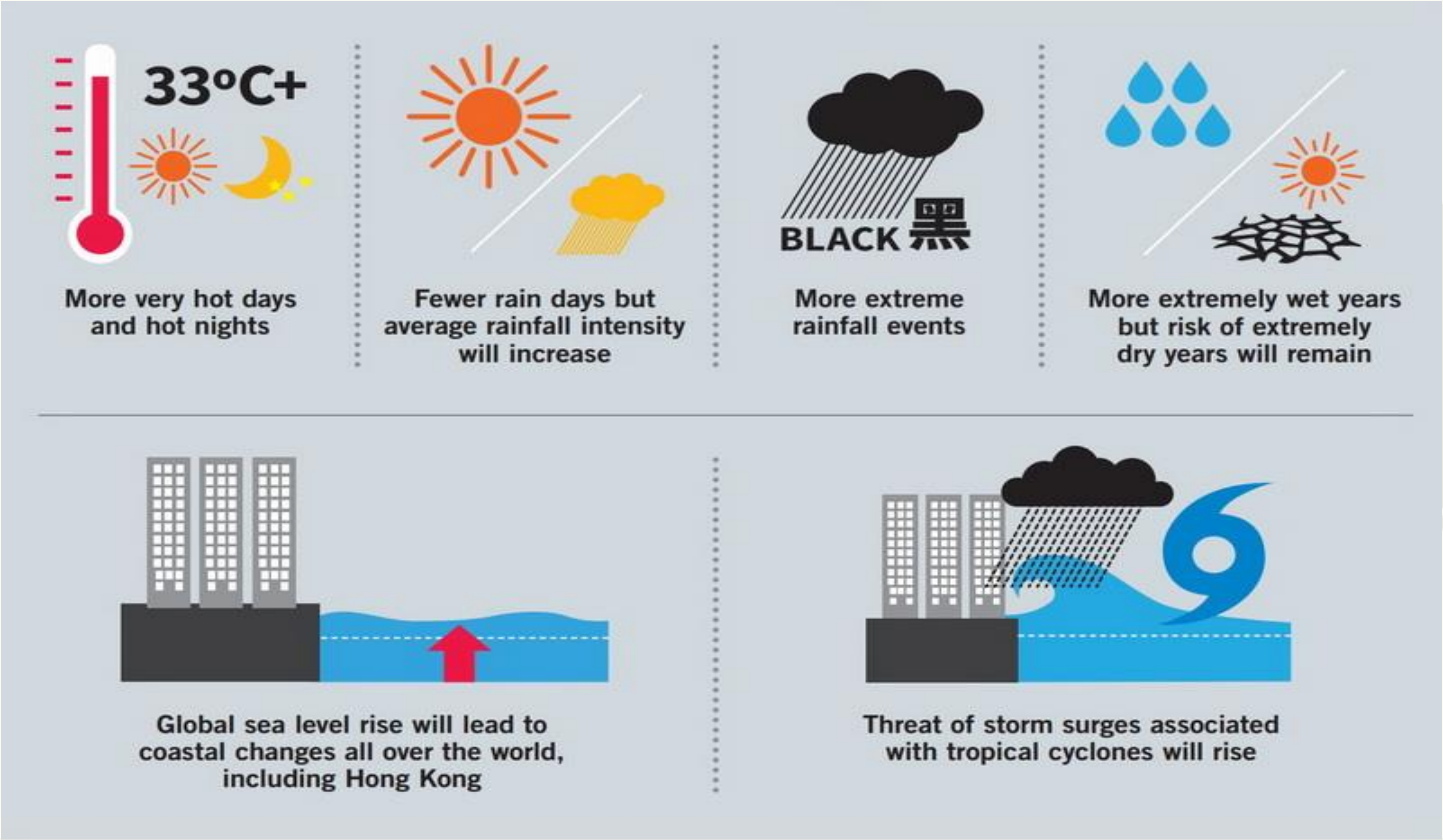


Demand on Green Construction

- Global challenge of limited energy resources
- Environmental challenge of climatic changes
- Reduce energy consumption
- Reduce greenhouse gas emissions
- Better living conditions / environment
- Low embodied carbon raw materials
- Materials with less harmful chemicals
- Highly effective and more durable products
- Lower operation cost and simple maintenance



Hong Kong's Climate on the 21st Century



Hong Kong Target on Carbon Reduction

Environment Bureau, HKSAR Government

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Global Warming

Greenhouse Gas

Hong Kong's Climate Change Strategy and Action Agenda

Target to reduce carbon intensity by 50-60% by 2020 when compared with 2005

Hong Kong Progress on Carbon Reduction

In 2012, the carbon intensity dropped by 19% using 2005 as the base

By 2020 → ??%

Sources of Greenhouse Gas (GHG) Emissions

Hong Kong

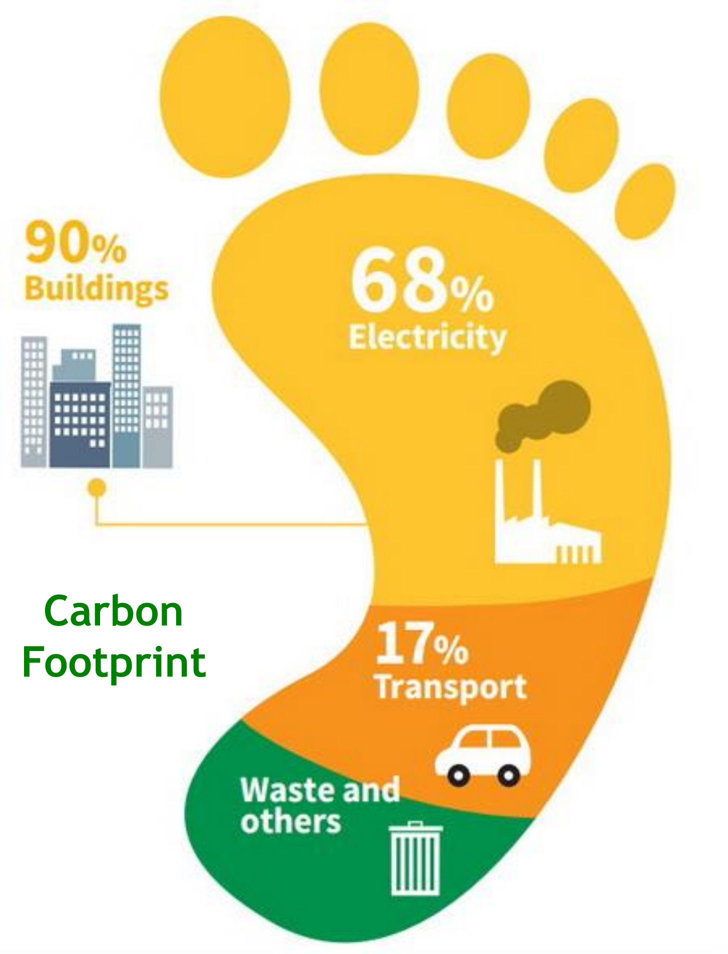
Main Source (~60%)

Buildings

Reduce Energy Consumption

Reduce Embodied Carbon

Adopt Greener Construction Practice

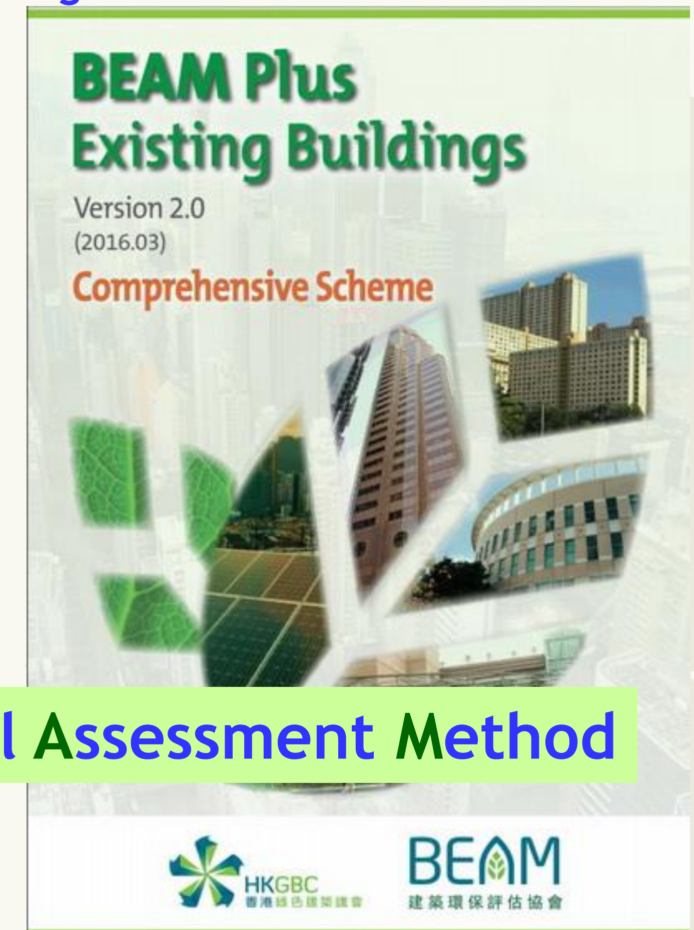


Carbon Footprint

BEAM Plus Ver.1.2 & 2.0

PLATINUM STANDARD
GOLD STANDARD
SILVER STANDARD
BRONZE STANDARD

Sustainable Building Design Guidelines



Building Environmental Assessment Method

Voluntary Green Building Certification Scheme

BEAM Plus - Assessment Categories

New Buildings - Version 1.2

6 Major Categories:

- Site Aspects (Sa)
- Materials Aspects (Ma)
- Energy Use (Eu)
- Water Use (Wu)
- Indoor Environmental Quality (Ieq)
- Innovations and Additions (Ia)

Design

Construct

Operation

Green Product Labelling Schemes in Hong Kong

HKGBC Green Building Product Labelling Scheme

PLATINUM | GOLD | SILVER | BRONZE | GREEN

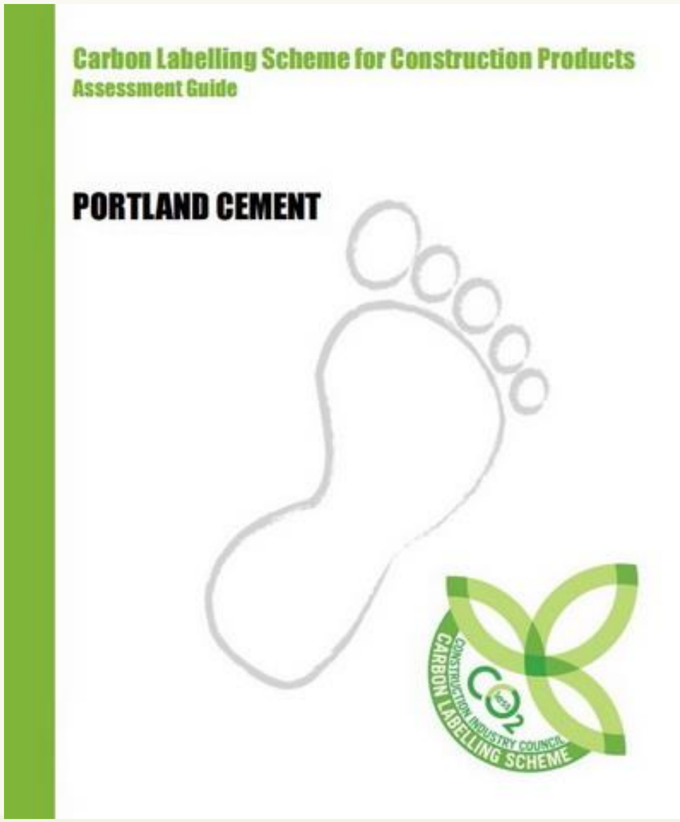
CIC Carbon Labelling Scheme

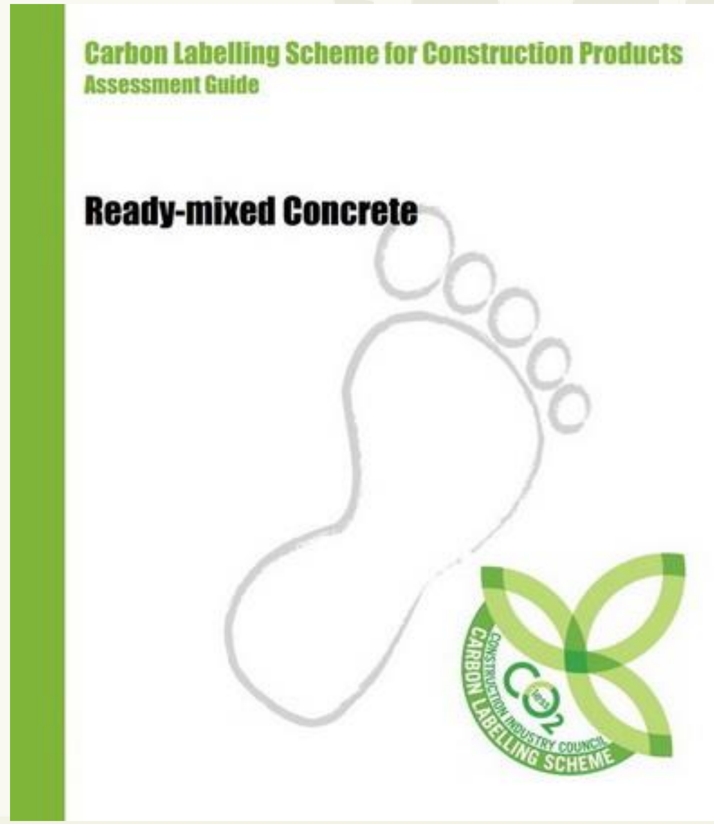
A	B	C	D	E
Outstanding	Very Good	Good	Fair	Improvement Needed

Green Product Labelling Schemes in Hong Kong

CIC Carbon Labelling Scheme

Construction Products

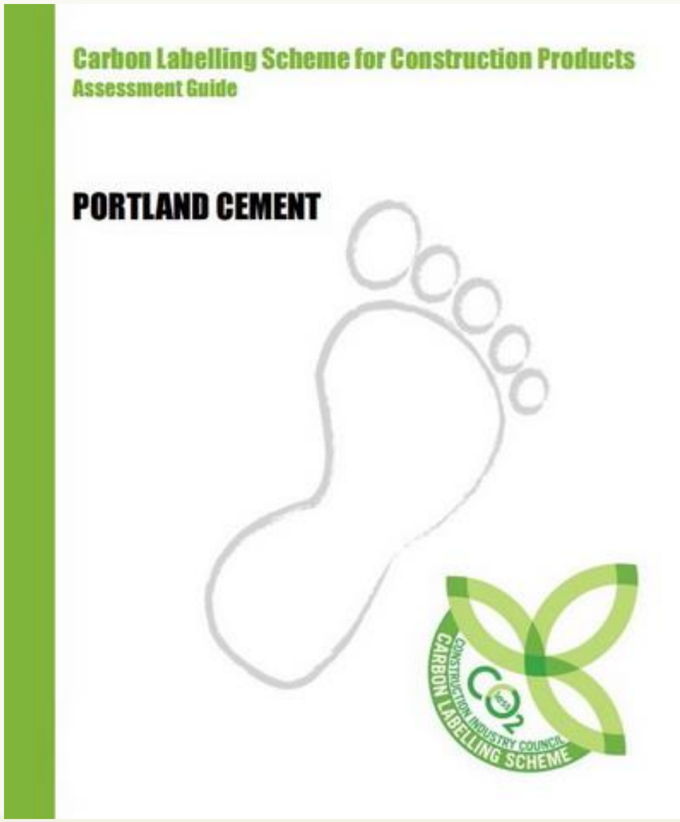


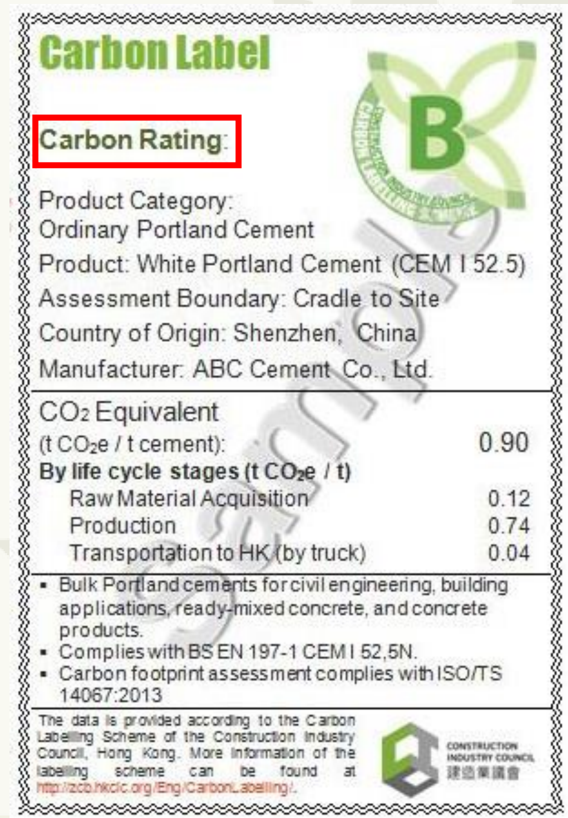


Green Product Labelling Schemes in Hong Kong

CIC Carbon Labelling Scheme

Construction Products





An Overview of Concrete Today

The most used construction material in the world:

- Versatile - can be poured into moulds and formwork
- High compressive strength
- High thermal mass
- Well established supply chain and infrastructure
- Ready-mix and precast components

Problems associated with OPC-based concrete:

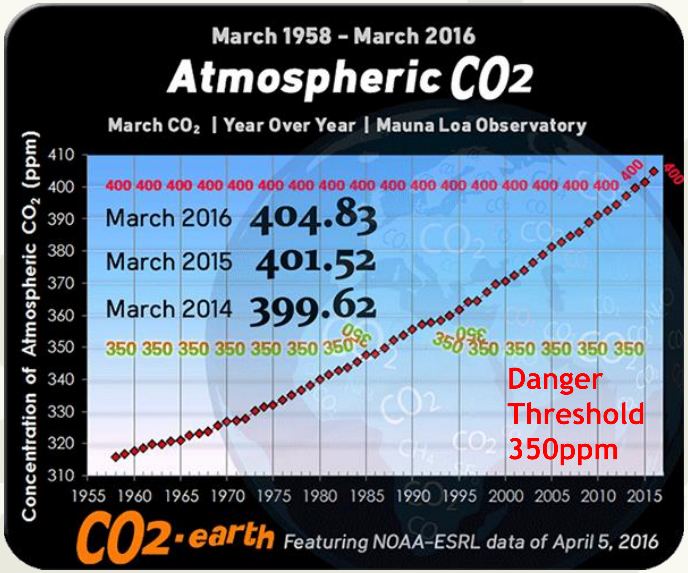
- CO_2 Legacy - High embodied carbon
- Limited durability - Low resistance to acids, chlorides
- High water demand
- High heat of hydration
- Prescriptive based specification

Concrete Usage in Hong Kong

Annual consumption per person is ~5 times of the world average

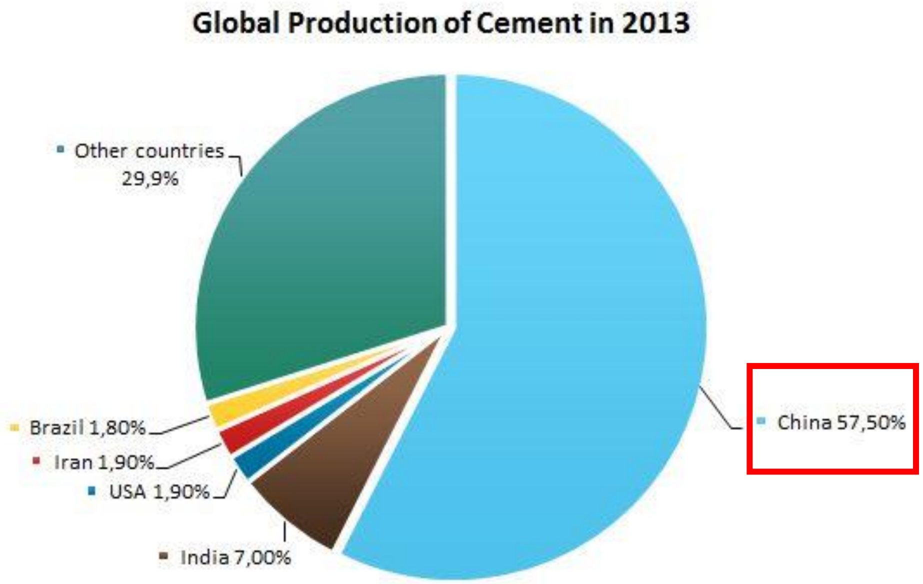
Carbon Footprint of Cement (1Ton = ~0.9Ton CO_2)

- The cement industry creating 5-8% of worldwide greenhouse gas CO_2 emission
- Third man-made producer of CO_2 after transport and energy generation



- Around one third of the CO_2 was produced in China

Cement Production in the World

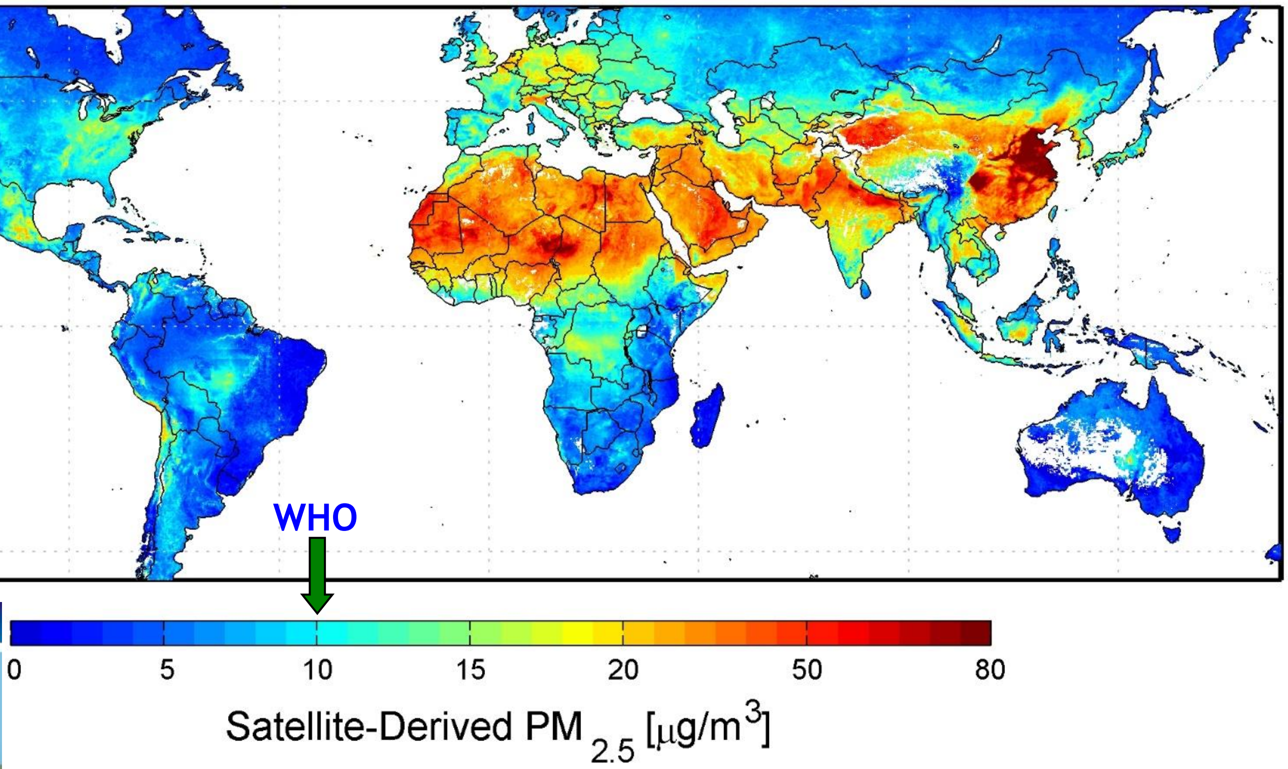


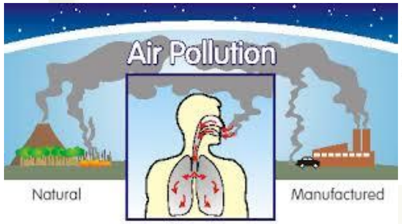
Rank	Country/Region	mil Tonnes
1	People's Republic of China	2,480
2	India	280
3	United States	77.8
4	Iran	75
5	Indonesia	71
6	Brazil	70
7	Turkey	70
8	Russia	65
9	Viet Nam	65
10	Japan	53
11	Saudi Arabia	50
12	South Korea	49
13	Egypt	46
14	Mexico	36
16	Thailand	35
17	Germany	34
18	Pakistan	32
19	Italy	29
20	Algeria	21
	Others	597
	2013 World Production	**4000**

- Over half of the cement was manufactured in China
- Can we reduce the cement usage?

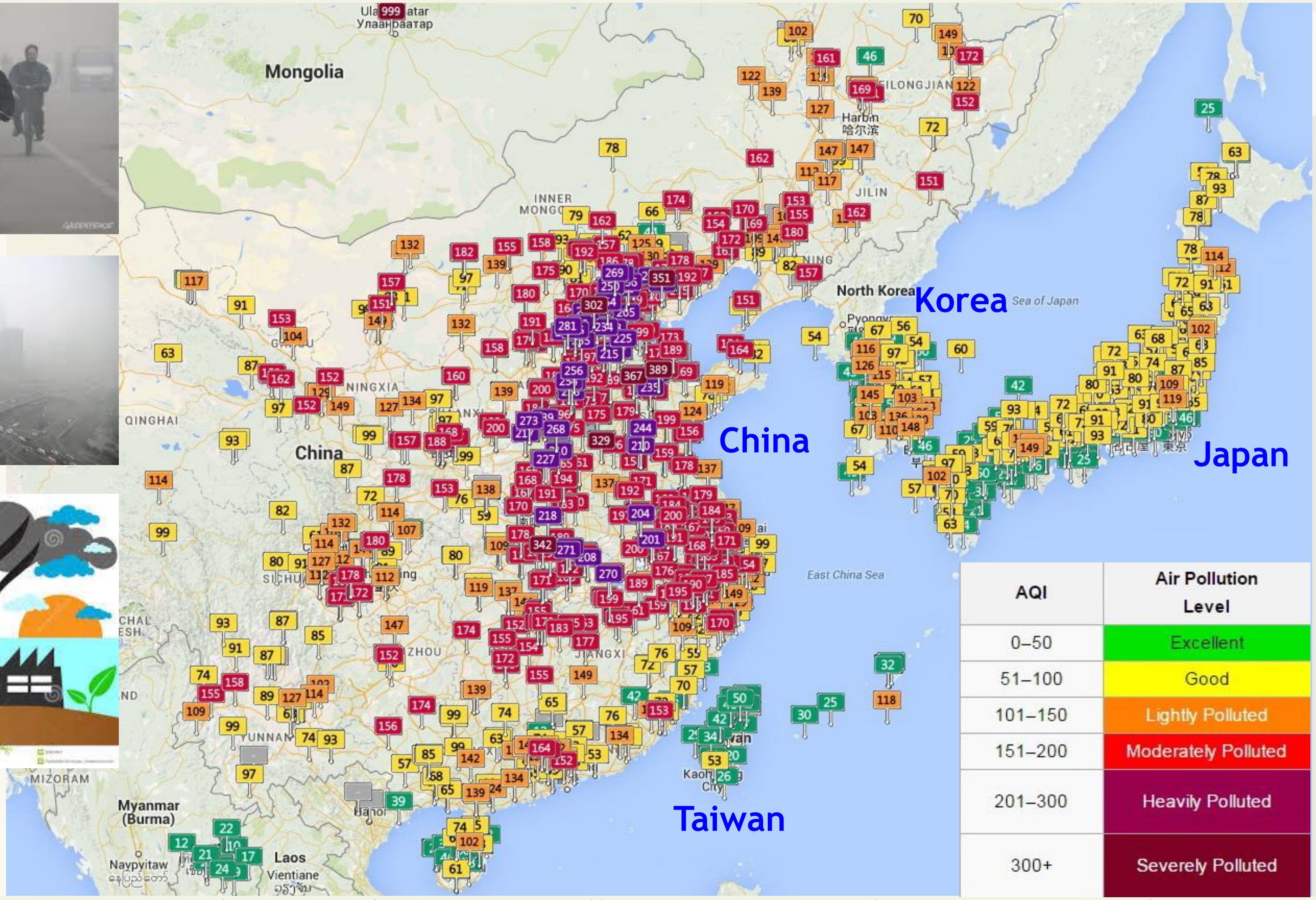
Air Pollution

The Air Pollutants ($PM_{2.5}$) Distribution around the World





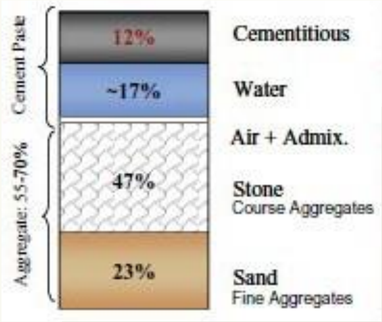
Air Quality Index (AQI) in the Region



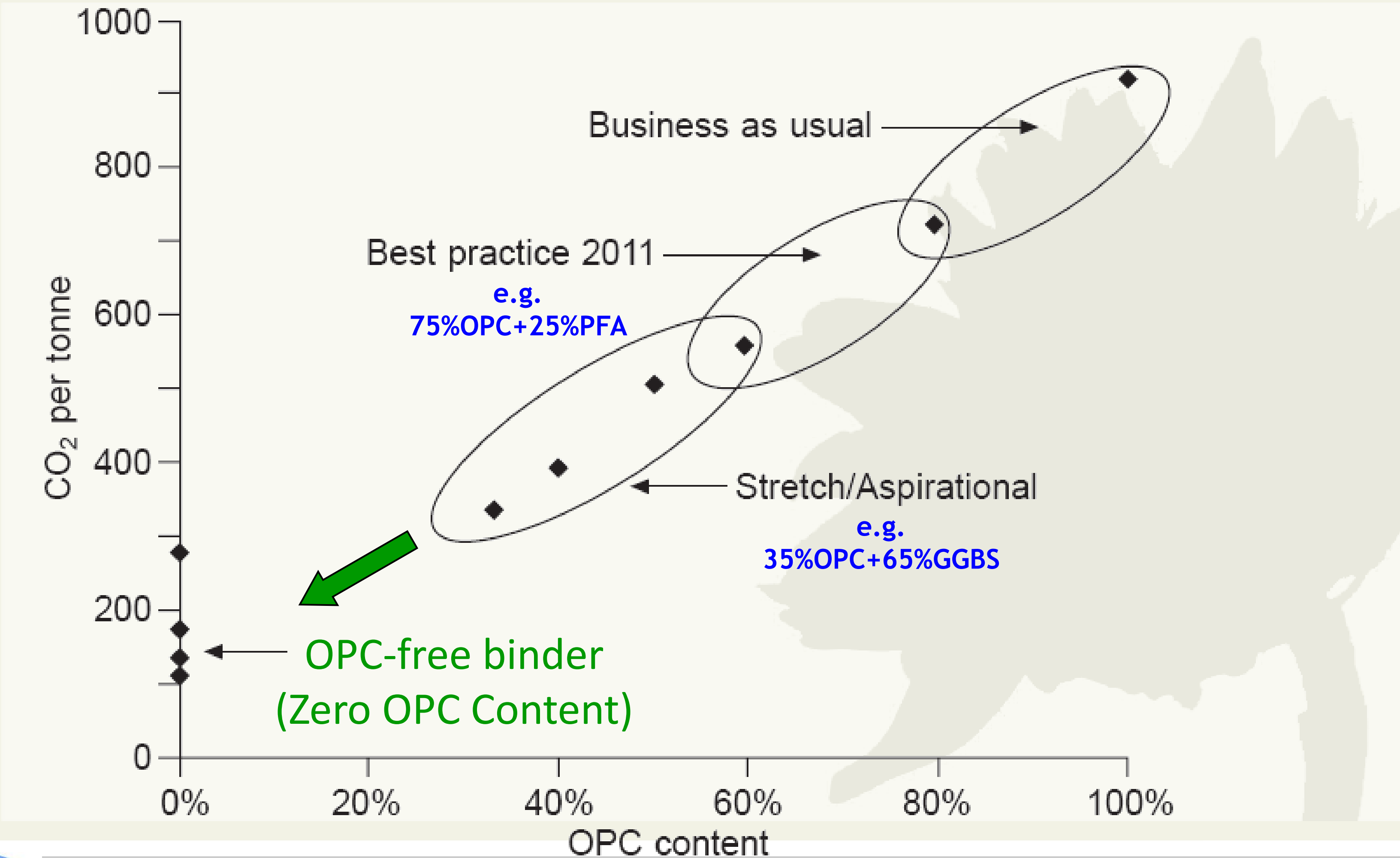
Urgent needs to seek eco-friendly cementing alternatives in the region

Green Concrete Technologies

- Highly optimized mix design
- Re-cycle / lightweight aggregates
- PFA
- GGBS
- Silica Fume
- Metakaolin, superfine calcium carbonate
- Self-compacting concrete
- Effective use of admixtures
- OPC-free concrete



Green Concrete with Low Carbon Footprint



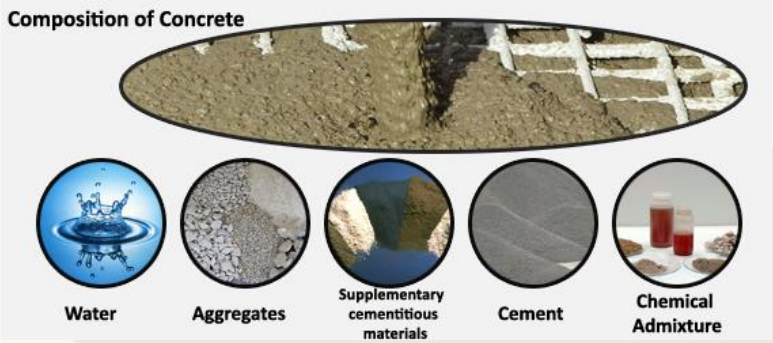
OPC-free Binders for Green Concrete

Low Energy, Low Carbon Cementing Materials

- Alkali-activated materials (AAM)
- Low energy CSA-belite cements
- Cements based on magnesium oxide derived from carbonates or from silicates
- Eco cements based on municipal solid waste incinerator ash (MSWIA)
- Thermoplastic carbon-based cements

Binder Systems for Concretes and Mortars

- **Ordinary Portland Cement (OPC)** — Hyrdation – Calcium Silicates
  - OPC
  - OPC + PFA — 25% PFA
  - OPC + GGBS — 65% GGBS
  - OPC + PFA + SF
  - OPC + GGBS + SF



- **Alkali Activated Materials (AAM)** — Crystallisation – Alumino Silicates
  - Alkali + PFA — 90% PFA
  - Alkali + GGBS — 95% GGBS
  - Alkali + Metakaolin
  - Alkali + PFA + GGBS
  - Alkali + GGBS + Metakaolin

Alkali Activator
(Li, Na, K, Rb, Cs)

Silicate, hydroxide, carbonate, sulfate

For Example

Na_2SiO_3, $NaOH$, Na_2SO_4
Na_2CO_3, KOH, $NaHCO_3$

Advantages of AAM over OPC

- Abundant raw materials resources (waste / by-products)
- Energy saving and environment protection
- Good volume stability
- Reasonable strength gain in early age
- Ultra-excellent durability
- High fire resistance and low thermal conductivity
- Ability to immobilize toxic and hazardous wastes
- Superior resistance to chemical attack

AAM Structural Use in Queensland

Suspended floors built from AAM precast slabs

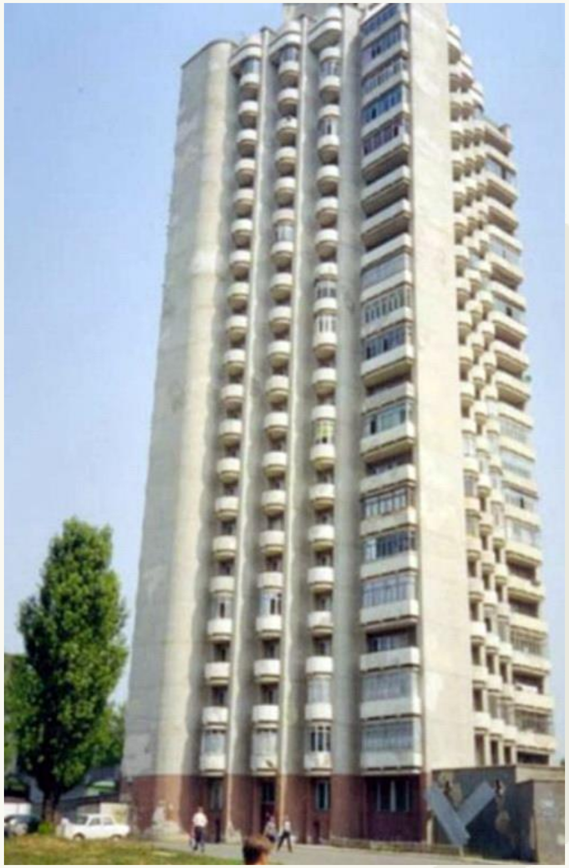
AAM Structural Use in Melbourne

Library built with AAM precast walls

AAM Structural Use in Brisbane

Airport pavement built with in-situ AAM concrete

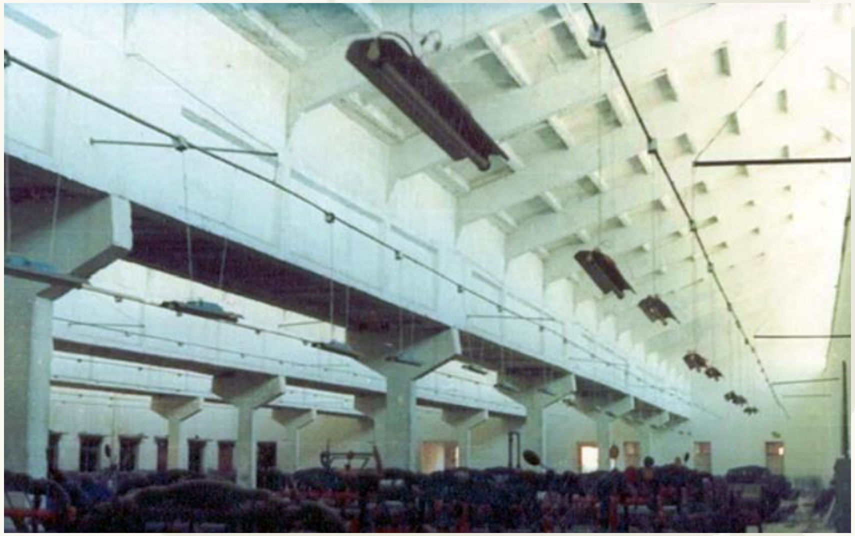
AAM Structural Use in Russia



24-storey building from insitu and precast AAM concrete

AAM Structural Use in China

6-storey building



Beam & Columns of workshop

Built with AAM (slag concrete)

AAM Recent Usage in United Kingdom

Precast Stair

Insitu Wall (No Joint) 34m Long

Insitu Floor (No Joint) $1000m^2$

Insitu Mass Pour

AAM Precast Elements and Components

Precast Pipes

Precast Walls

AAM Restoration of Cultural Heritage

Conservation of terracotta sculptures in Czech Republic

Pottery Restoration in Italy

AAM Maintenance of Highways Structures

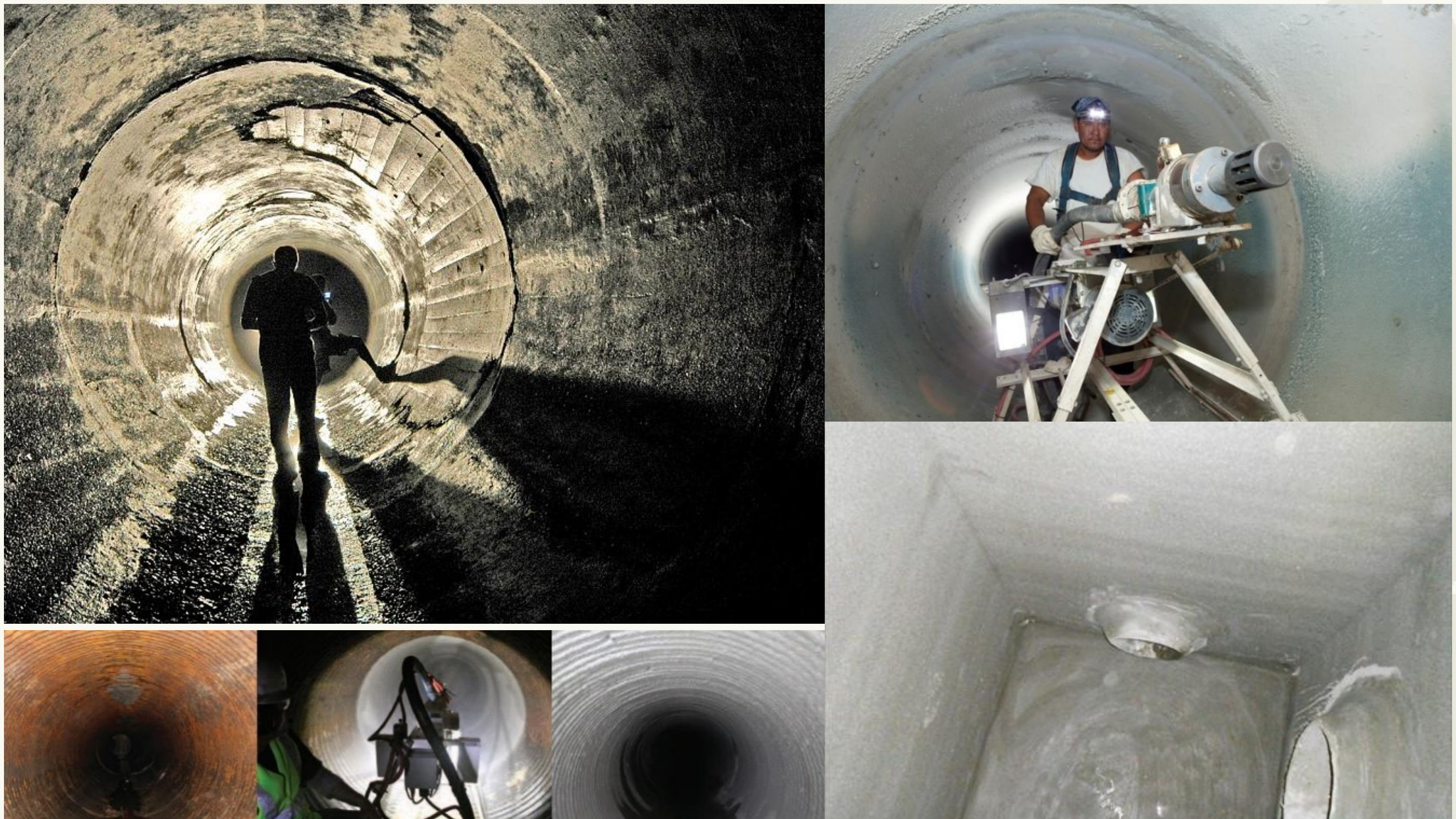
High Early Strength

Rapid Repair for Carriageway and Road

AAM Maintenance of Sewerage System

High Chemical Resistance

Renovation of Sewerage Lining



Concrete Specifications in Hong Kong

Limitations on usage of Cementitious Materials in Concrete Mixes

Concrete Mixes	ASD (2012 Version)	CEDD (2013 Version)	HKHA (2012 Version)	MTRC (2009 Version)
PFA	<35%	<35%	25-35%	25-35%
GGBS	<40%	35-75%	N.A.	36-75%
CSF	<10%	N.A.	N.A.	5-10%
Min. Cementitious (for Water Retaining)	>325kg/m^3	>325kg/m^3	>325kg/m^3	N.A.
Max. Cementitious (for Water Retaining)	<450kg/m^3	<450kg/m^3	N.A.	N.A.
Min. Cementitious (for Grade 40/20)	>300kg/m^3	>350kg/m^3	>350kg/m^3	>350kg/m^3
Maximum Cementitious Content	<550kg/m^3	N.A.	<550kg/m^3	<450kg/m^3 (Cat A) <550kg/m^3 (Cat B & C)

Constraints to the Mix Proportions

Not Ready For AAM Concrete

Prescriptive-based Specifications

Standardisation & Guidelines for Concrete

There is a move towards **performance-based standards** for industry in Europe, USA, etc.

- Russian & Czech Republic (over 60 standards)
- USA : ASTM C1157
- Canada : CSA A3004-E1
- Australia : AS 3972
- Switzerland : SIA 2049
- European Union : EN 206
- Rilem : TC 224-AAM
- United Kingdom : BSI PAS 8820:2016

Standardisation & Guidelines for AAM

Performance-Based Standard

BS EN 206:2013

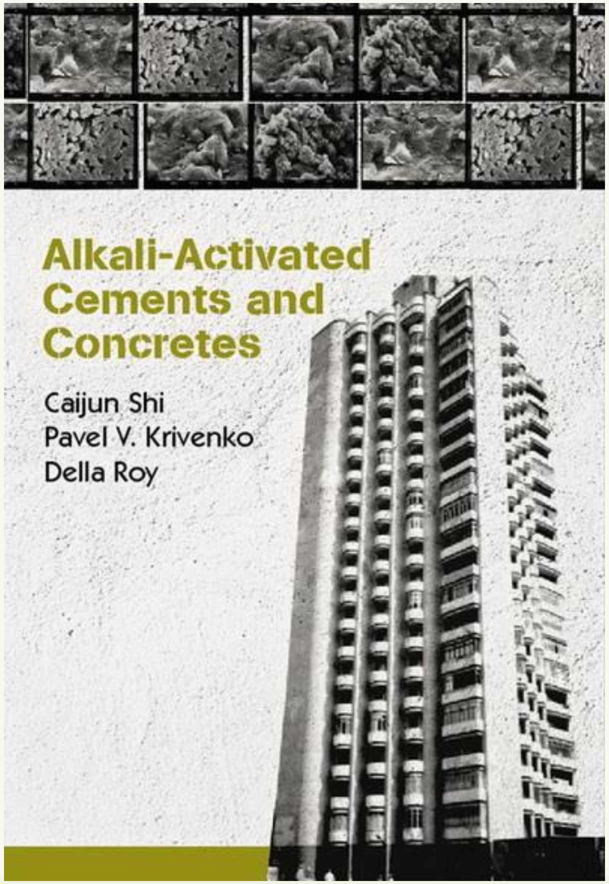
Incorporating corrigendum May 2014

BSI Standards Publication

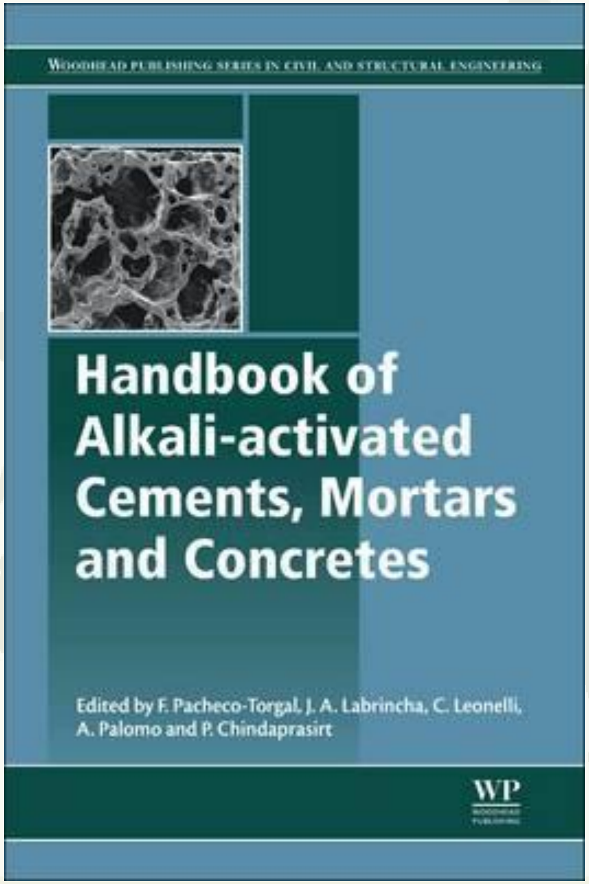
Concrete — Specification, performance, production and conformity

Standardisation & Guidelines for AAM

Book by Prof Caijun Shi

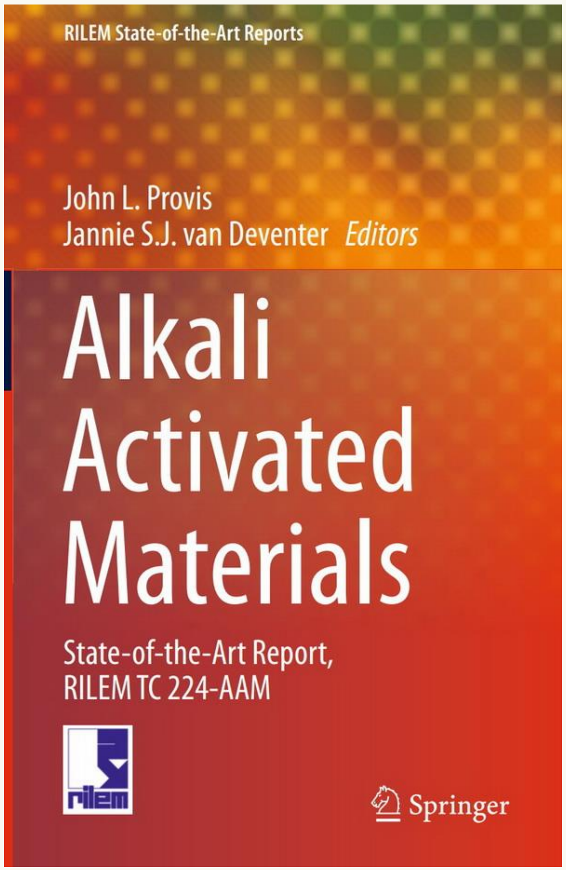


Handbook of AAM

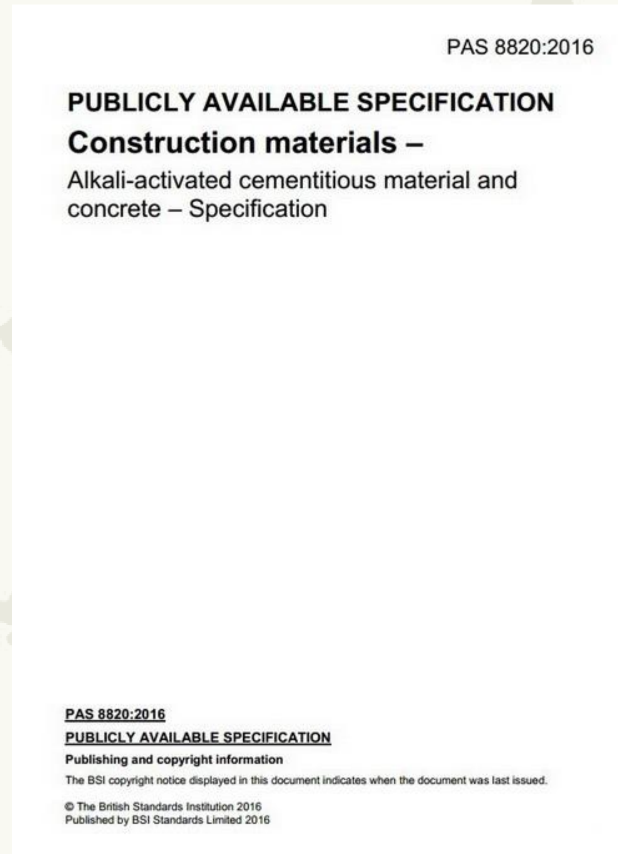


Standardisation & Guidelines for AAM

Rilem TC 224-AAM:2014



BSI : PAS 8820:2016


PAS 8820:2016

PUBLICLY AVAILABLE SPECIFICATION

Construction materials –

Alkali-activated cementitious material and concrete – Specification

PAS 8820:2016

PUBLICLY AVAILABLE SPECIFICATION

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Potential Applications of AAM

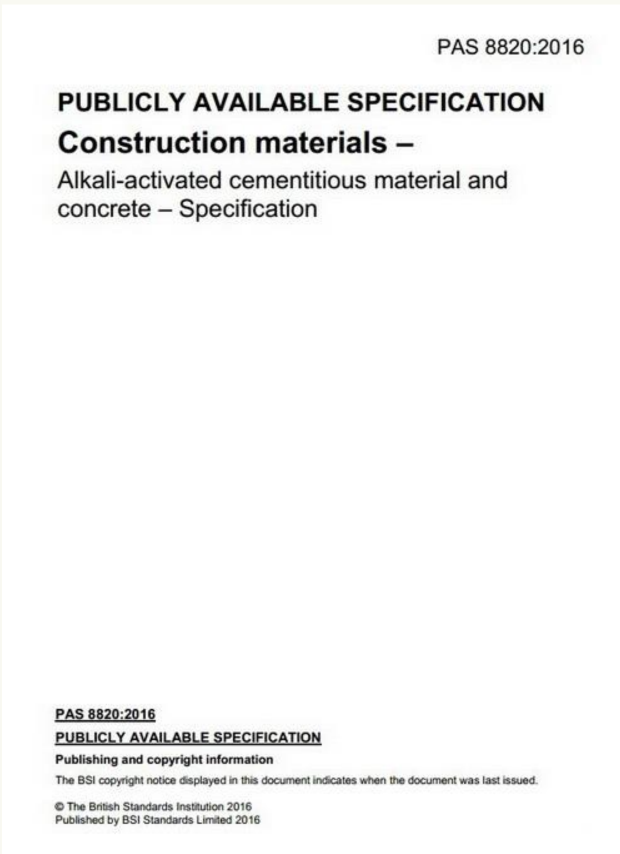
UK BSI : Draft PAS 8820:2016

Draft PAS 8820:2016, 2015-06-09

Table A.1. Potential applications of AACM concretes

Classification	Application
Ready mix	Foundations Pathways Retaining walls Pavements
Precast	Pipes Manhole covers Structural or semi-structural elements Tunnel lining segments Insulating panels Tiles Paving slabs Railway sleepers
On-site application	Repair/patch material Sprayed concrete

BSI : PAS 8820:2016 - Specification for AAM


PAS 8820:2016

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- Mechanical & Physical Requirements
- Heat of Reaction
- Admixtures
- Aggregates
- Mixing, Placing & Curing
- Tests for Fresh & Hardened Properties
- Durability Tests - ASR, Freeze-thaw, Sulfate Resistance, Carbonation, Chloride Ingress
- ….. ….. …..

Alkali-silica Reaction of AAM

UK BSI : PAS 8820:2016

Avoidance of alkali-silica reaction

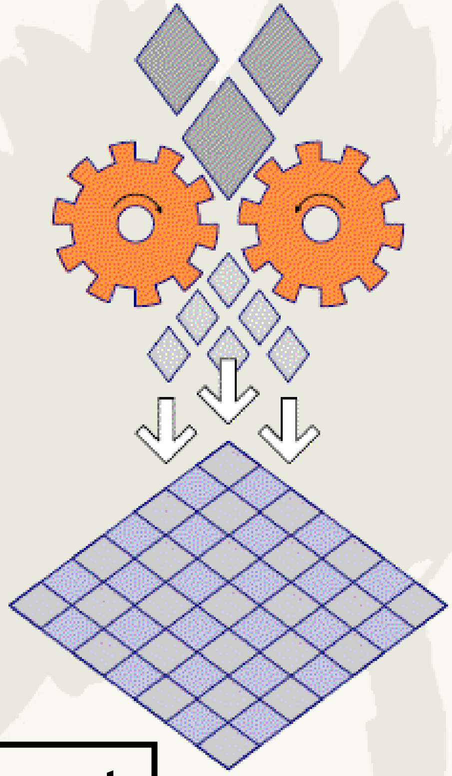
The consensus in the academic literature regarding alkali-silica reaction in AACM mortars and concretes is that the alkaline component of the cement reacts with siliceous aggregates, but that the reaction does not seem to be deleterious or significantly expansive. The fact that the reaction is taking place is evident through the formation of rims of reaction products around the aggregate grains, which can be observed by scanning electron microscopy. However, the degree of expansion observed in specimens exposed to standard testing regimes is uniformly observed to be low; much less than would be expected from simple consideration of the alkali content and aggregate reactivity. The reason for this has been identified as being linked with the binder chemistry, and specifically the high content of reactive alumina present in most AACM formulations. As the alkaline pore solution etches the aggregate particles in an AACM, rather than forming the highly expansive and damaging gel products, which are observed in materials based on Portland cement, the reaction product is instead a non-expansive, cross-linked aluminosilicate gel. This gel resembles the key binding phase in low-calcium AACMs, and thus contributes to the strong binding of the aggregate particles into the AACM rather than introducing any deleterious effects.

Rilem TC 224-AAM:2014 – Chapter 8 Section 8.3

OPTIMIX

Enhanced Properties of AAM over OPC-based

- Environmental friendly binder
- Rapid and controllable strength gain
- Resistance to acid & chemical attack
- Resistance to high temperature
- Good volumetric stability
- Low susceptibility to degradation by ASR
- Low permeability
- …. …. ….



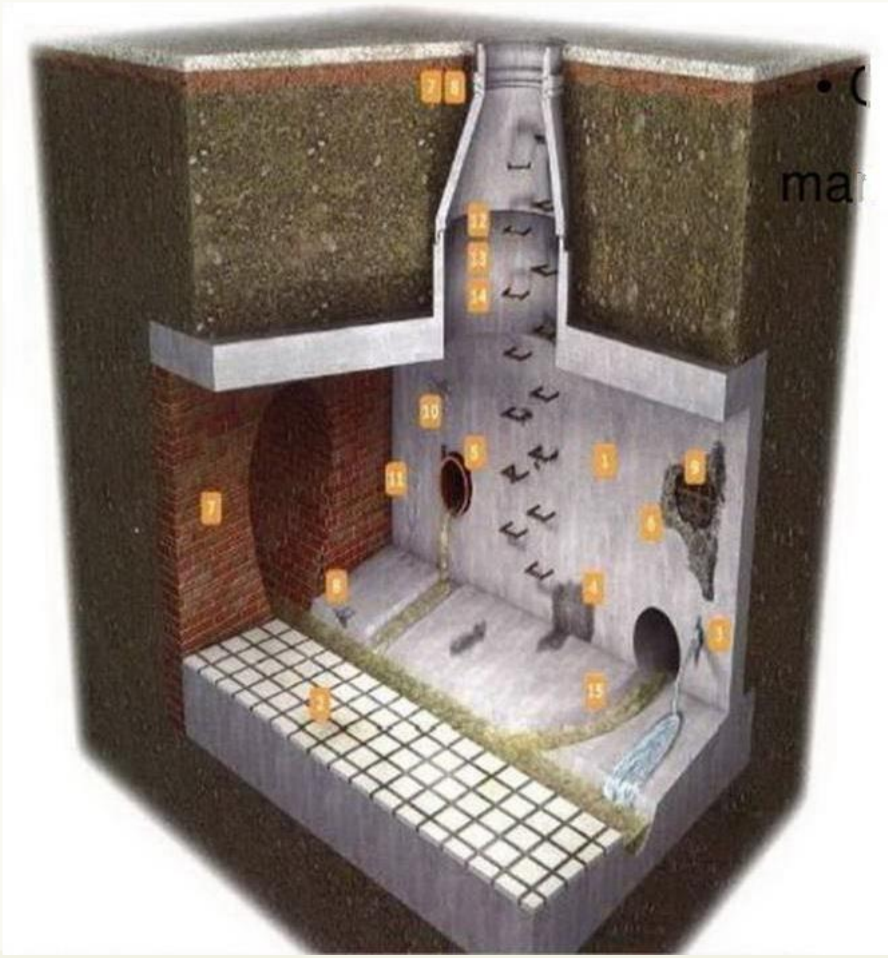
AAM Concrete or Surface Treatment

Protection Against Chemical Attacks

Acid Resistance
for
Concrete Structures

Use of Materials

Chemical Resistance to Sewerage Components



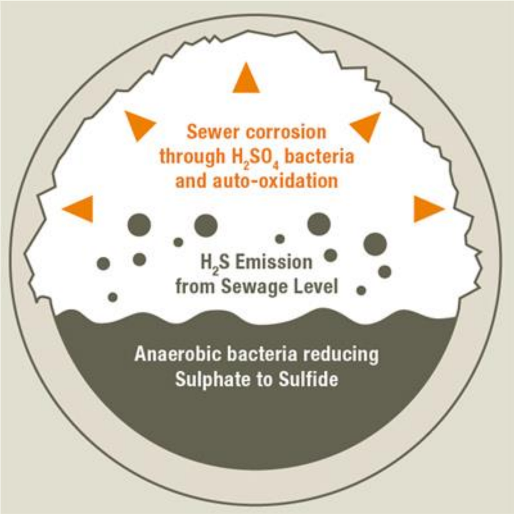
Sewage / Drainage

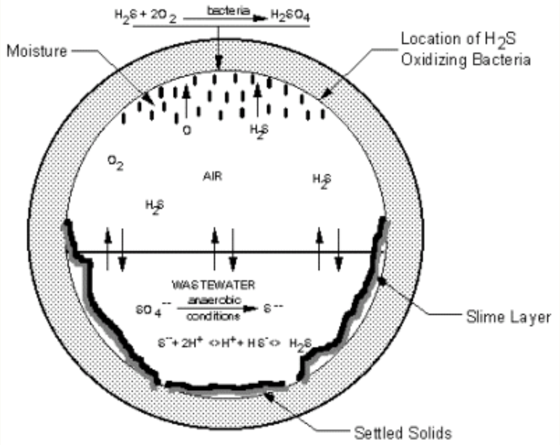
- Manhole
- Sewage Pipe
- Culvert
- Sewage Tank
- Pumping Station
- Treatment Work

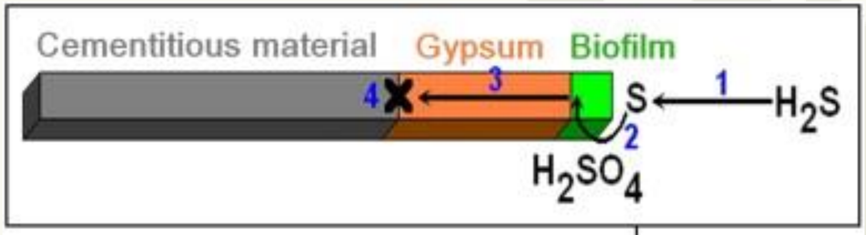
Sulfuric Acid Attack

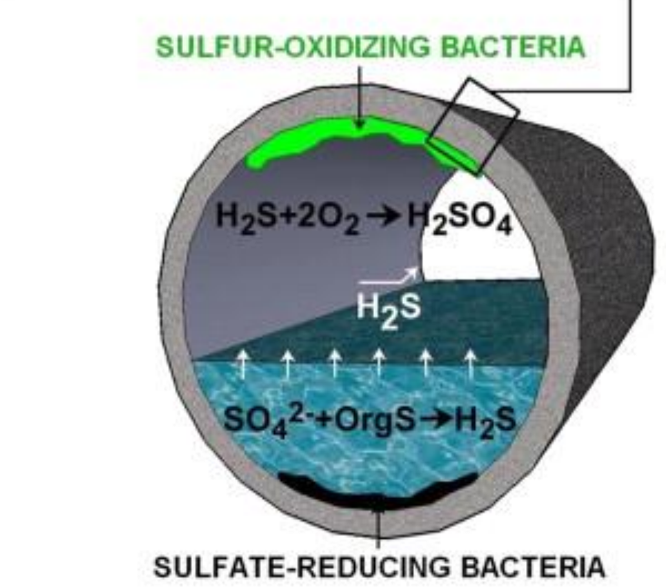
Biogenic Sulfuric Acid Attack

$H_2S + 2O_2 \rightarrow H_2SO_4$ pH 2 - 5





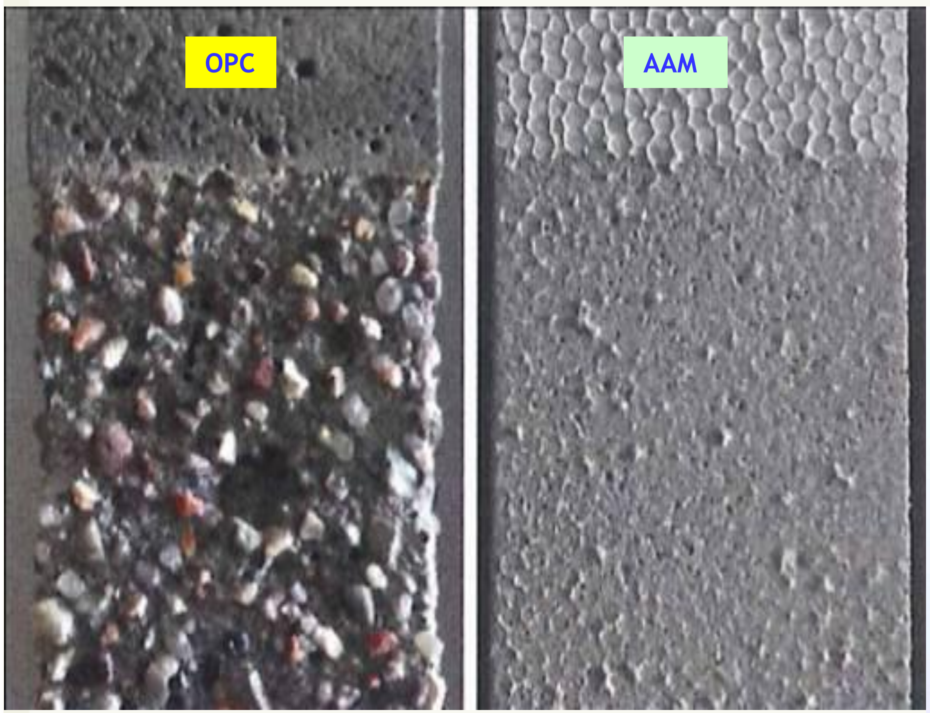




Acid Resistance Test in Germany for AAM Treatment

Test Under 2% H_2SO_4 for 28 Days

Concrete

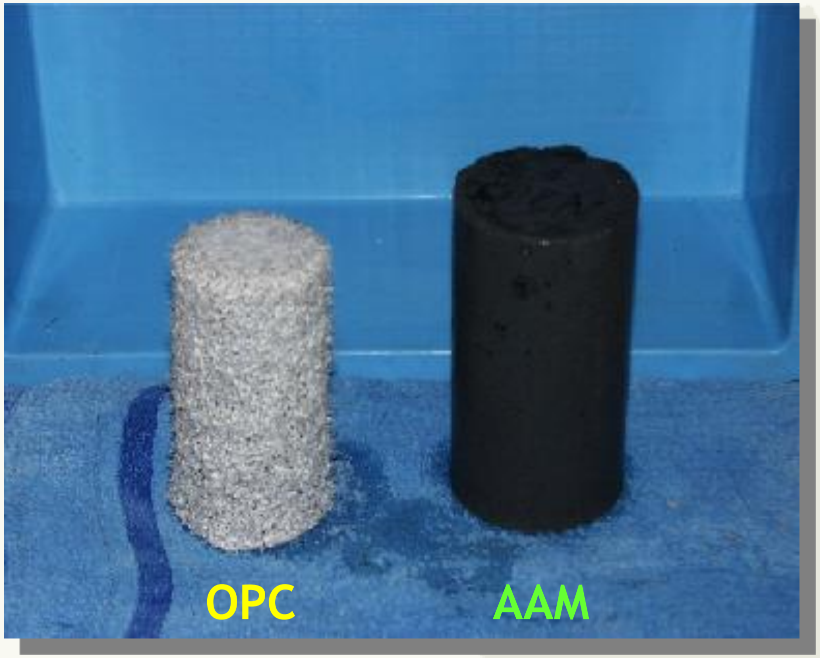


Mortar

Acid Immersion Tests in Japan for AAM Protection

OPC

Weight Loss
31%

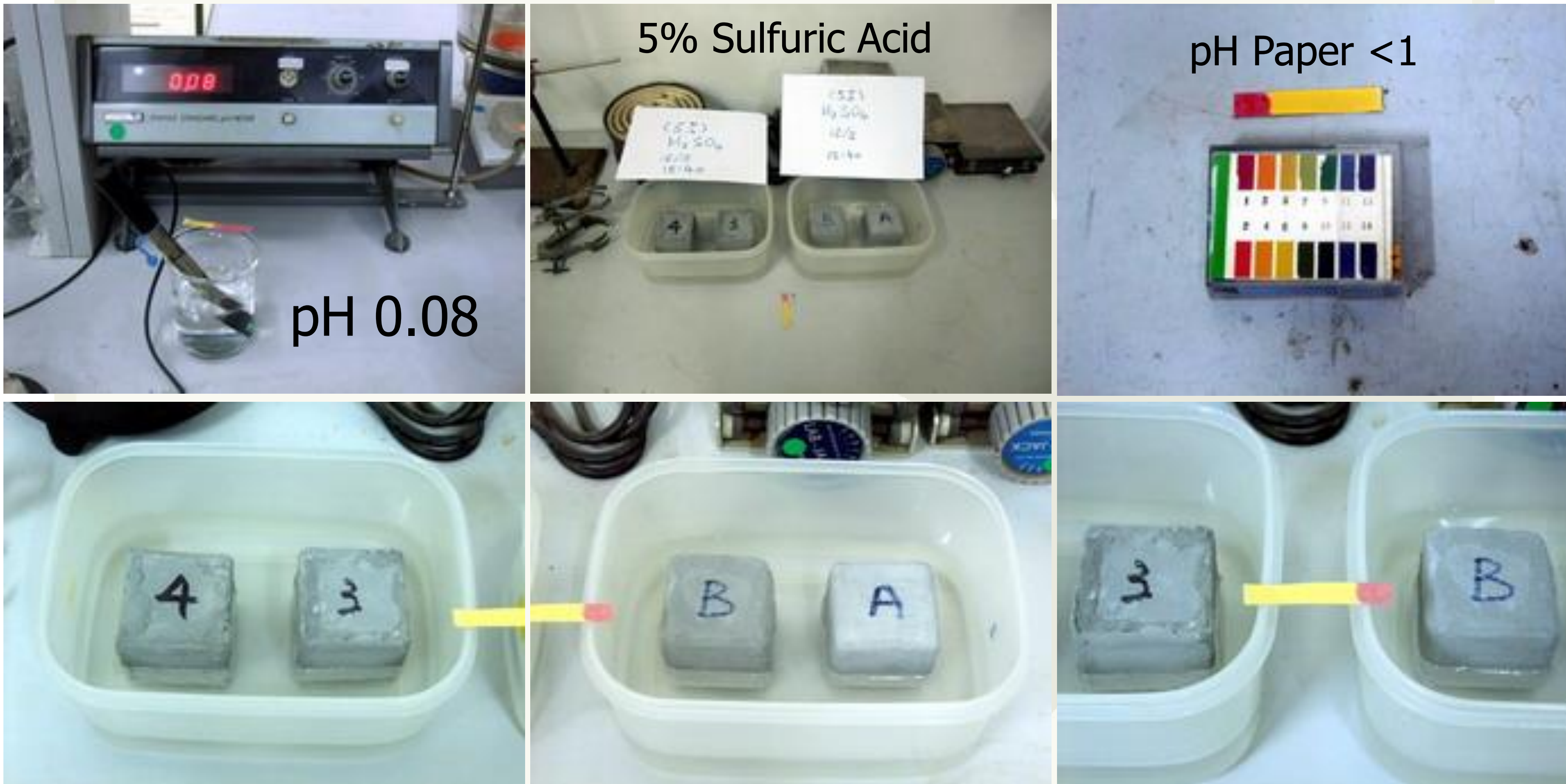


AAM

Weight Gain
0.5%

5%H_2SO_4(pH=0.4) 30Days Immersion

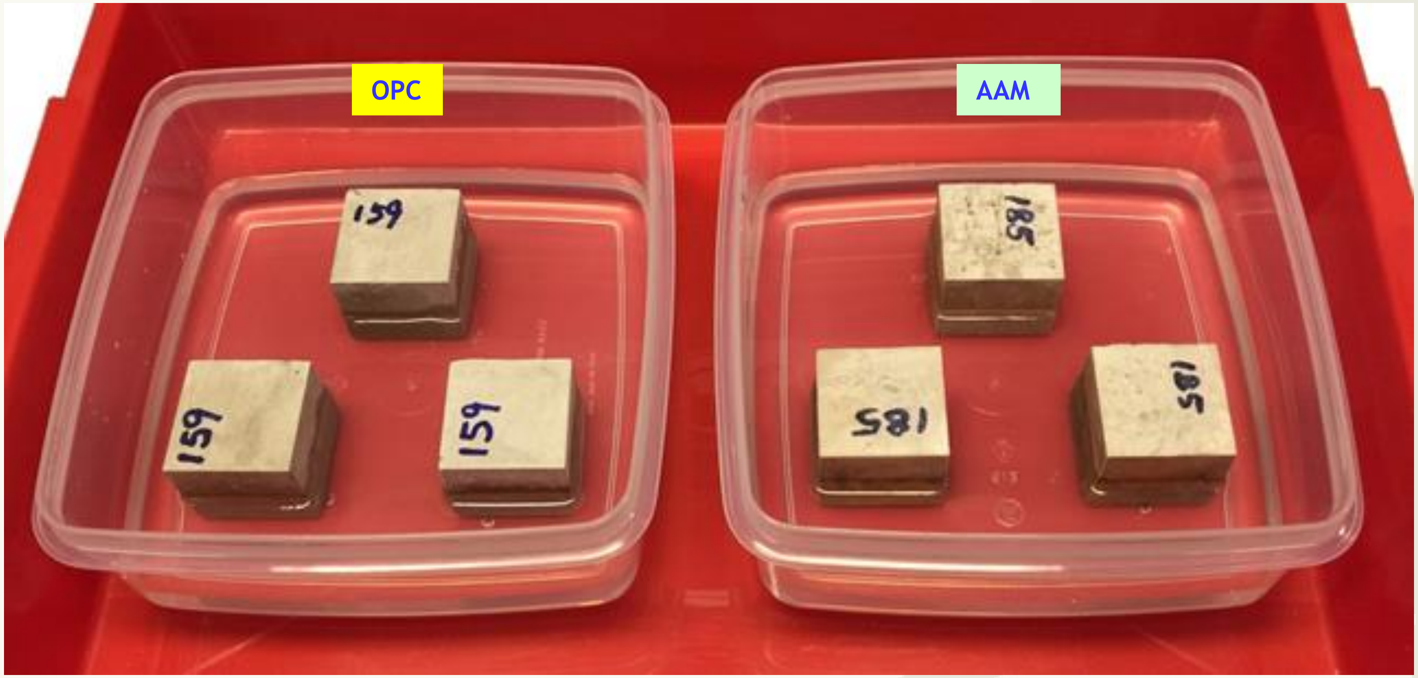
Acid Resistance (Long Term Test) for AAM Coated Specimens



Long Term Test : 1 / 2 / 3 / 6 / 12 Month → Surface No Damage

Acid Resistance for AAM Specimens

- Demould within 24 hours
- Submersion in 5% H_2SO_4 solution (pH~0.5)
- Cubic specimens with OPC & AAM

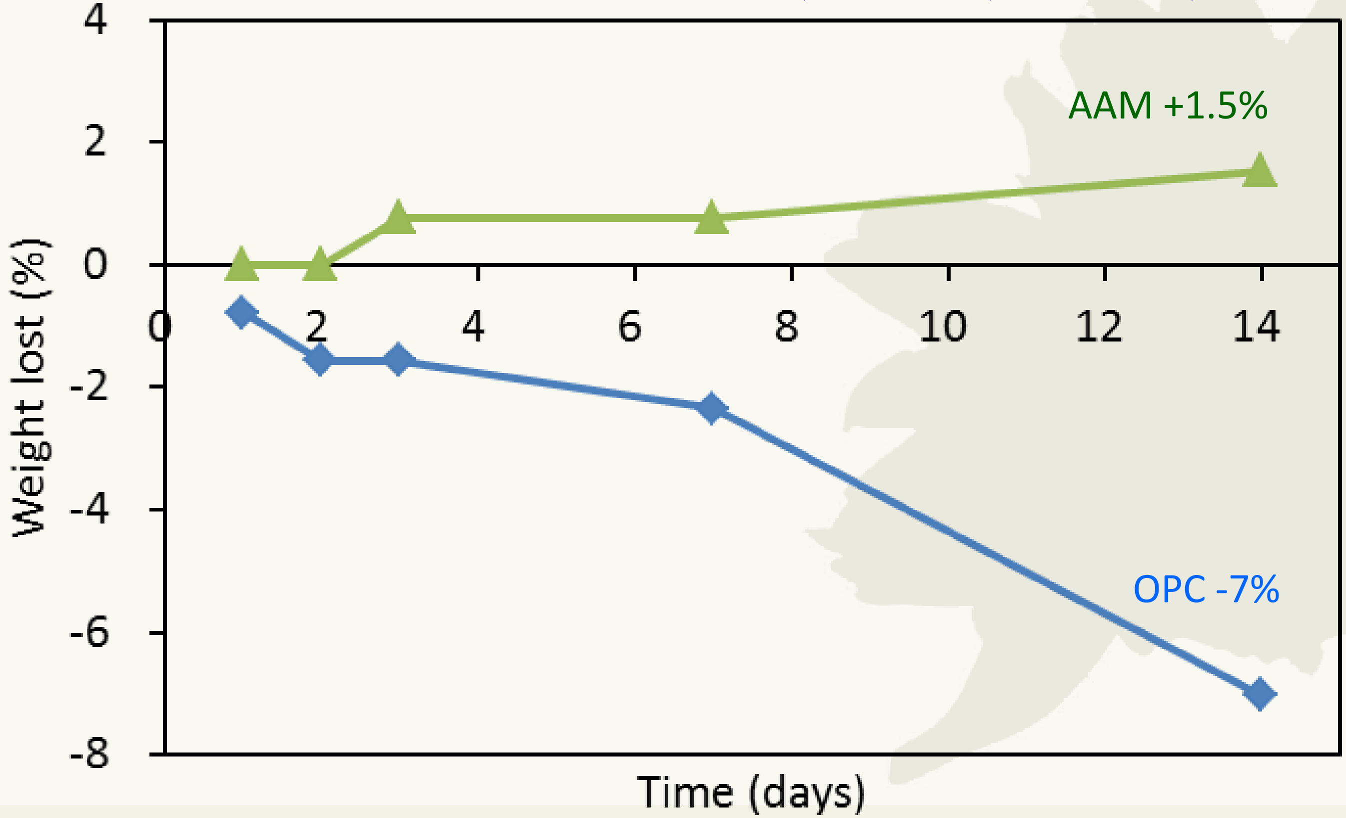


Tests performed by NAMI

Acid Resistance of AAM Specimens

Residual properties after 14-day acid (pH~0.5) immersion

Compressive strength : AAM (54 MPa) / OPC (39 MPa)



Remarks

- Alkali activation is a green materials technology contributing to the sustainable development with low carbon footprint
- Alkali activated material (AAM) is a prominent alternative cementing material for replacing commonly used OPC-based
- Initial usage of AAM can be considered for those repair areas requiring rapid strength development and chemical resistance such as highways and sewerage structures
- Next possible application may be precast concrete components due to high early strength and they can be produced under factory controlled conditions

Green Technology inside

Ongoing Works

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- In order to allow the full use of AAM in buildings and structures, the current concrete specifications may need to be adjusted or upgraded in line with the world's trend on performance-based standards or approach
- Future standards in the area of concreting materials should be based on performance criteria and open the potential to integrate or incorporate new technologies
- Studies and trial comparisons of the performance between traditional OPC concrete and AAM concrete are urged to be established by public and private stakeholders
- The world looks for greener construction materials, it may be a starting point for engineers in Hong Kong considering the AAM technology as alternative green concrete materials

20.04.2016

Transforming our Built Environment
共建綠色建築環境

Annual Concrete Seminar 2016
"Green Concrete"

HONG KONG Green Label 香港

Thank You !

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