Alkali-Aggregate Reaction (AAR) of Concrete Structures

Outline

- What is AAR?
- How does AAR work?
- How to assess AAR?
- How to minimise AAR risk in new concrete structures?

AAR

- Alkali-silica Reaction (ASR):
  - only type of AAR occurred in HK
- Alkali-silicate Reaction
- Alkali-carbonate Reaction

Concrete failure due to ASR

Concrete failure due to ASR

Effect of ASR

- Concrete Quality
  - Loss of strength, stiffness, impermeability
  - Affect concrete durability and appearance
  - Premature failure of concrete structures
- Economic Costs
  - Maintenance cost increased
  - The life of concrete structure is reduced
- Overall Result
  - No concrete structures had collapsed due to ASR damage
  - Some concrete structures/members were demolished because of ASR

Example: Daqing Railway Bridge, China

Alkali-Aggregate Reactions in Railway Bridge

- Railway Bridge built in 1987
- Precast prestressed concrete beams cast at Gaogezhuang, North of Beijing

Example: Daqing Railway Bridge, China

Example: Daqing Railway Bridge, China

Local Example in HK

Shek Wu Hui Treatment plant

Built in early 1980s
ASR was reported in 1991

Local Example in HK

Shek Wu Hui Treatment plant

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Shek Wu Hui Treatment plant

Local Examples of ASR

Structures Affected by ASR:

Site	Year constructed	Year ASR reported	Approx. time for ASR to develop
Shek Wu Hui Treatment Works	1980 - 1983	1991	about 9 - 12 years
Fan Ling Footbridges	1982	1998	16 years
North Point Govt. School	1987	about 1999	about 12 years
Hill Road Flyover	1982	1997	15 years

Local History of ASR

Background

- ASR was first diagnosed in HK (1991)
- AAR Sub-Committee under SCCT was set up

- **Hong Kong Specification**

- WBTC 14/94 issued
  3 Kg/m^3 limit on reactive alkali content in concrete

- Quality Scheme for the Production and Supply of Concrete (QSPSC)
  Cl. 7.1.1(e) Use of chemical method ASTM C289

- Increasing use of AMBT (included in PS) in major concrete structures

How to assess ASR

Test for Potential ASR

- Reaction of alkali with silica is slow

- ASR can be accelerated by:
  - increasing temperatures,
  - increasing moisture availability,
  - increasing alkali concentrations

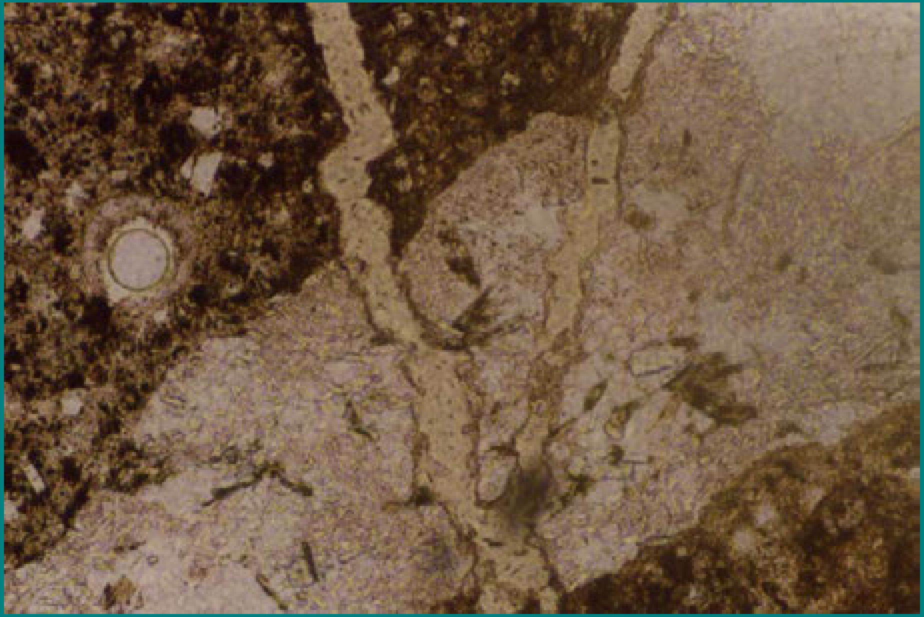
Common Test Methods to assess ASR

- Petrographic Examination
- Chemical Test
- Accelerated Mortar Bar Test (AMBT)
- Concrete Prism Test (CPT)
- Accelerated Concrete Prism Test (ACPT)

Common Test Methods to assess ASR

Test Method	RILEM	ASTM Standard	Canadian Standard	British Standard
Petrographic Examination	AAR-1	ASTM C295	---	BS 812:Part 104
Accelerated Mortar Bar Test (AMBT)	AAR-2	ASTM C1260	CSA A23.2-25A	DD 249: 1999
Concrete Prism Test (CPT)	AAR-3	ASTM C1293	CSA A23.2-14A	BS 812:Part 123
Accelerated Concrete Prism Test (ACPT)	AAR-4	---	---	---
Chemical Method		ASTM C289		

Petrographic Examination



Petrographic examination of concrete cores from Shek Wu Hui Treatment Plant

Crack running through aggregate particle and into surrounding cement paste

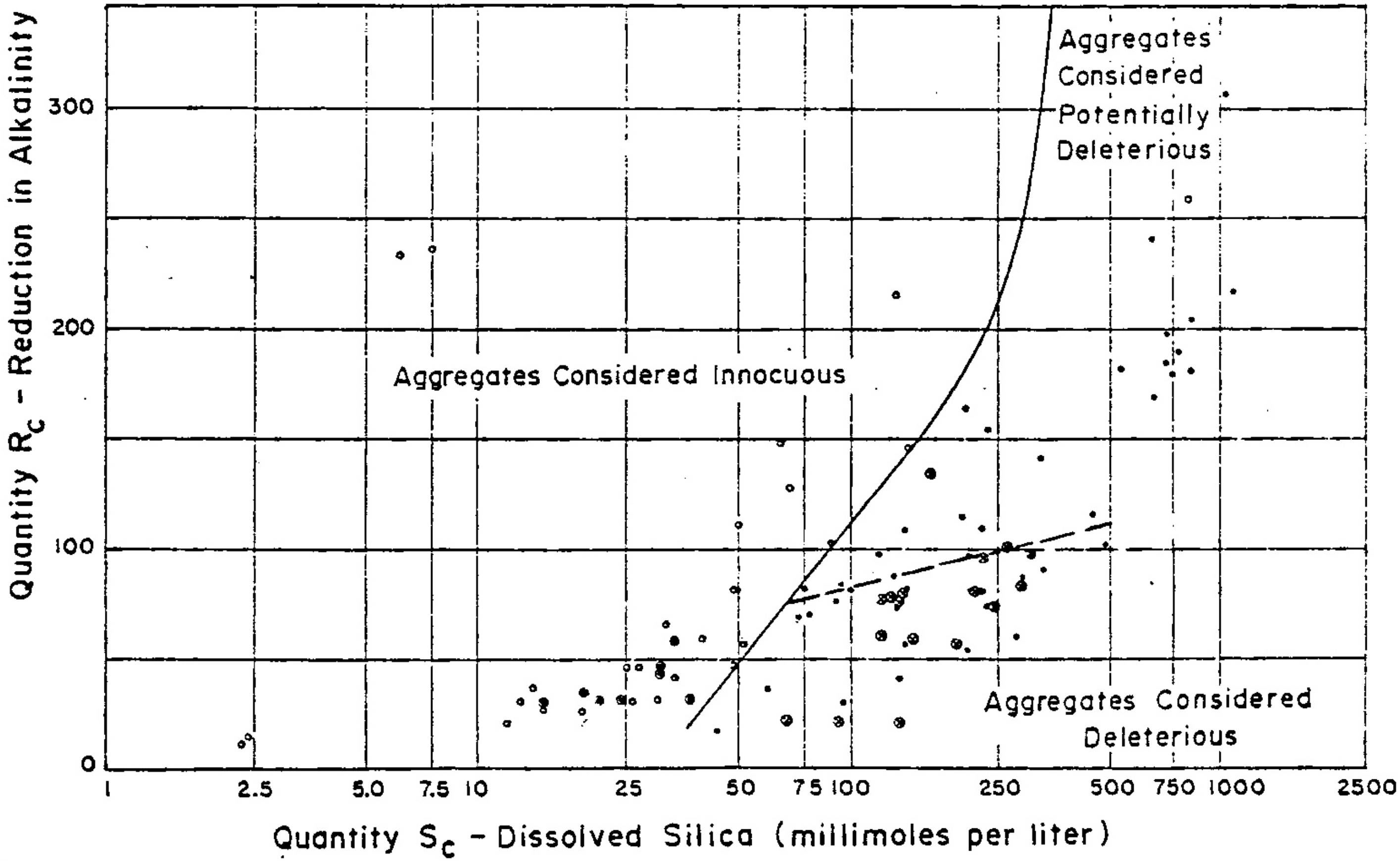


FIG. 2 Illustration of Division Between Innocuous and Deleterious Aggregates on Basis of Reduction in Alkalinity Test

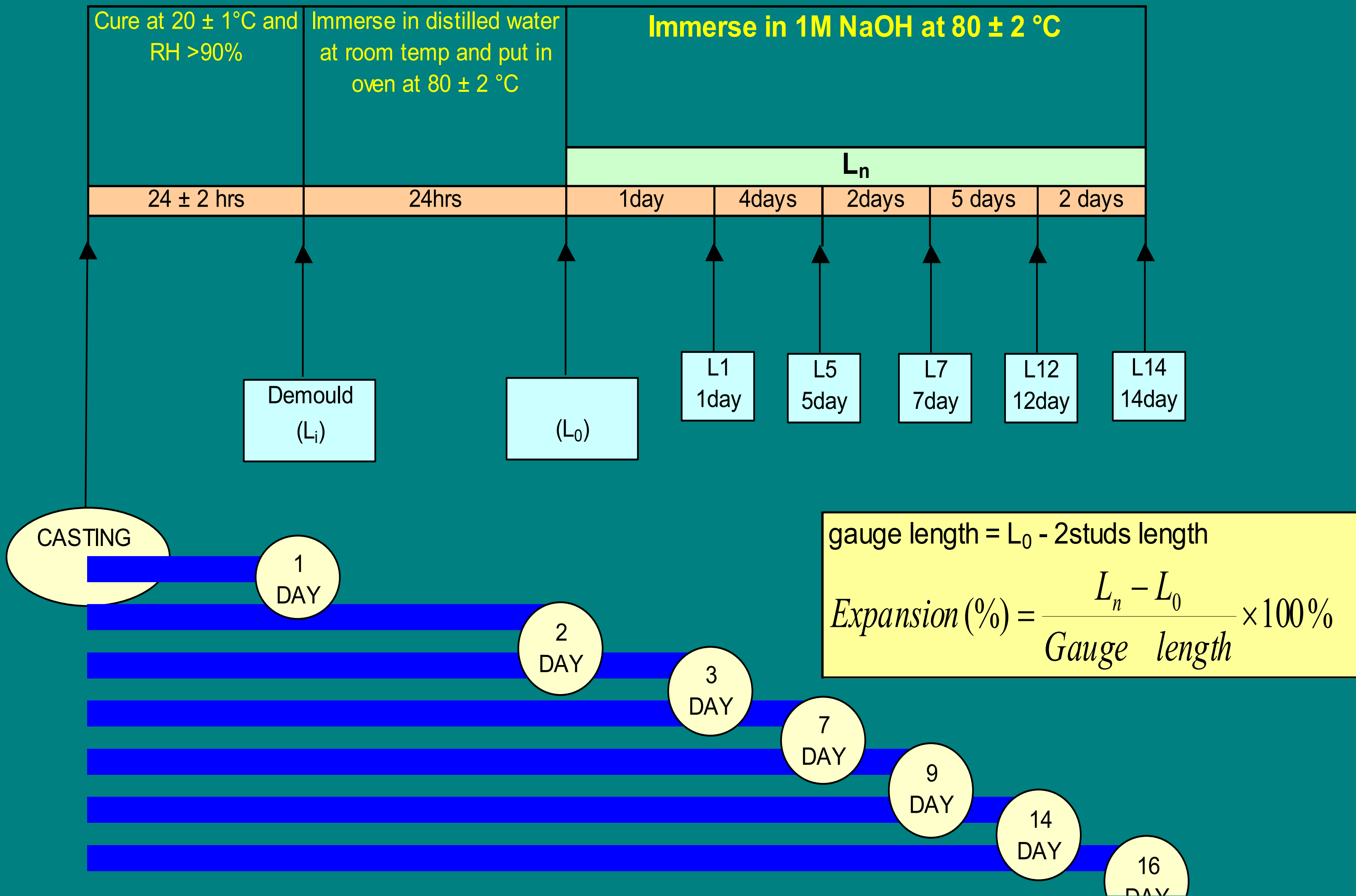
Use of Chemical Method (ASTM C289)

Use of AMBT in HK

- PWL CON 5.5 Method
- RILEM AAR-2
- Others: ASTM C1260, CSA A23.2-25A
- GEO Technical Note TN 6/2002 issued in December 2002

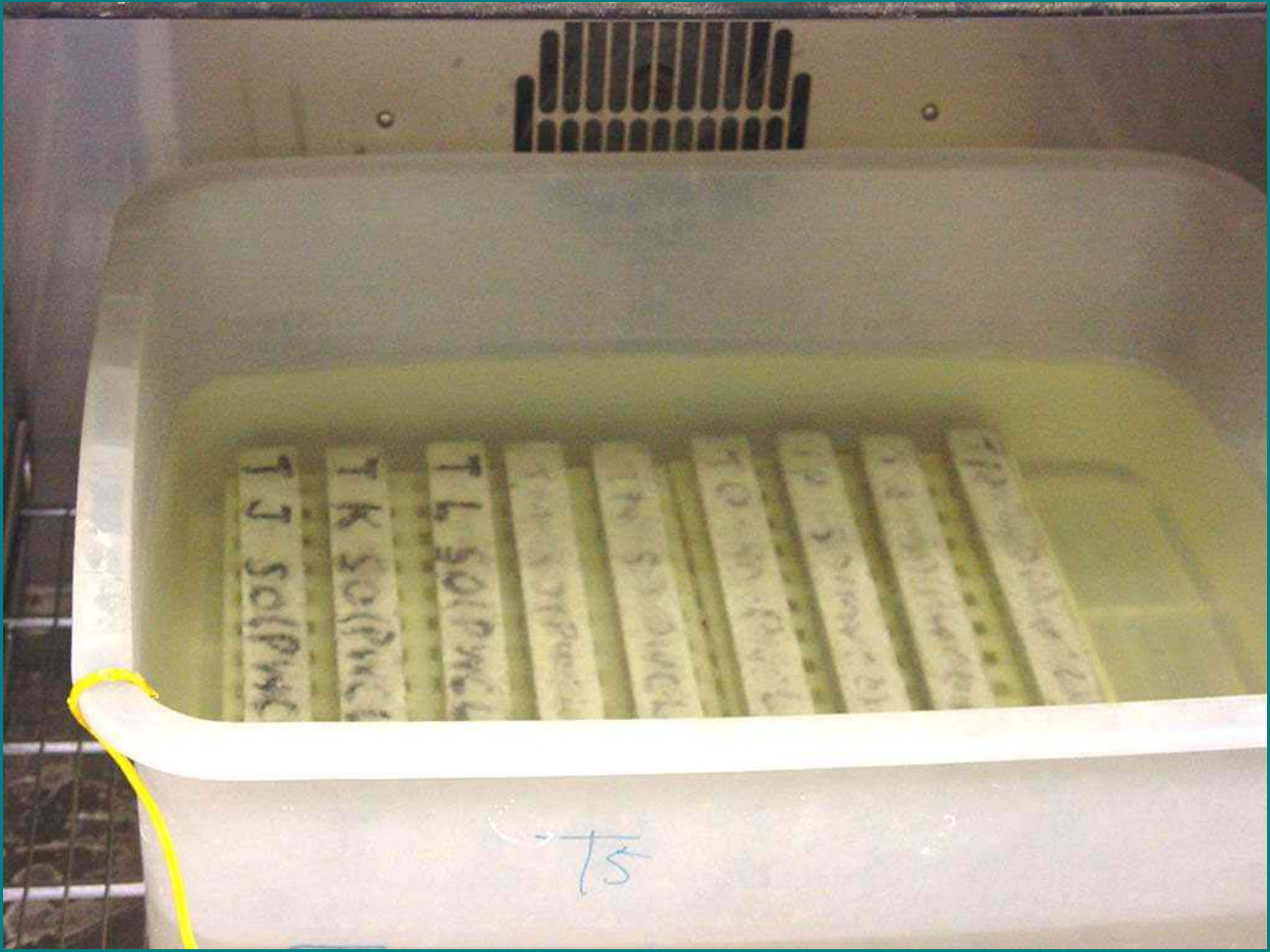
AMBT : RILEM AAR-2

Public Works Central Laboratory
Flow Chart for Rilem TC-106-2

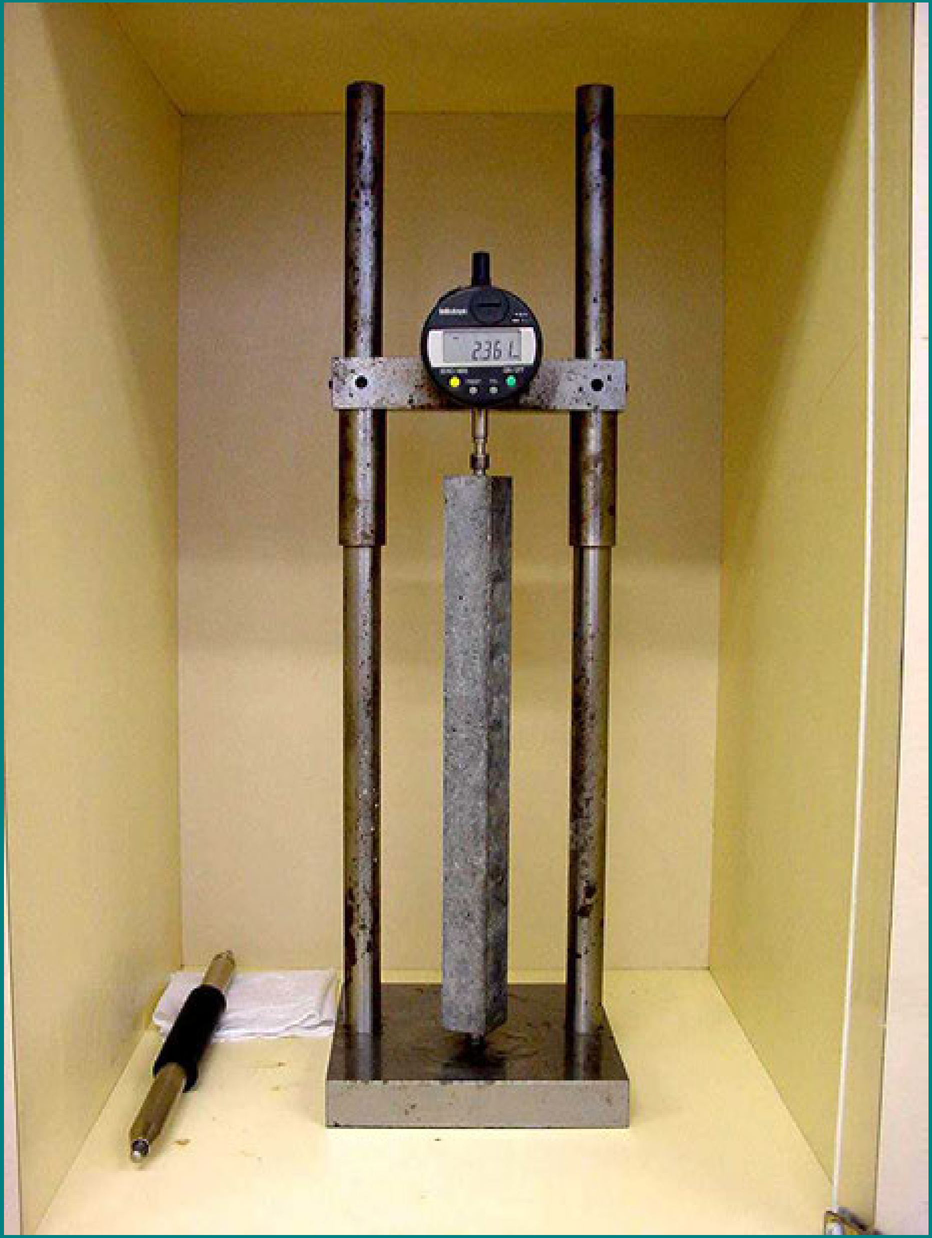


AMBT : RILEM AAR-2

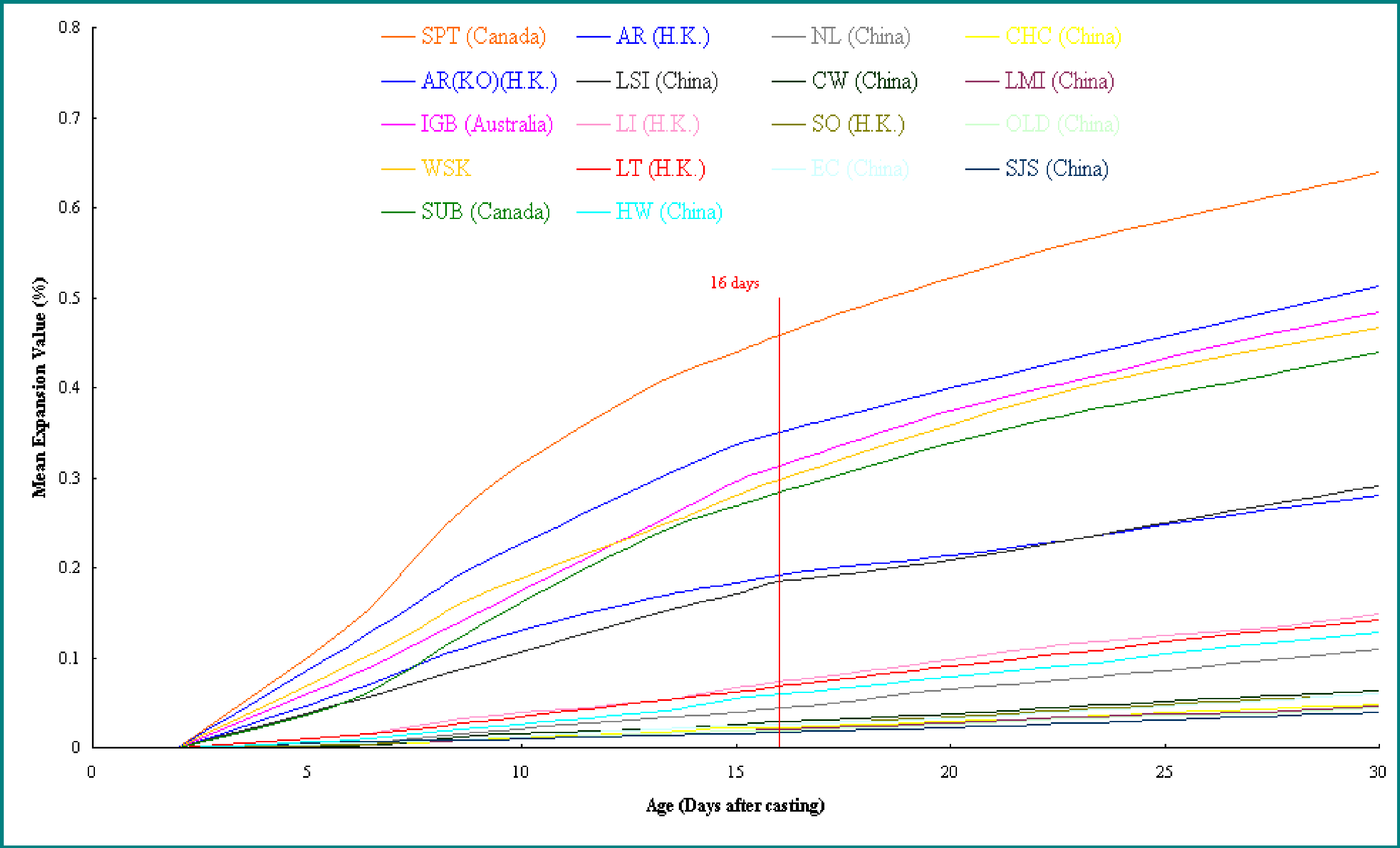
AMBT: RILEM AAR-2



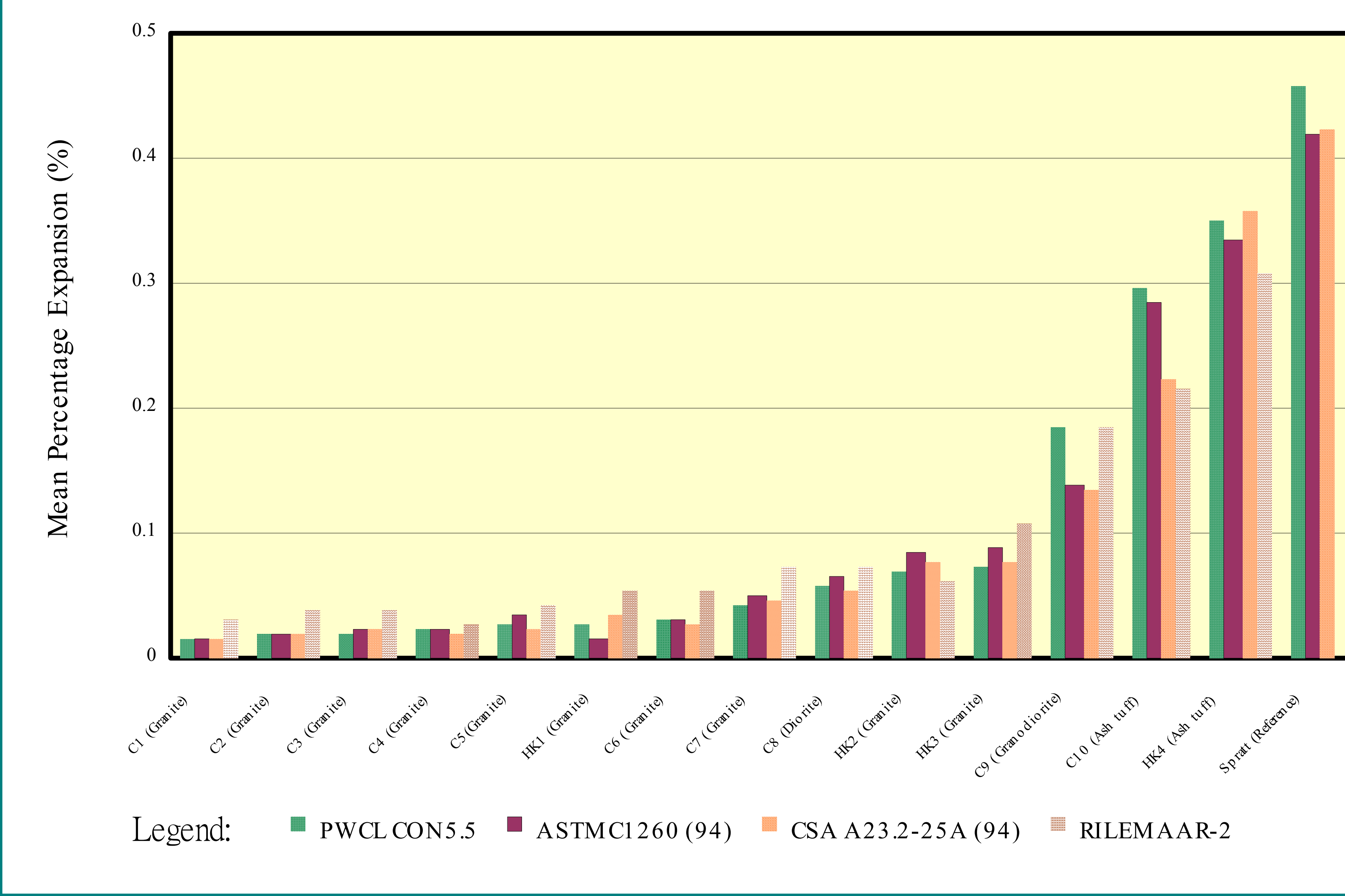
AMBT: RILEM AAR-2



AMBT Results of Local & Reference Aggregate

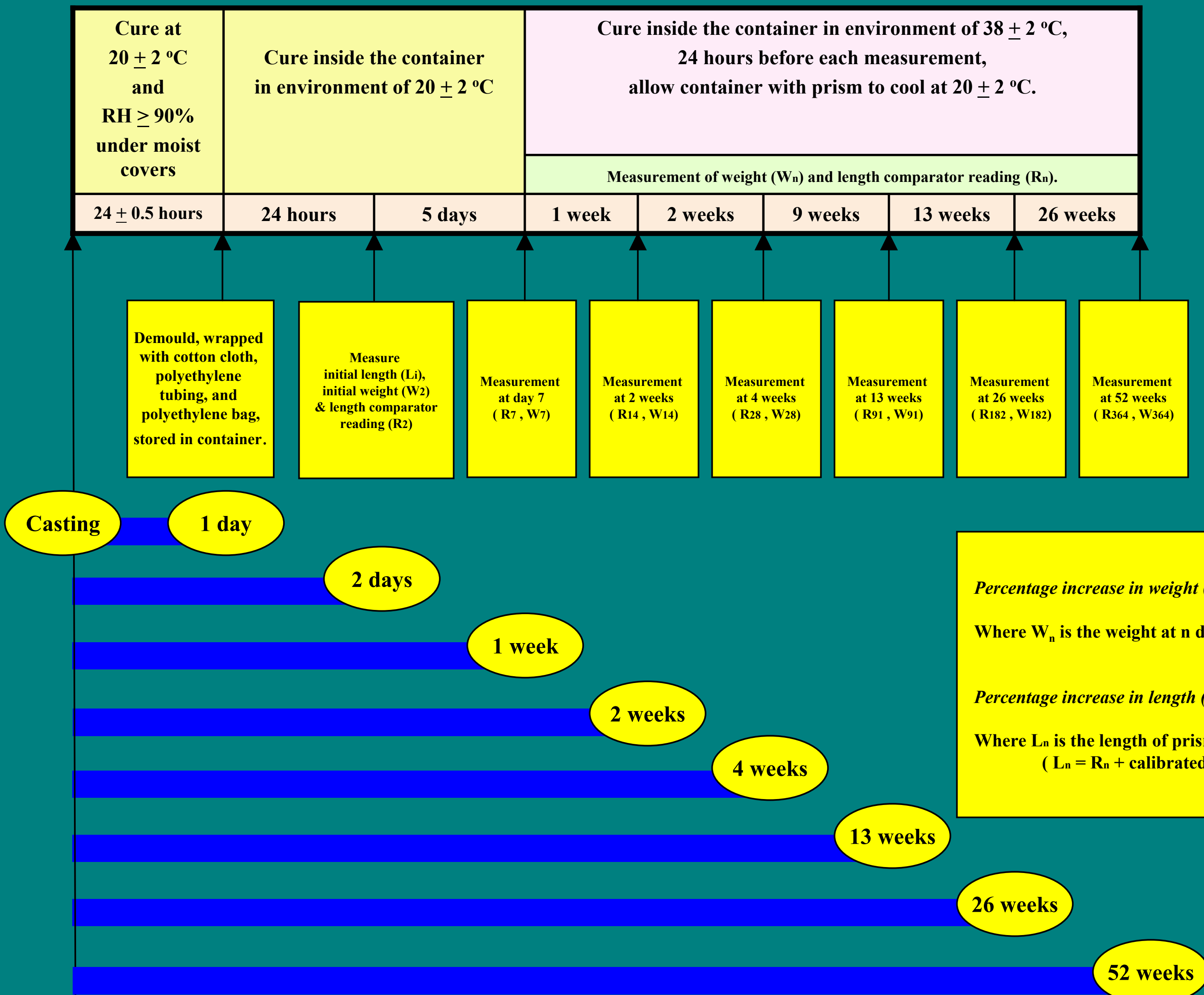


AMBT Results of Local & Reference Aggregate



Rilem AAR-3 (TC 106-3)
Detection of Potential Alkali-reactivity of Aggregates

Flow Chart of Measurement



Percentage increase in weight (%) $= \dfrac{W_n - W_2}{W_2} \times 100\ \%$

Where W_n is the weight at n days age.

Percentage increase in length (%) $= \dfrac{L_n - L_2}{L_i} \times 100\ \%$

Where L_n is the length of prism with studs at n days age.
($L_n = R_n$ + calibrated length of reference bar).

CPT: RILEM AAR-3

CPT: RILEM AAR-3

- Steel Mould with Gauge Studs

CPT: RILEM AAR-3

CPT: RILEM AAR-3

CPT: RILEM AAR-3

CPT: RILEM AAR-3

- Interior of Container

CPT: RILEM AAR-3

- Interior of Oven

CPT: RILEM AAR-3

ACPT

- A Faster test when compared with CPT
- Determination of alkali threshold limit
- Performance test for concrete mix

- Development of ACPT will be the next task of PWCL

ASR Testing Methods

- Hong Kong Experience

- Chemical test is not reliable
- AMBT show reliable result
- CPT is under development by PWCL
- Development of ACPT will be the next task

Preventive Measures against ASR in New Concrete Structures

Factors affecting ASR Reactivity

- Reactivity of the siliceous material
- total alkali content of the concrete
- supply of moisture

Preventive Measures against ASR

- Cements

- Limiting the alkali content of the mix, means that a low-alkali cement have to be used

- most countries adopted the limit of 0.60% Na_2O equivalent

Preventive Measures against ASR

- Restriction of alkali level in concrete

Canada, Denmark	1.8 to 3.0 Kg/m³ Na_2O equivalent, depending on information about AAR reactivity of aggregate and the level of risk
South Africa	2.0 to 4.5 Kg/m³ Na_2O equivalent, depending on information about AAR reactivity of aggregate
New Zealand	2.5 Kg/m³ Na_2O equivalent
UK	2.5 to 5.0 Kg/m³ Na_2O equivalent, depending on information about AAR reactivity of aggregate
Belgium, China, Japan, USSR	3.0 Kg/m³ Na_2O equivalent
France	3.0 to 3.5 Kg/m³ Na_2O equivalent, depending on information about variability of cement alkalis
Ireland	4.0 Kg/m³ Na_2O equivalent but 4.5 Kg/m³ Na_2O equivalent if reactive aggregate is only Carboniferous chert

Preventive Measures against ASR

- Supplementary Cementitious Materials (SCM)

- Pulverized-fuel ash (PFA)
- Ground granulated blastfurnace slag (GGBS)
- Microsilica, also called silica-fume

Preventive Measures against ASR

- Use of Cementitious Replacement Materials

- PFA, GGBS used in most countries

- microsilica used in Australia, Belgium, Canada, Denmark, Iceland, New Zealand, South Africa & USA

- Usual Range of Replacement Levels
  - 15 to 40% PFA
  - 25% to 70% GGBS
  - 7% to 15% microsilica

Preventive Measures against ASR

- Aggregates
- If the aggregate is non-reactive, no other precautions are necessary
- If not, a variety of precautions are invoked
- Preclusion of reactive aggregates from particular uses.

Preventive Measures against ASR

- Moisture

- Reduce the access of moisture and maintain the concrete in a sufficiently dry state

Preventive Measures against ASR

- Others

- Modify the properties of any gel such that it is non-expansive, e.g. using lithium salts

Review of International Practice with ASR

- 3 Basic Approaches

- (1) aggregates are classified as reactive or innocuous; mitigation measures are prescribed for use with reactive aggregates.

- (2) the reactivity of an aggregate is first classified; mitigation measures are prescribed for use of the aggregate according to the nature of the structure and the environment it is in.

- (3) consideration starts with the nature of structure to be constructed and the service environment; aggregate reactivity is considered for the choice of supply sources and the mitigation measures needed to prevent AAR

Typical Framework

- Determination the level of precaution
- Characterisation of the structural needs
- Characterisation of the environment

Classes of Structures

- Structures classified by risk category

- S1 – some deterioration from AAR is acceptable, e.g. temporary or short service life structures, easily replaceable elements

- S2 – minor AAR and resulting cosmetic cracking is acceptable, e.g. most building and civil engineering structures

- S3 – no AAR damage is acceptable, even if only cosmetic - long service life or highly critical structures, e.g. nuclear installations, dams, tunnels, exceptionally important bridges or viaducts, structures retaining hazardous materials

Classes of Environment

- Characterisation of the environment
- E1 – protected from external moisture, e.g. internal concrete within buildings, external concrete protected by cladding
- E2 – exposed to external moisture, .e.g. internal concrete within buildings where humidity is high (laundries, swimming pools), external concrete exposed to atmosphere
- E3 – exposed to external moisture + aggravating factors such as de-icing salts, freezing and thawing or a marine environment

Level of Precaution

- An example of Level of Precaution
- P1 – no special precautions against ASR
- P2 – normal level of precaution
- P3 – special level of precaution

Environment Category	E1	E2	E3
Category of Structure			
S1	P1	P1	P1
S2	P1	P2	P2
S3	P2	P3	P3

Example of Control Framework:
RILEM: Draft International Specification to Minimise Damage from ASR in Concrete

- Level of Precaution
- P1 – no special precautions against ASR
- P2 – normal level of precaution

  M1: Restrict the alkalinity of pore solution, e.g. limit the alkali content of concrete, use of low alkali cement, include PFA, GGBS, etc.

  M2: Avoid the presence of a critical amount of reactive silica, e.g. identify non-reactive aggregate

  M3: reduce the access of moisture and maintain the concrete in a sufficiently dry state, e.g. use external cladding or tanking

  M4: modify the properties of any gel such that it is non-expansive, .e.g. use lithium salts
- P3 – special level of precaution

  Combined application of at least two of the precautionary measures from level 2

What shall we do?

What we know:

- Which reactants involved and their sources
- How alkali-silica gel is created
- ASR prevention can be achieved by using low alkali cement and non-reactive aggregate
- Cement replacement such as PFA, GGBS and microsilica help mitigate ASR damage

What we don’t know:

- Cement Replacement: its mechanism of inhibition, which compounds work best, how much of each compound is needed to prevent expansion, its long term performance
- Which test method most suit local aggregate

What shall we do?

- SCCT: Review of Concrete Related Standards

- (1) Cement Standard
- (2) Aggregate Standard
- (3) Unifying Concrete Specification
- (4) CS1 - Concrete Testing
- (5) CS2 – Reinforcement Bar

- Proposed framework for controlling risk of ASR in Hong Kong is being prepared and will be circulated to relevant parties

THANK YOU