24.06.2015

Materials Science and Technology in Engineering Conference

MaSTEC 2015

HKIE THE HONG KONG INSTITUTION OF ENGINEERS 香港工程師學會

Materials Division 材料分部

Frontier of Sustainable Materials

Green Materials based on Alkali Activation Technology for the Sustainable Development for the Construction Industry

HONG KONG 香港 Green Label

Research on Materials Innovation

Ir Raymond Wan

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

Technical Director

OPTIMIX (Hong Kong) Limited

BEAM

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Research on Materials Innovation

Dr Garrison CK Chau

Project Leader

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Technical Manager

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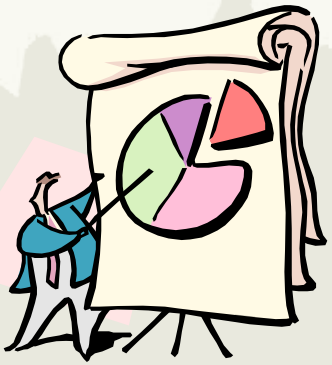
納米及先進材料研發院有限公司

Nano and Advanced Materials Institute Limited

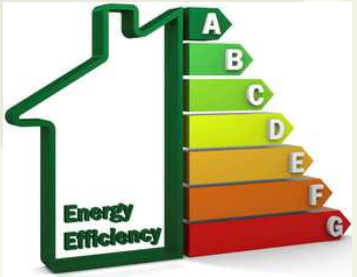
Outline

- Demand on Green Construction
- Green Policies & Eco Labelling Systems
- Carbon Footprint of OPC-based Materials
- Green Alternatives – Alkali Activated Materials (AAM)
- Standardisation and Guidelines for AAM
- Protection against Chemical Attacks
- 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 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

Buildings Department APP-151

January 2011

Buildings Department	Practice Note for Authorized Persons, Registered Structural Engineers and Registered Geotechnical Engineers	APP-151

Building Design to Foster a Quality and Sustainable Built Environment

There has been rising public concern over the quality and sustainability of the built environment, including issues regarding building bulk and height, air ventilation, greening and energy efficiency in buildings. In 2009, the Council for Sustainable Development (SDC) launched a public engagement process entitled "Building Design to Foster a Quality and Sustainable Built Environment" in collaboration with the Government. The exercise has pointed to a need for putting in place a package of new measures to foster a quality and sustainable built environment. This practice note sets out a package of measures, covering the following major elements, to promote a quality and sustainable built environment:

(a) sustainable building design guidelines (SBD Guidelines) on building separation, building set back and site coverage of greenery,

(b) gross floor area (GFA) concessions, and

(c) energy efficiency of buildings.

Projects from 1 April 2011

Buildings Department APP-151

(b) Submission of the official letter issued by the Hong Kong Green Building Council (HKGBC) acknowledging the satisfactory completion of project registration application for BEAM Plus certification;

(c) Submission of a letter by the developer or owner undertaking to submit to the BD the following documents:

(i) Result of the Provisional Assessment under the BEAM Plus certification conferred / issued by the Hong Kong Green Building Council to be submitted prior to the application for consent to commence the building works shown on the approved plans;

(ii) Information on the estimated energy performance / consumption for the common parts (for domestic developments) or for the entire building (for non-domestic developments) to be submitted in the standard form (Appendix B) prior to the application for consent to commence the building works shown on the approved plans;

(iii) Information specified in item (ii) above to be updated and submitted at the time of submitting application for occupation permit; and

(iv) Result of the Final Assessment under the BEAM Plus certification conferred / issued by the Hong Kong Green Building Council, within 6 months of the date of issuance of the occupation permit by the BA;

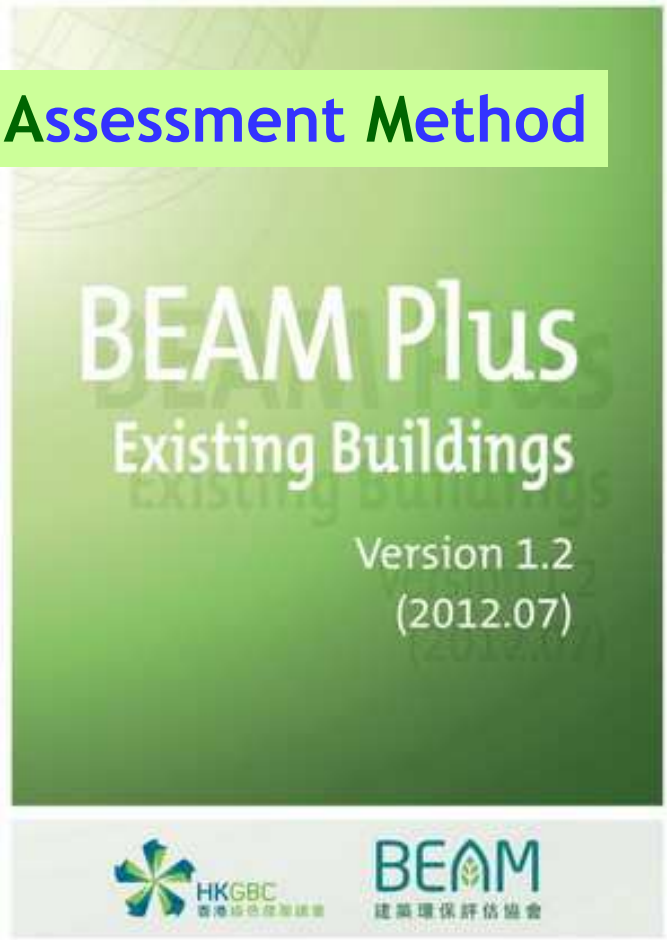
Green Building

Design Stage

Post Construction Stage

BEAM Plus Version 1.2

Building Environmental Assessment Method



Voluntary Green Building Certification Scheme

BEAM Plus – Assessment Categories

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

Eco Labelling System in Hong Kong

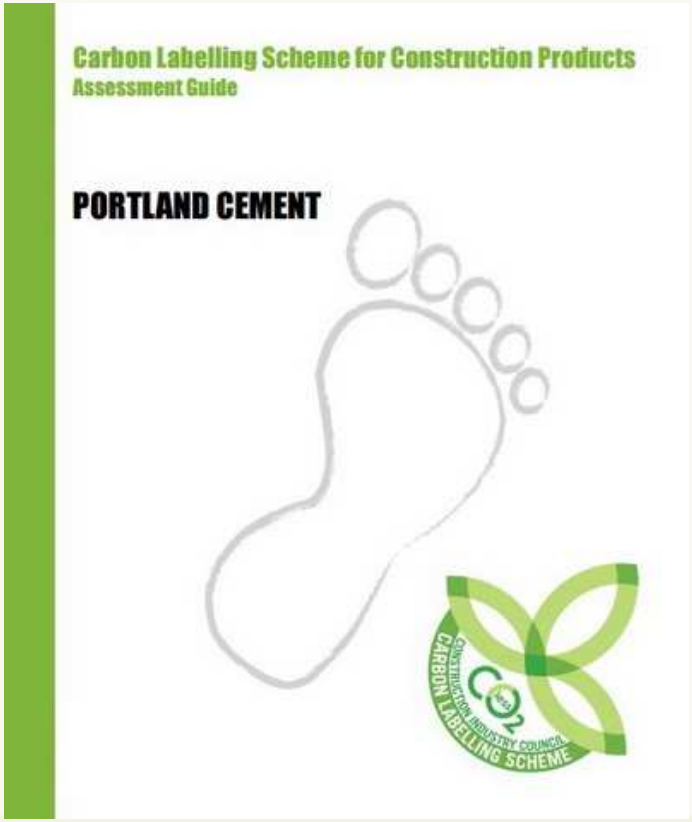
HKGBC Green Building Product Labelling Scheme

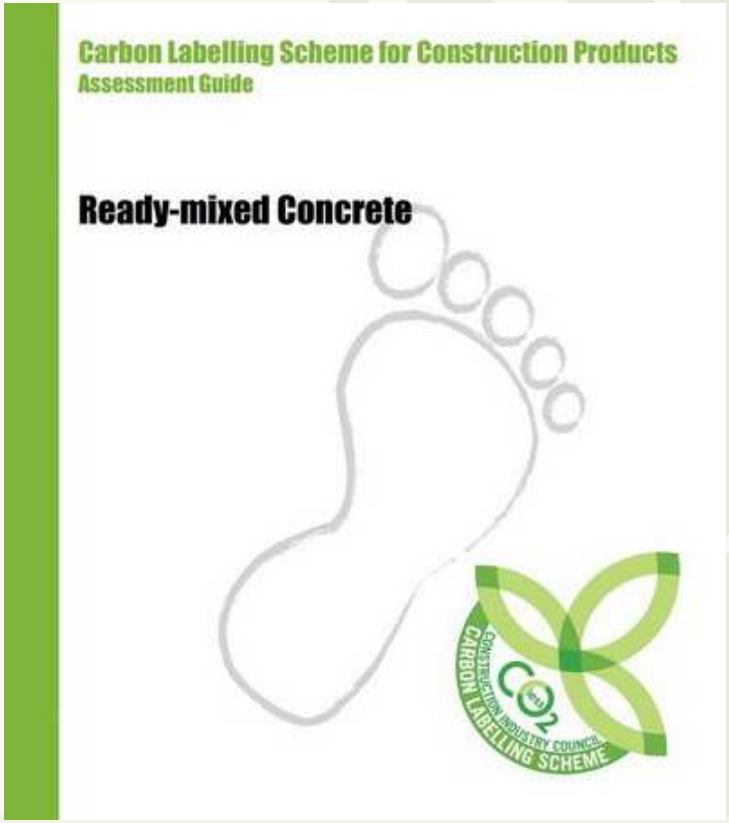
CIC Carbon Labelling Scheme

Eco Labelling System in Hong Kong

CIC Carbon Labelling Scheme

Construction Products

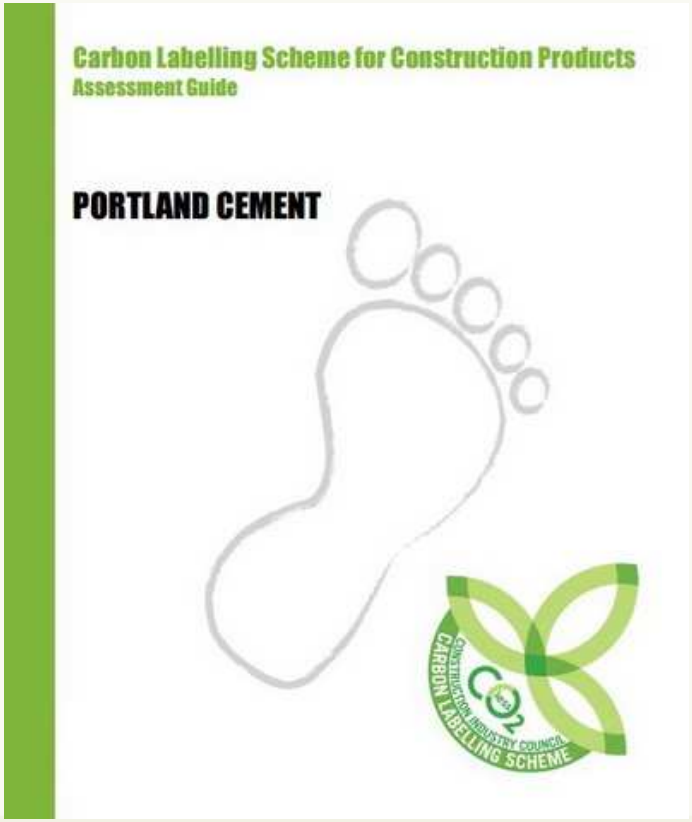


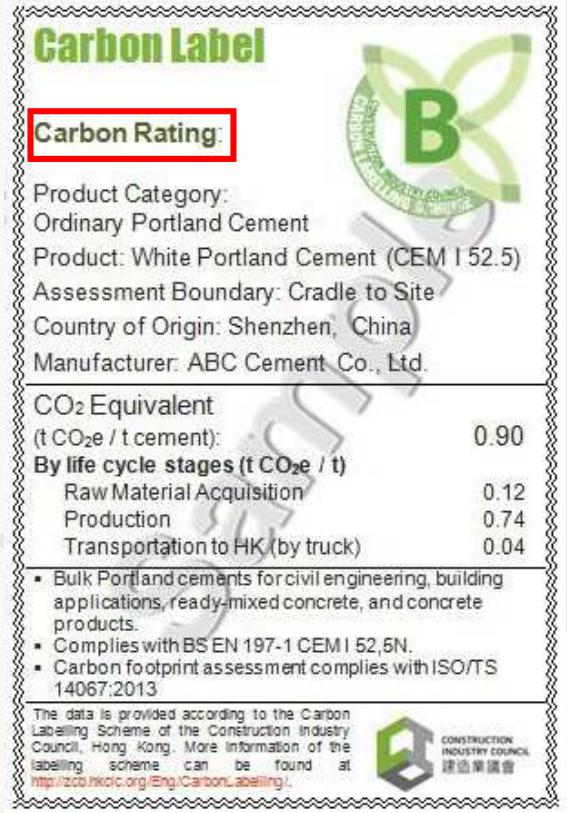


Eco Labelling System in Hong Kong

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:

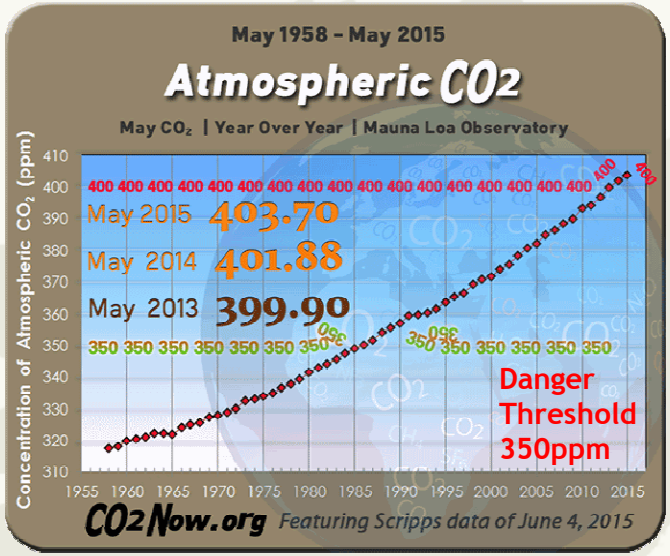
- CO_2 Legacy - High embodied carbon
- Limited durability - Low resistance to acids, chlorides, etc
- High water demand
- High heat of hydration

Concrete Usage in Hong Kong

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

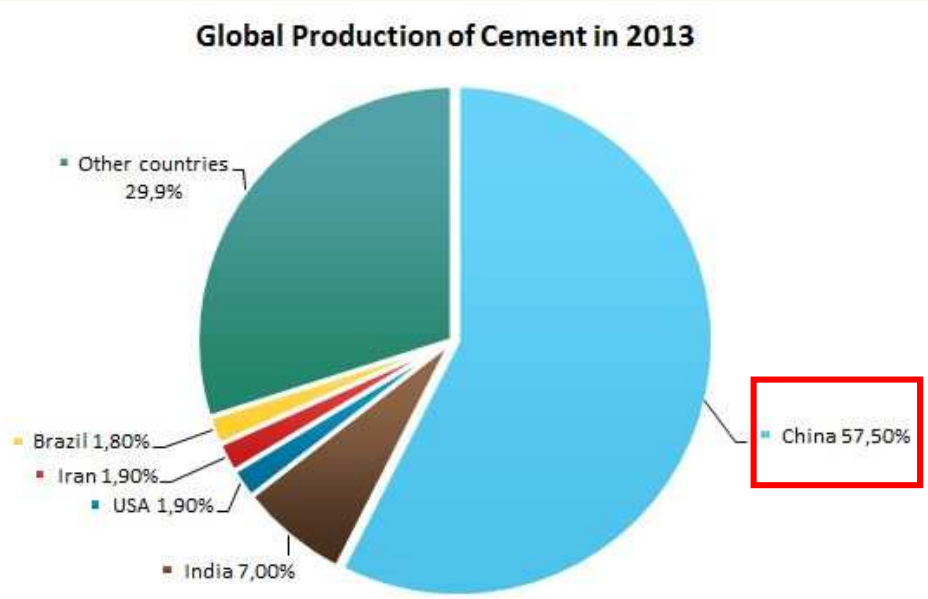
Carbon Footprint of Cement (1Ton = ~0.9Ton CO_2)

- 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



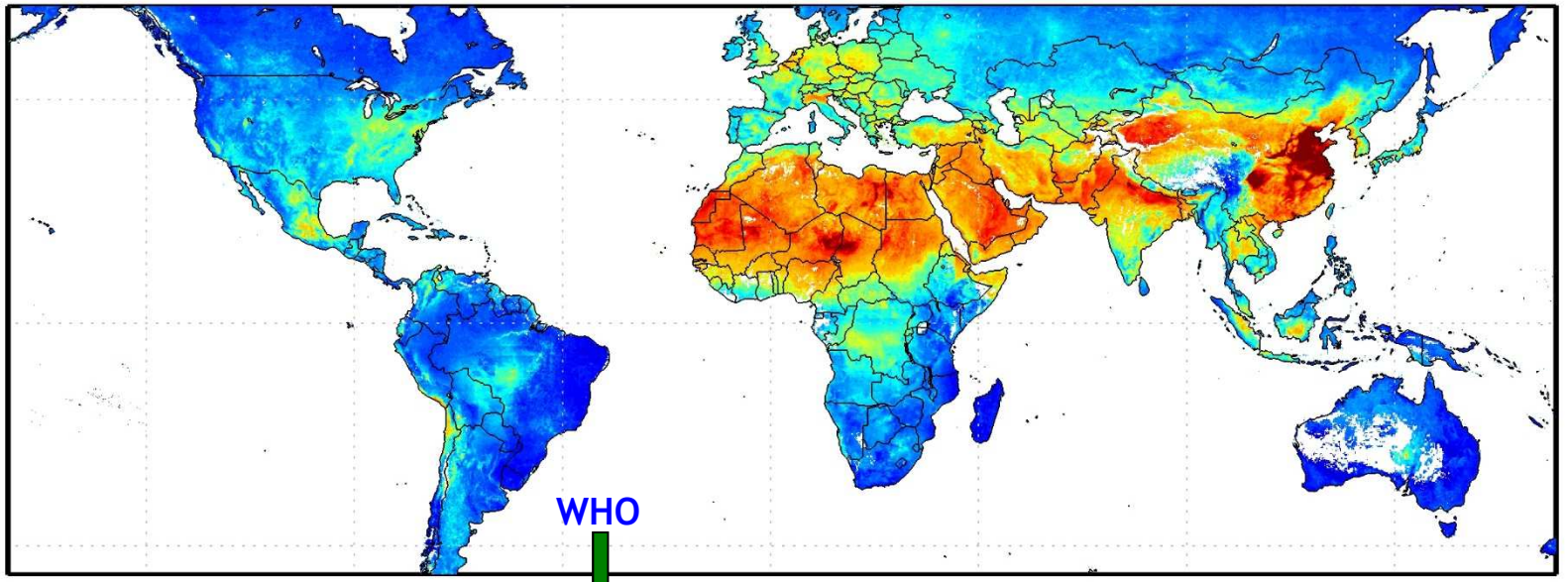
Rank	Country/Region	mil Tonnes
1	People's Republic of China	2,480
2	India	280
3	United States	77.8
4	Iran	75
5	Indonesia	71
6	Brazil	70
7	Turkey	70
8	Russia	65
9	Viet Nam	65
10	Japan	53
11	Saudi Arabia	50
12	South Korea	49
13	Egypt	46
14	Mexico	36
16	Thailand	35
17	Germany	34
18	Pakistan	32
19	Italy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

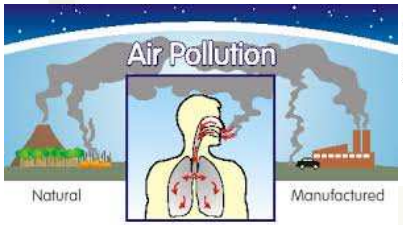
- Over half of the cement was manufactured in China
- Can we reduce the cement usage?

Air Pollution

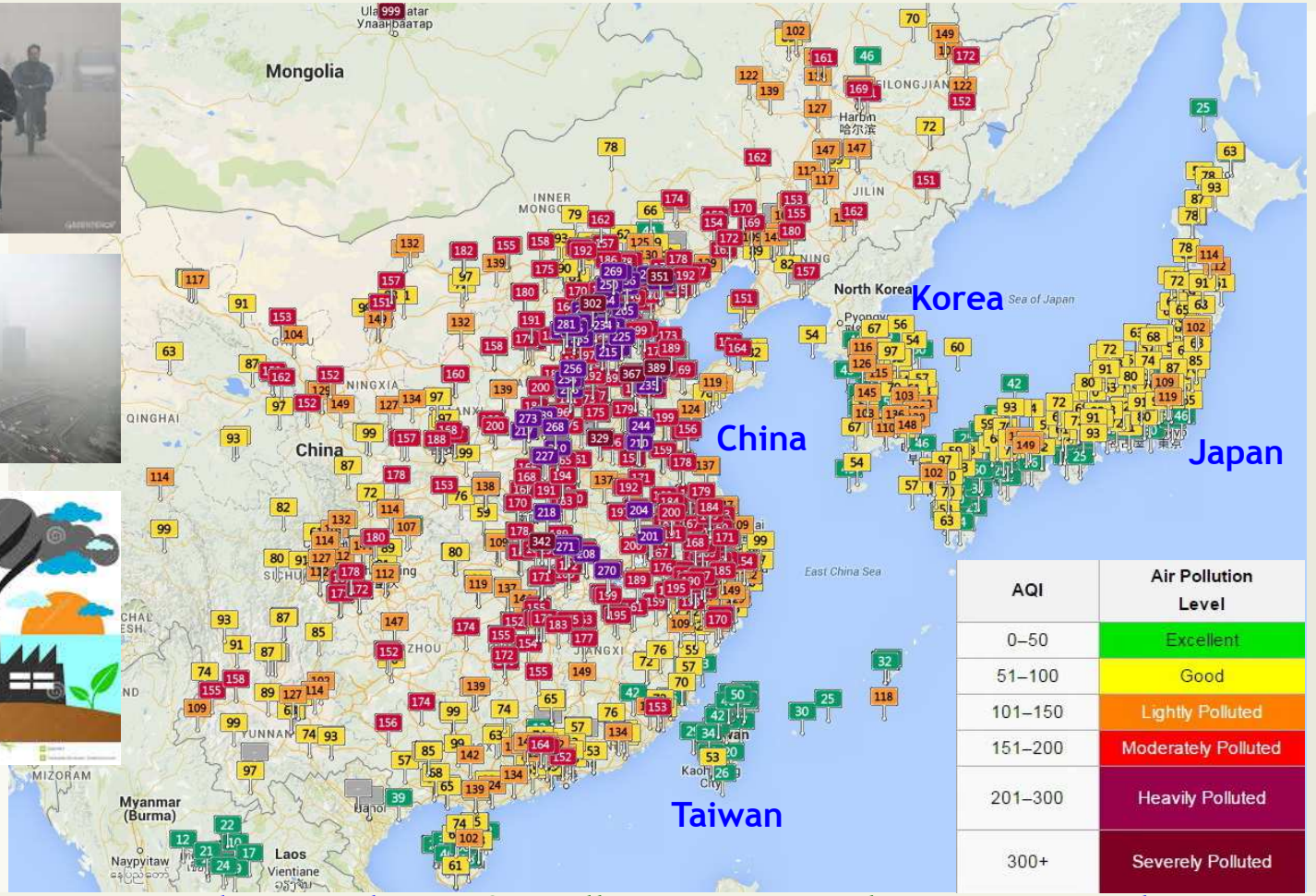


The Air Pollutants ($PM_{2.5}$) Distribution around the World





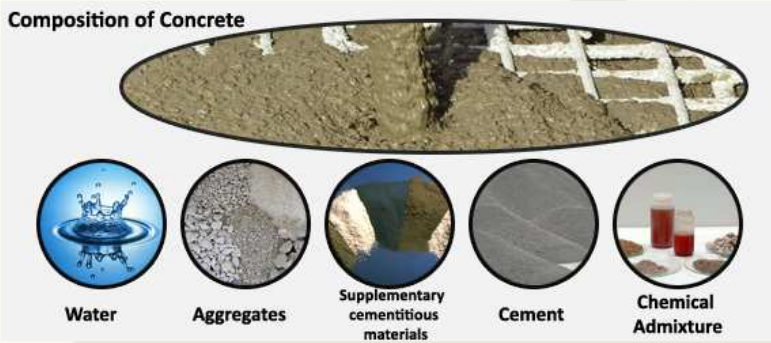
Air Quality Index (AQI) in the Region



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

Binder Systems for Concretes and Mortars

- **Ordinary Portland Cement (OPC)**
  - OPC
  - OPC + PFA 25% PFA
  - OPC + GGBS 65% GGBS
  - OPC + PFA + SF
  - OPC + GGBS + SF



- **Alkali Activated Materials (AAM)**
  - 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

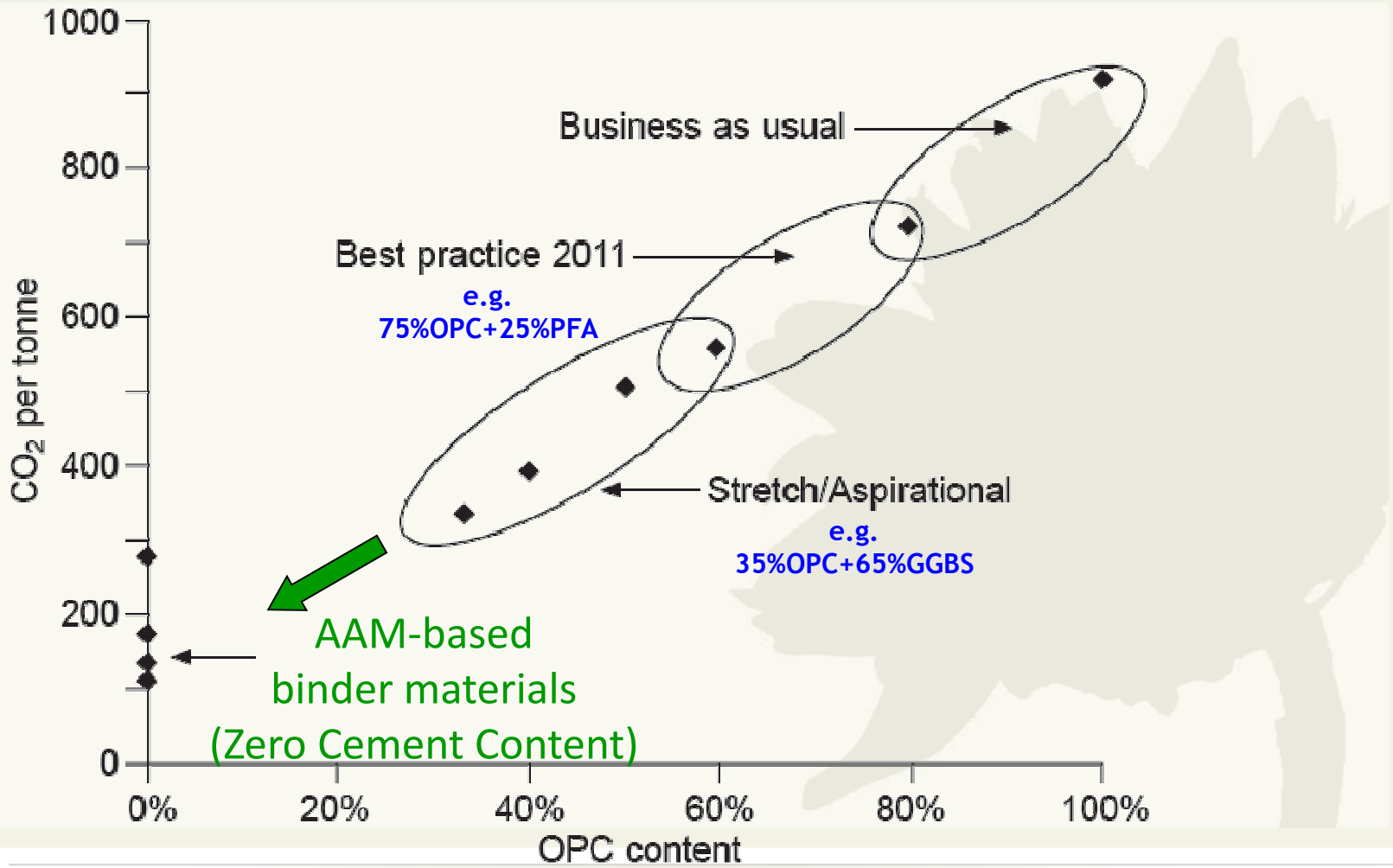
For Example

Na_2SiO_3, NaOH, Na_2SO_4

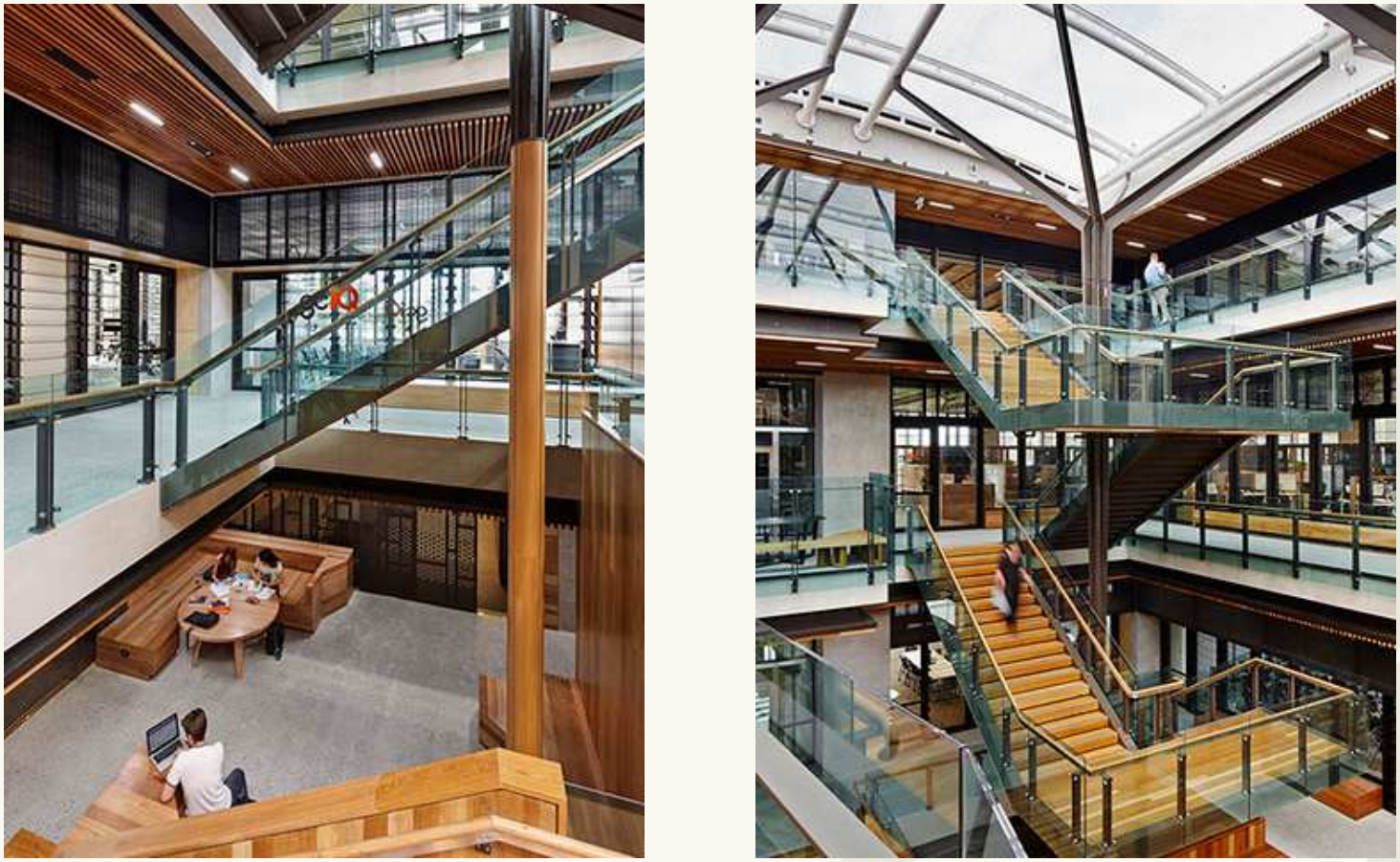
Na_2CO_3, KOH, $NaHCO_3$

(Alternative Cementing Materials)

Green Concrete & Mortar Technology



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 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

AAM Maintenance of Sewerage System

High Chemical Resistance

Manhole Repair

Standardisation & Guidelines for AAM

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

ASTM INTERNATIONAL
Standards Worldwide

CANADIAN STANDARDS ASSOCIATION

ISO

cen

STANDARDS Australia

rilem
International union of laboratories and experts in construction materials, systems and structures

BSI

Standardisation & Guidelines for AAM

Performance-Based Standard

BS EN 206:2013

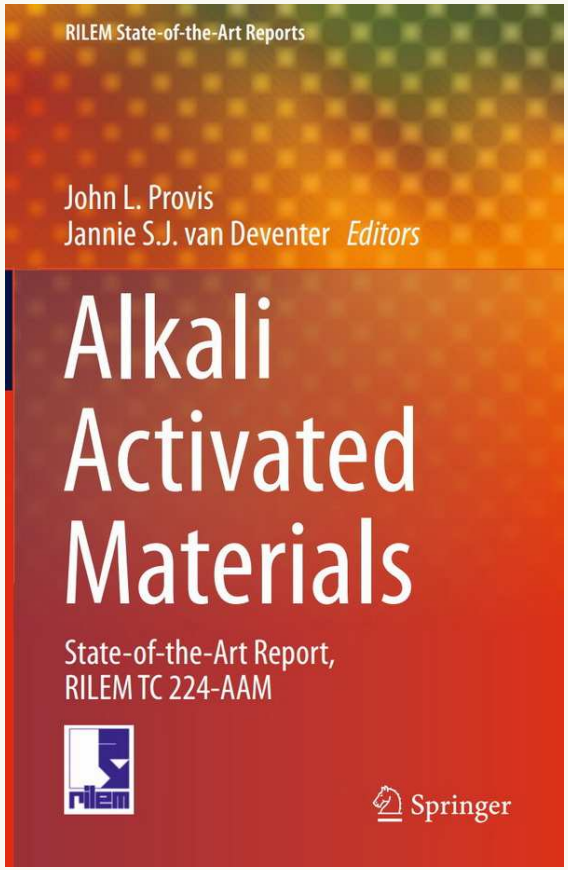
Incorporating corrigendum May 2014

BSI Standards Publication

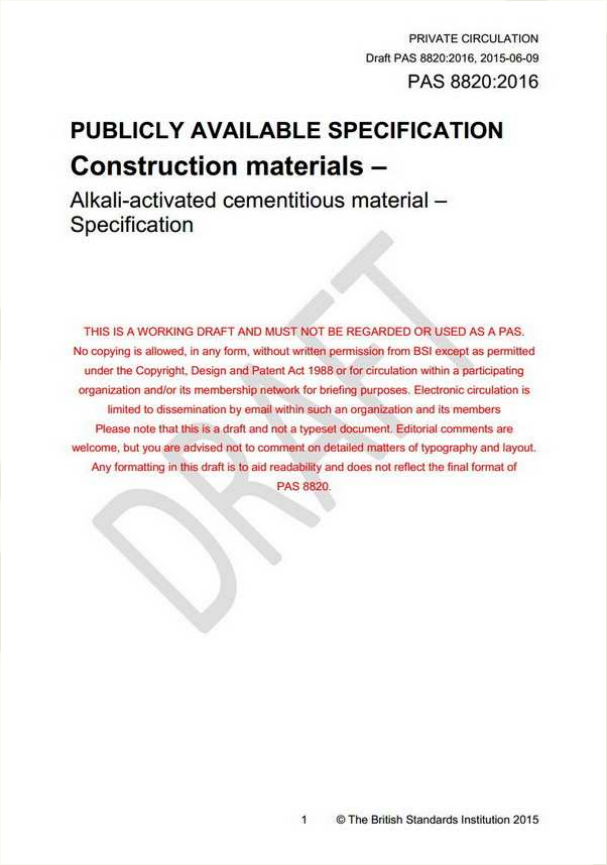
Concrete — Specification, performance, production and conformity

Standardisation & Guidelines for AAM

Rilem TC 224-AAM:2014



BSI : Draft PAS 8820:2016


PRIVATE CIRCULATION
Draft PAS 8820:2016, 2015-06-09
PAS 8820:2016

PUBLICLY AVAILABLE SPECIFICATION

Construction materials –

Alkali-activated cementitious material – Specification

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1 © The British Standards Institution 2015

Potential Applications of AAM

UK BSI : Draft PAS 8820:2016

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

Concrete Specifications in Hong Kong

Limitations on usage of Cementitious Materials in Concrete Mixes

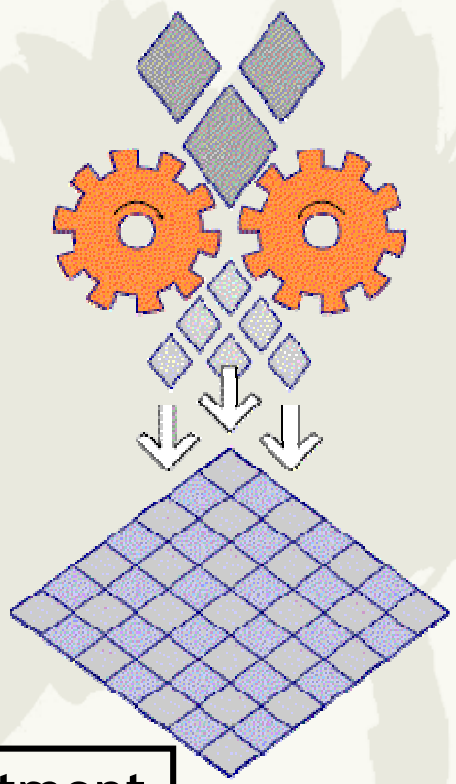
Concrete Mixes	ASD (2012 Version)	CEDD (2013 Version)	HKHA (2012 Version)	MTRC (2009 Version)
PFA	<35%	<35%	25-35%	25-35%
GGBS	<40%	35-75%	N.A.	36-75%
CSF	<10%	N.A.	N.A.	5-10%
Min. Cementitious (for Water Retaining)	>325kg/m^3	>325kg/m^3	>325kg/m^3	N.A.
Max. Cementitious (for Water Retaining)	<450kg/m^3	<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

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 Mortar or Surface Treatment

Protection Against Chemical Attacks

Acid Resistance for Concrete Structures

Use of Materials

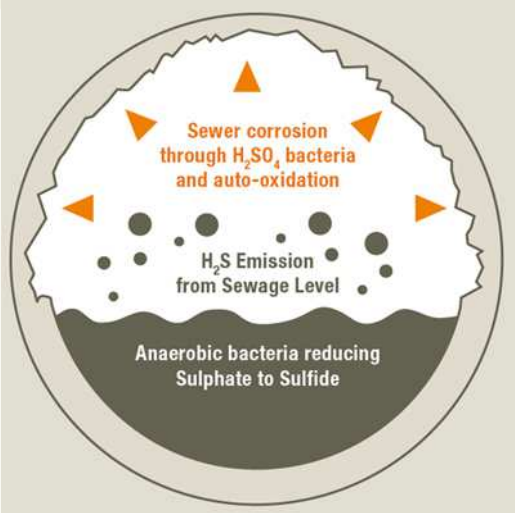
Chemical Resistance to Sewerage Components

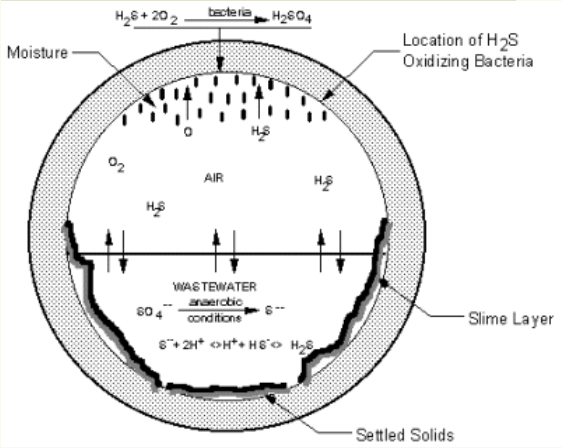
Sewage / Drainage

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

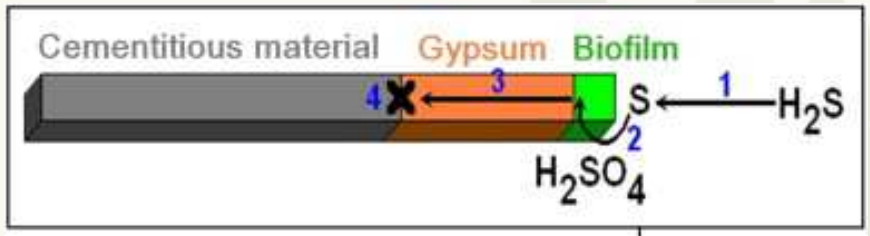
Sulfuric Acid Attack

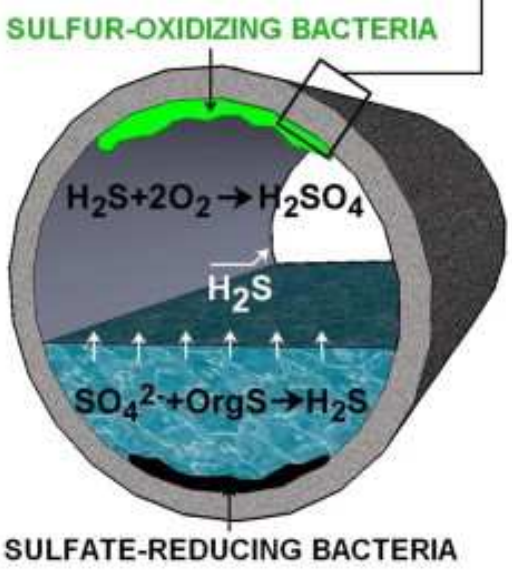
Biogenic Sulfuric Acid Attack





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

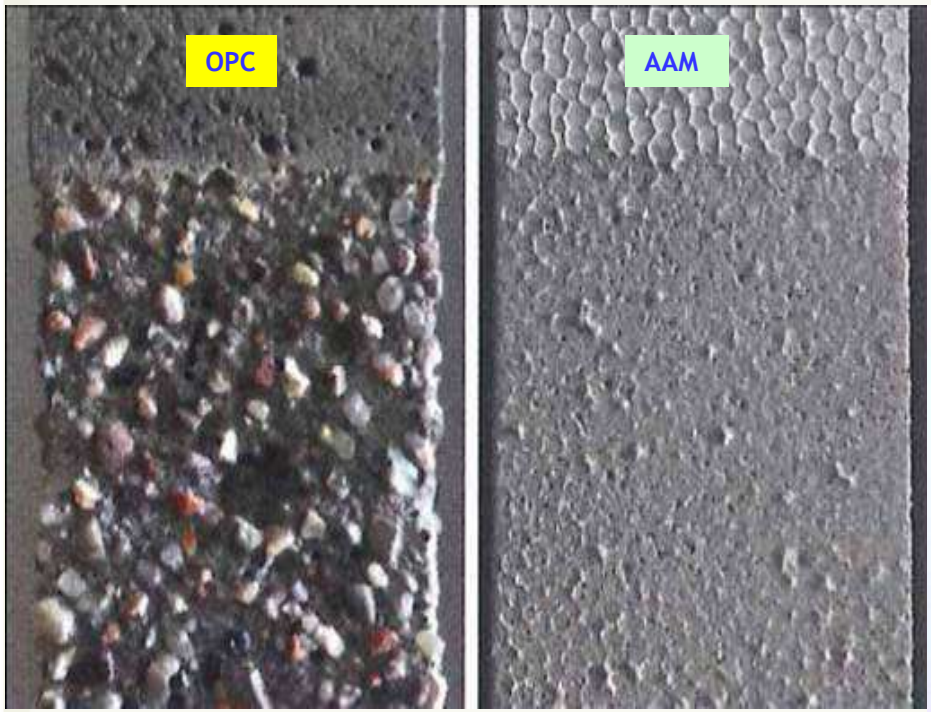




Acid Resistance Test in Germany for AAM Treatment

Test Under 2% H_2SO_4 for 28 Days

Concrete

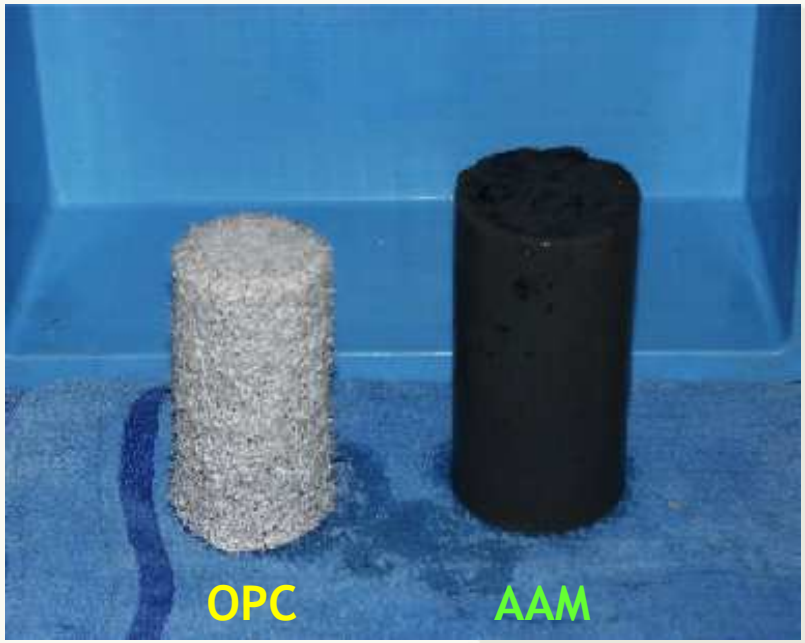


Mortar

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

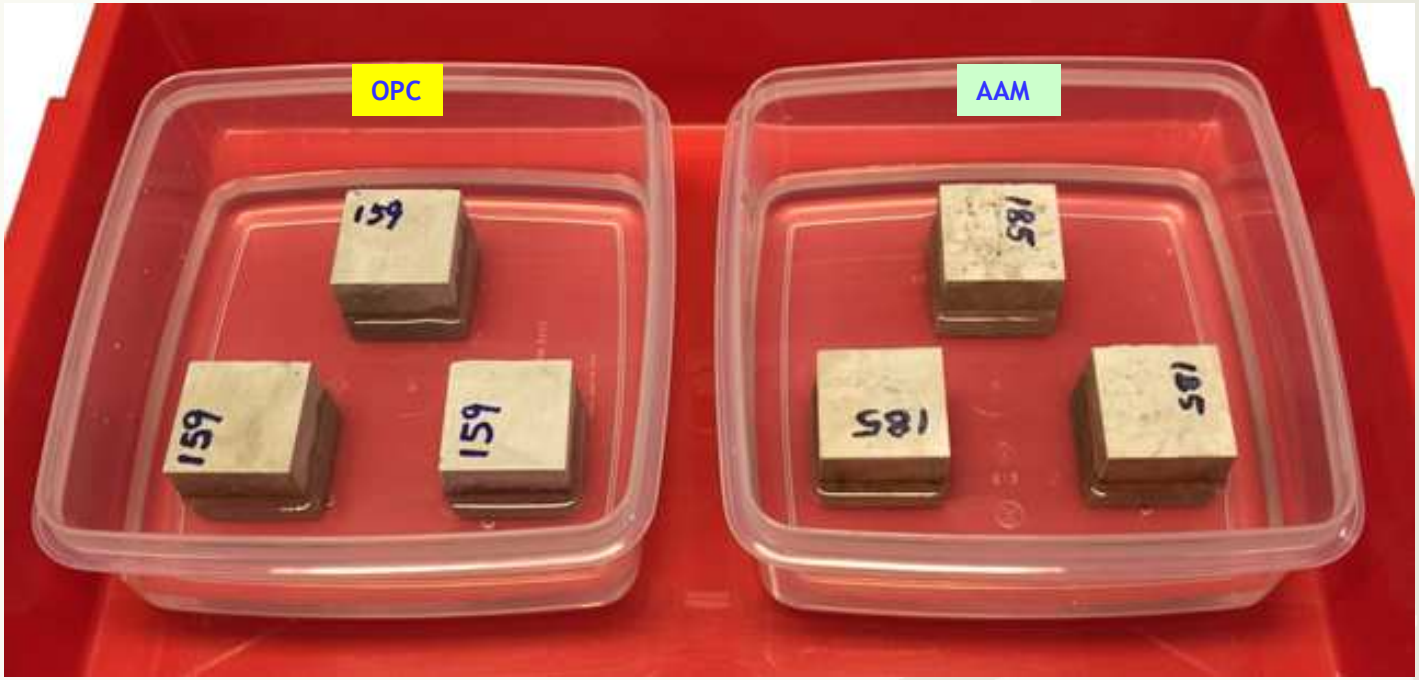
Protection Requirements for Sewerage in Tokyo

Performance Requirements for Repair (Tokyo Sewage Department)

Characteristics	Standard Requirements		Typical AAM
Compressive Strength	3 days	≥25MPa	30MPa
	28 days	≥45MPa	55MPa
Flexural Strength	3 days	≥3MPa	5.5MPa
	28 days	≥7MPa	9MPa
Acid Penetration	≤3mm		2mm
Linear Shrinkage	≤0.1%		0.05%
Adhesion Strength	28 days	≥1.5MPa	2.3MPa
Weight Change	±10%		0.5%
Application Thickness	20mm per layer		Capable

Acid Resistance for AAM Specimens

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

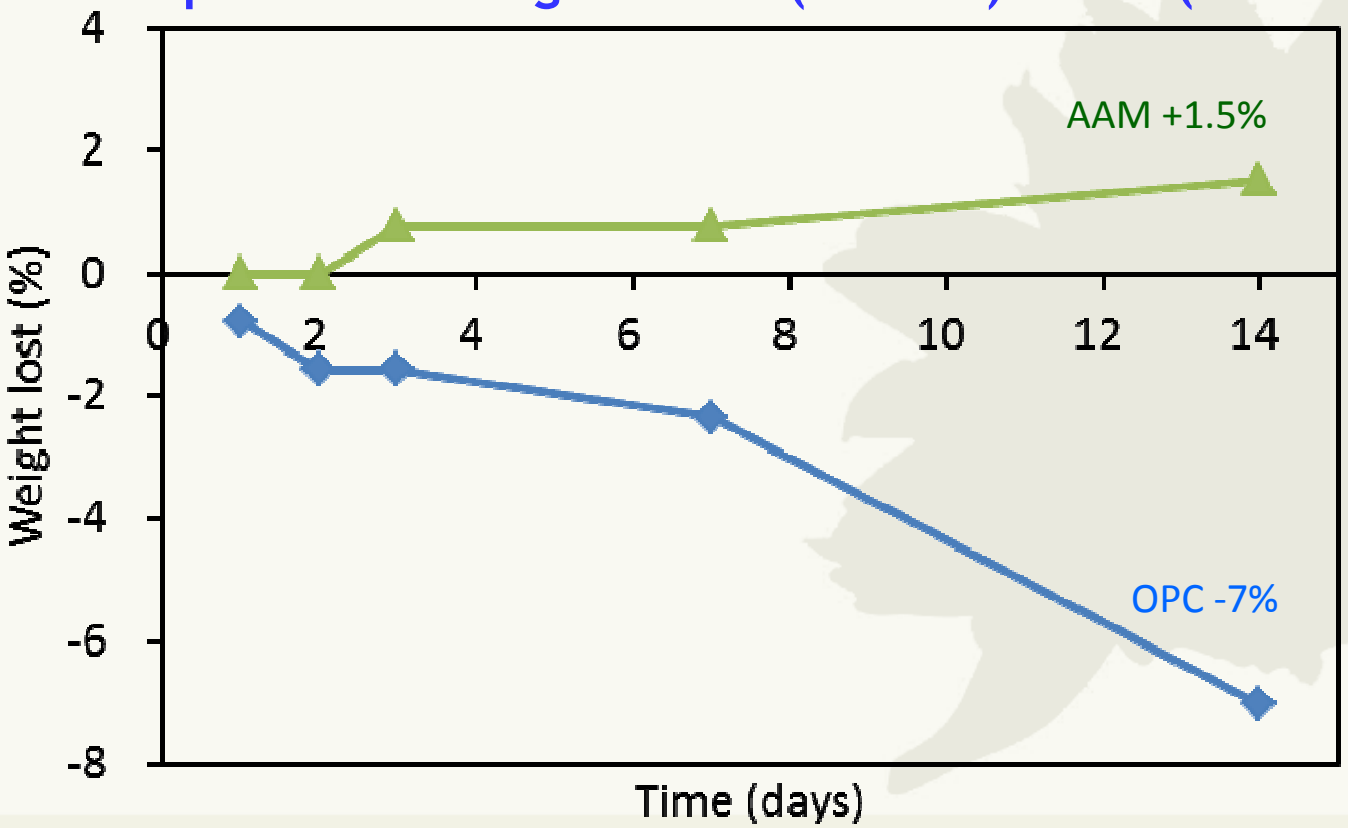


Tests performed by NAMI

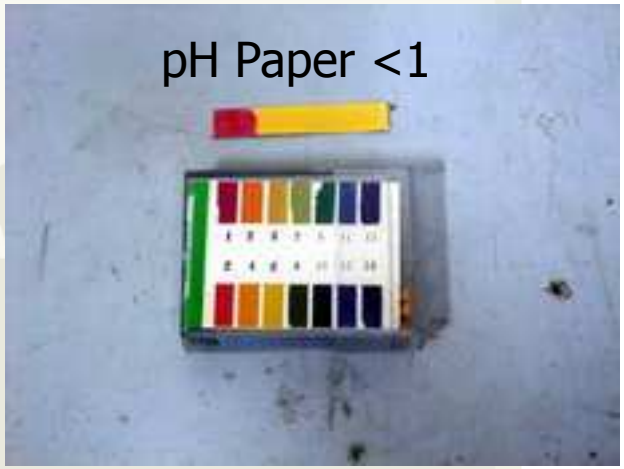
Acid Resistance of AAM Specimens

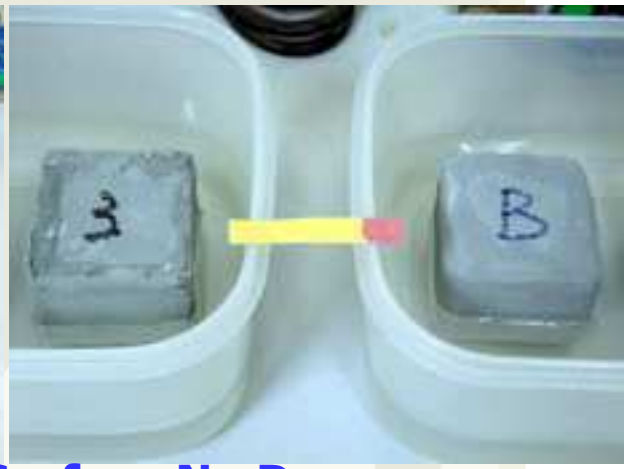
Residual properties after 14-day acid (pH~0.5) immersion

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



Acid Resistance (Long Term Test) for AAM Coated Specimens





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

Basic Considerations on Test Specimens for Acid Resistance Test

Smooth Edge vs Shape Edge

Basic Considerations on Test Specimens for Acid Resistance Test

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HONG KONG TESTING CO., LTD.
Room 205, 2/F., Fuk Shing Commercial Building, 28 On Lok Mun Street, On Lok Tsuen, Fanling, N.T., Hong Kong.
Tel: (852) 2692 2171 Fax: (852) 2691 4874 Email: testhk@netvigator.com

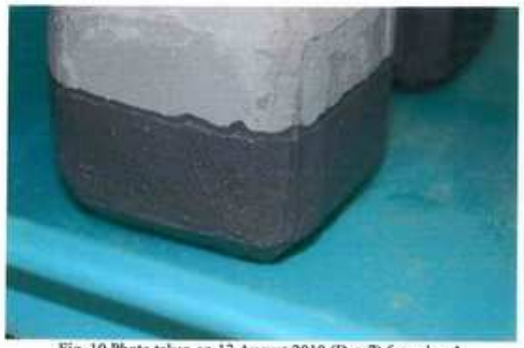

Fig. 10 Photo taken on 13 August 2010 (Day 7) for cube A

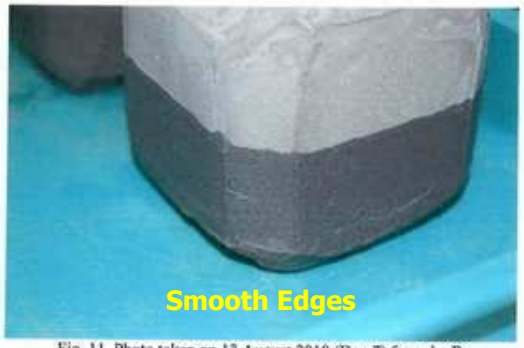

Fig. 11 Photo taken on 13 August 2010 (Day 7) for cube B

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Tel: (852) 2692 2171 Fax: (852) 2691 4874 Email: testhk@netvigator.com

Fig. 12 Photo taken on 13 August 2010 (Day 7) for Cube C

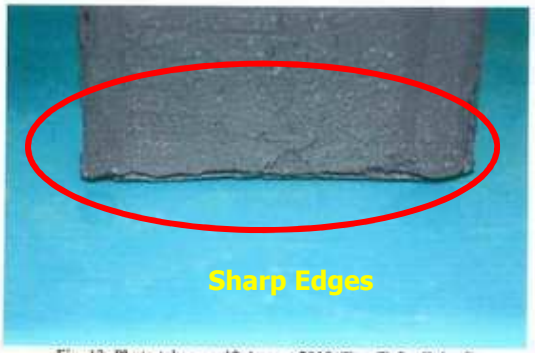
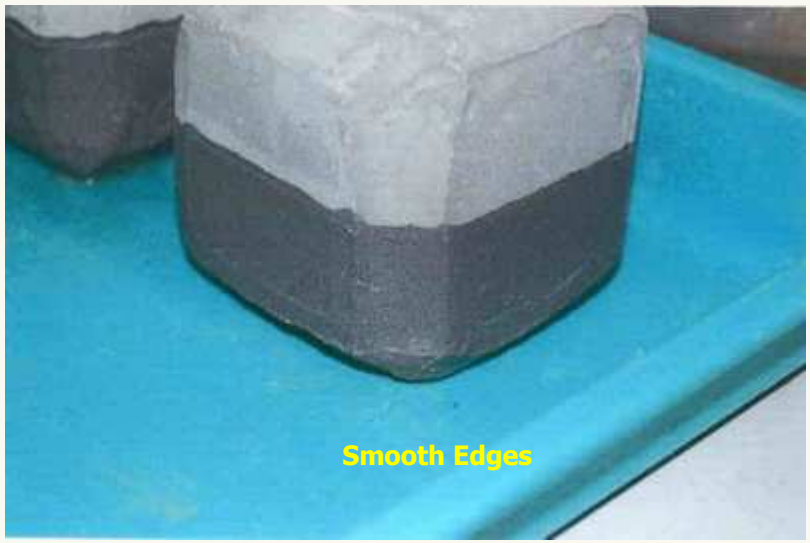


Fig. 13 Photo taken on 13 August 2010 (Day 7) for Cube C

Basic Considerations on Test Specimens for Acid Resistance Test

Coated Test Specimens of Smooth Edges & Sharp Edges

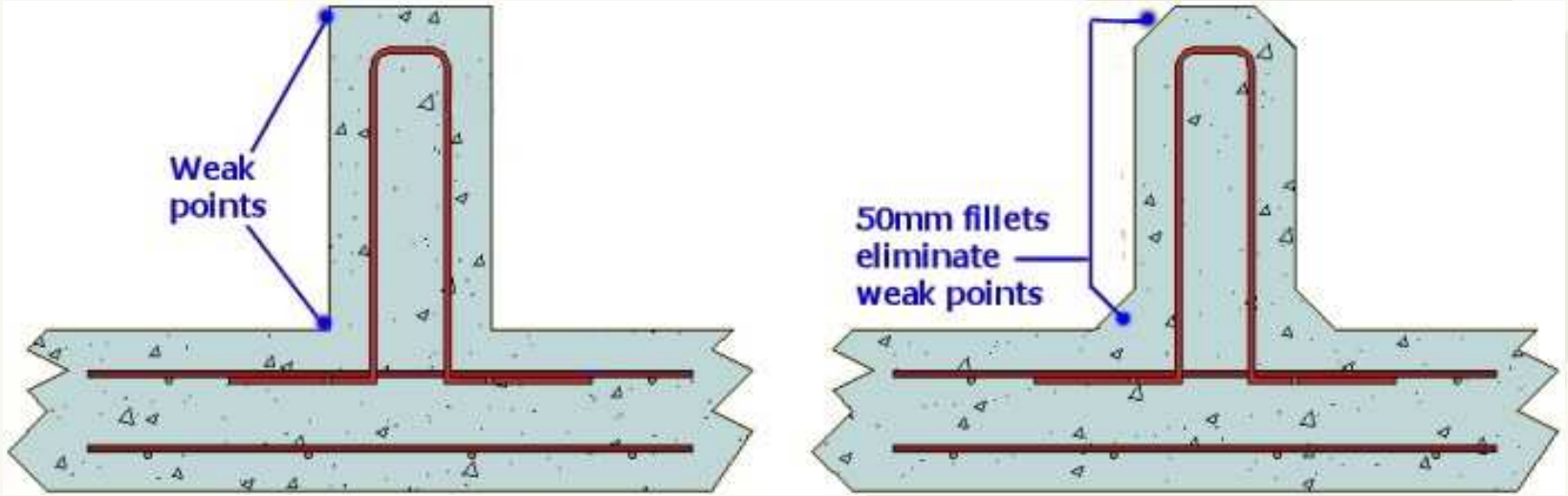


No Damage

Damage at Edges

Basic Considerations on Test Specimens for Acid Resistance Test

When Applying Protective Coating to Corners



Chamfers or Fillets should be applied to Corners

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

- 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 materials

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Thank You !

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