Mitigation of Alkali-Silica Reaction in Volcanic Aggregate CONCRETE USING PFA AND GGBS

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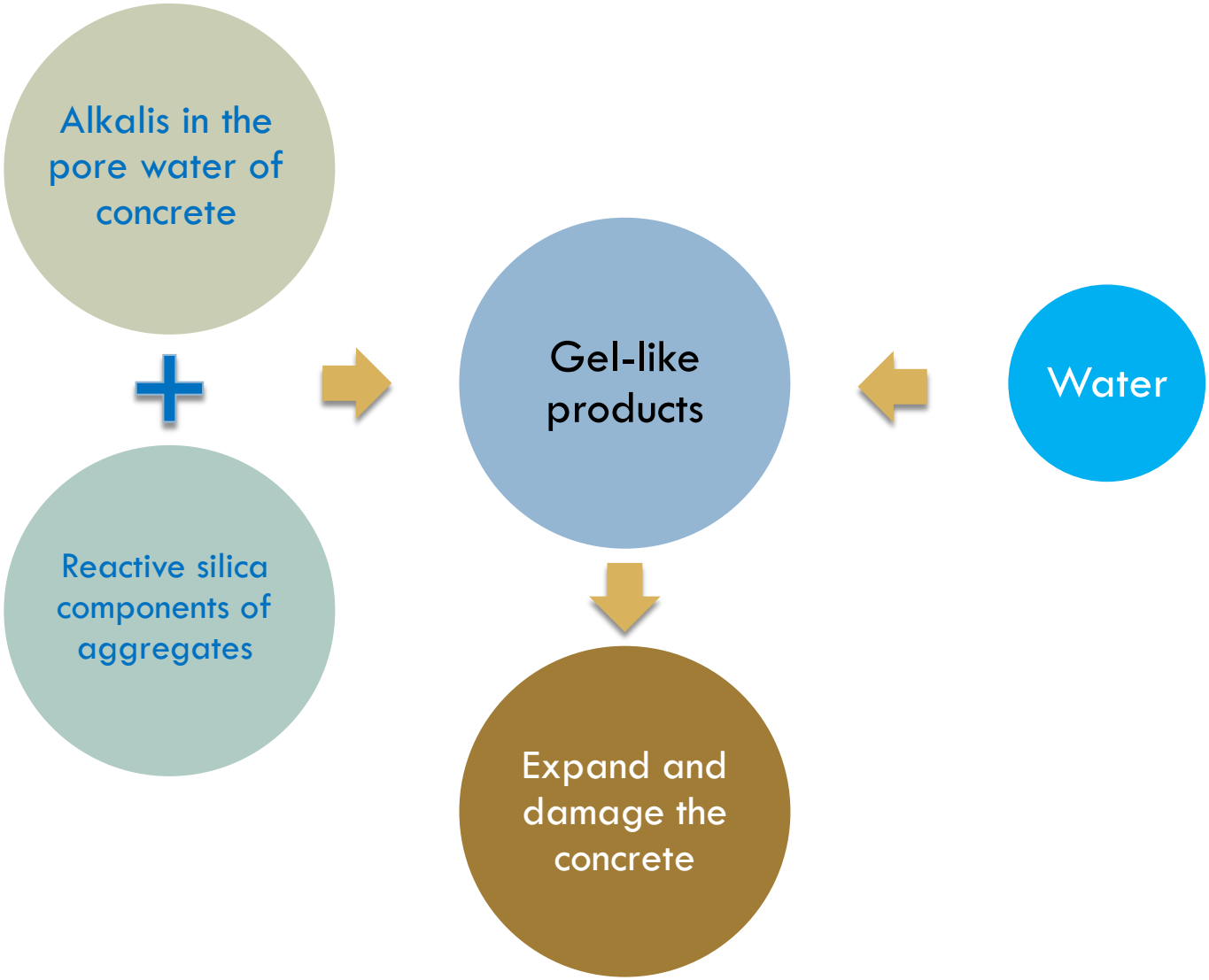
Outline

1. What is Alkali-silica Reaction (ASR)?
2. Cases of ASR damage in Hong Kong
3. Aggregates for concrete in Hong Kong
4. GEO's study on mitigating ASR in concrete using supplementary materials
5. Closing Remarks

Alkali-Silica Reaction (ASR)



Cases of ASR Damage

1. The first recognized cases of ASR damage: seawall, schools, and bridge piers in USA, in late 1930.
2. The first case in Hong Kong, a sewage treatment plant, in 1991.

Cases of ASR in HK

Structures	Year built	Year map pattern cracks found
A sewage treatment plant	1981	1991 (10 years)
A footbridge	1982	1998 (16 years)
A school building	1987	1999 (12 years)
A road bridge	1982	1997 (15 years)

- Time for ASR to be visible: 10 – 15 years.

Cases of ASR in HK

- First ASR case found in 1991

Cases of ASR in HK

- Not Architectural Finishes

Cases of ASR in HK

- A recent case in bridge footing.

Visual features of structures affected by ASR

- Map pattern cracks
- Cracks parallel to the reinforcement
- Cracks occur 10+ years after the structures built
- Pop-outs or swelling of concrete

Consequences

- Loss of concrete strength
- Concrete more permeable
- Reduced capacity
- Reduced service life
- Very costly to rectify

Control Measures in Public Works (1)

a) Section 16 of General Specification for Civil Engineering Works (2006)

1. Aggregates in the "Alkali-Reactive" category shall not be used.
2. Alkali content (eq. Na2O): no more than 3 Kg / m^3 of concrete.

b) SCCT – Construction Standard CS3:2013 Aggregate for Concrete

Aggregate producers/suppliers must have a quality control system to ISO 9001 implemented.

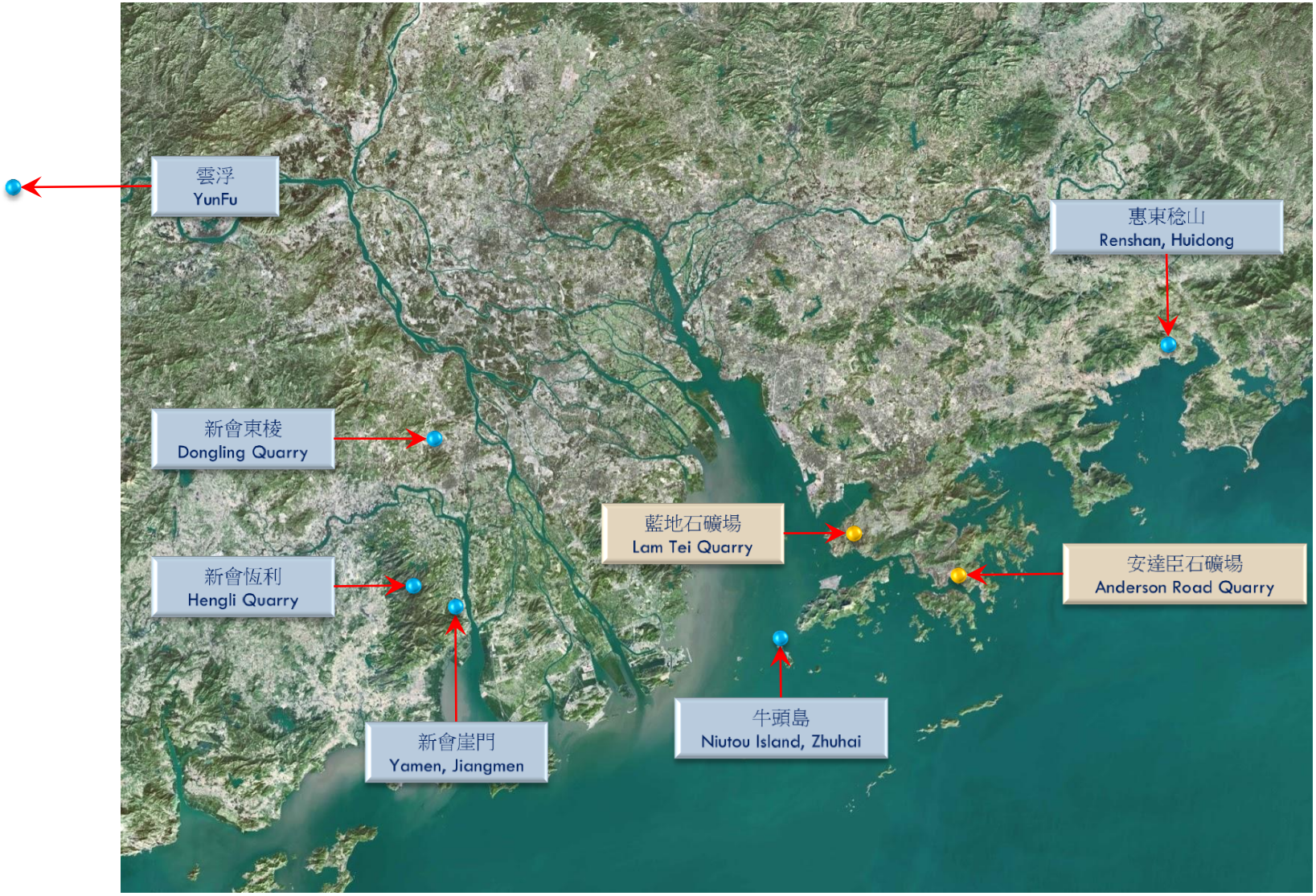
Control Measures in Public Works (2)

c) ETWB TC 57/2002 - Quality Assurance for Structural Concrete

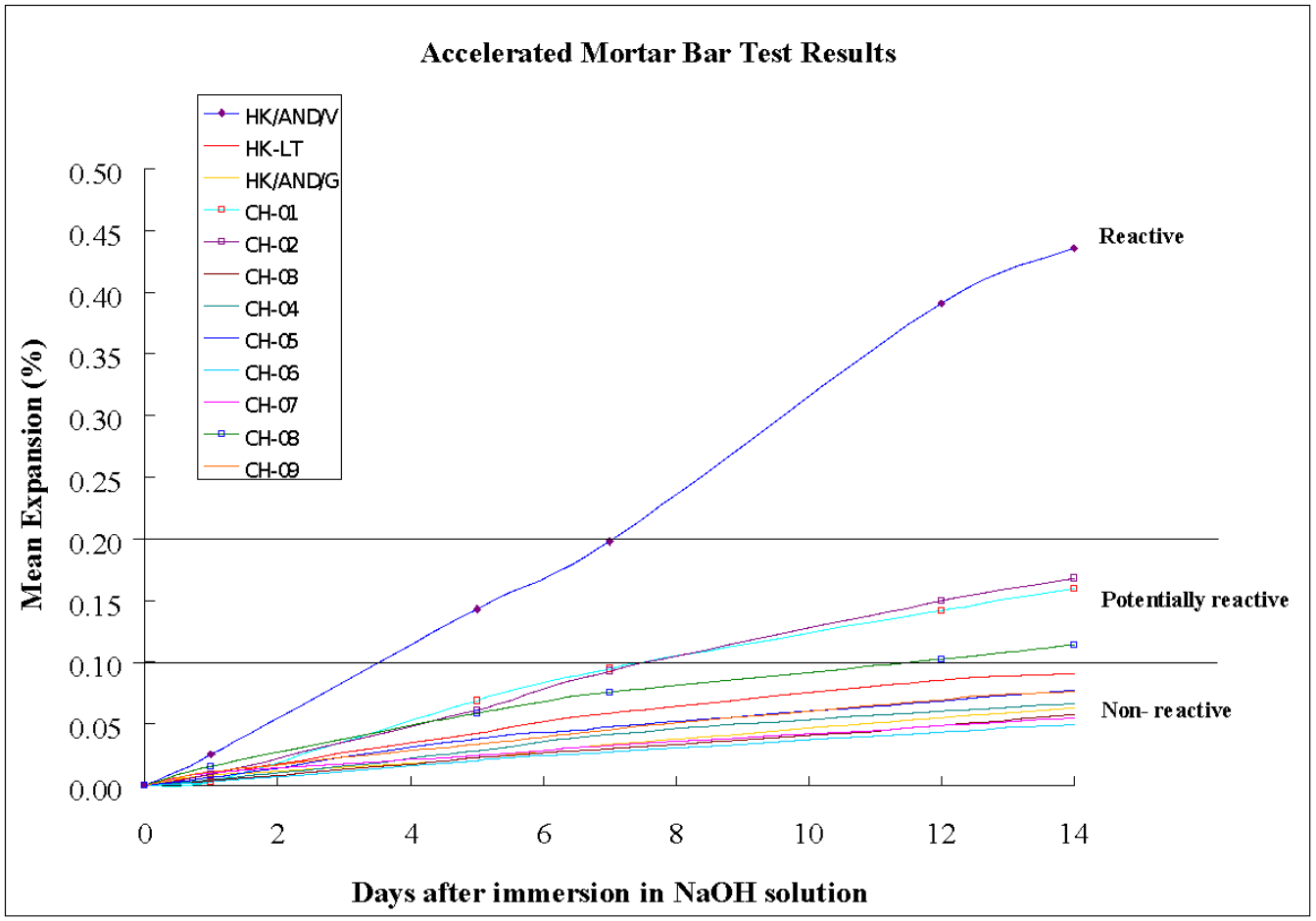
Structural concrete for public works must be obtained from concrete suppliers certified by the Quality Scheme for the Production and Supply of Concrete (QSPSC).

d) GEO regularly collect aggregate/rock samples from concrete batching plants and local/PRC quarries and carry out ultra-accelerated mortar bar tests and petrographic examinations.

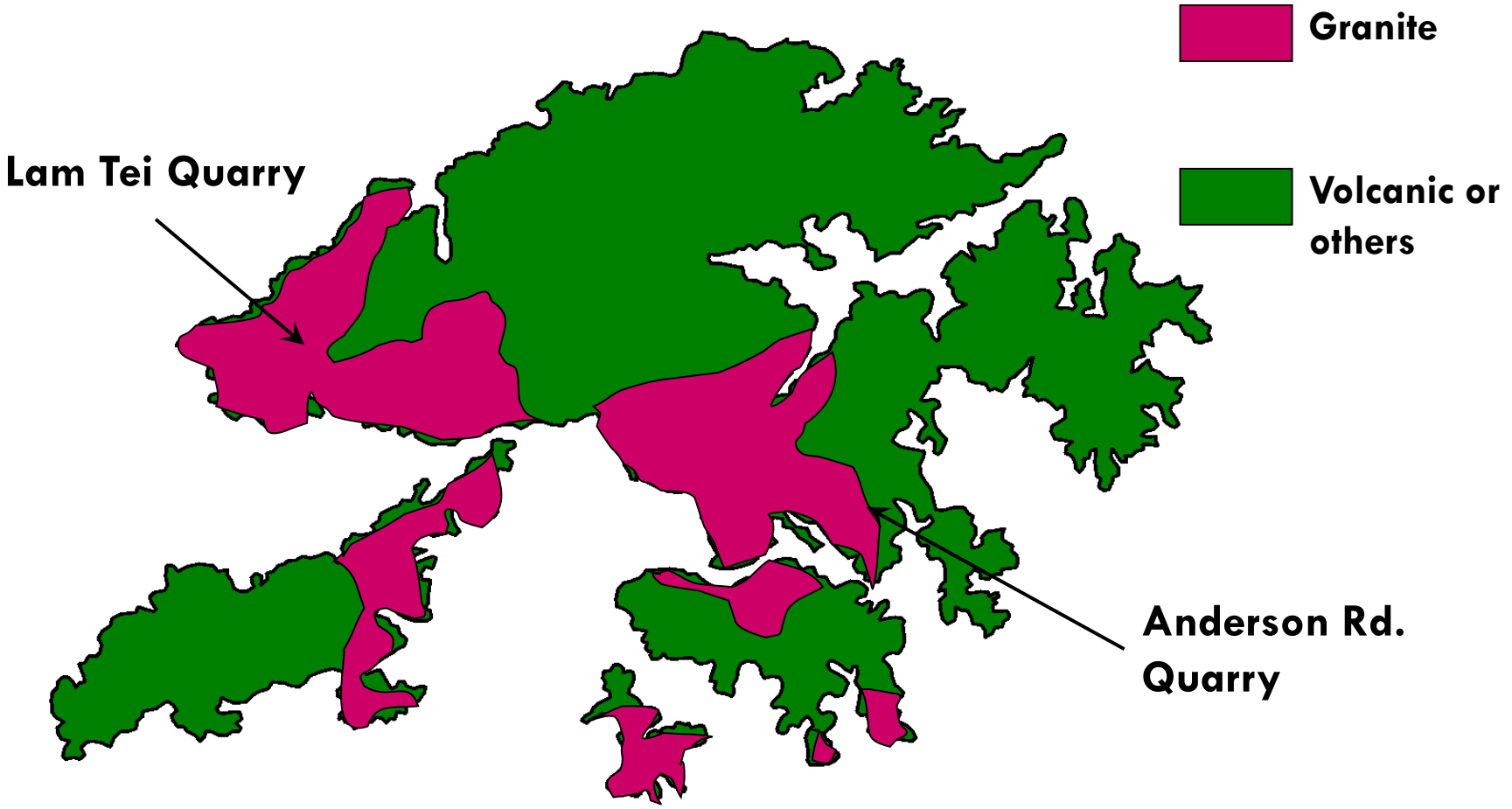
Aggregates for Concrete Production in HK



UAMBT Results of Commonly Available Aggregates

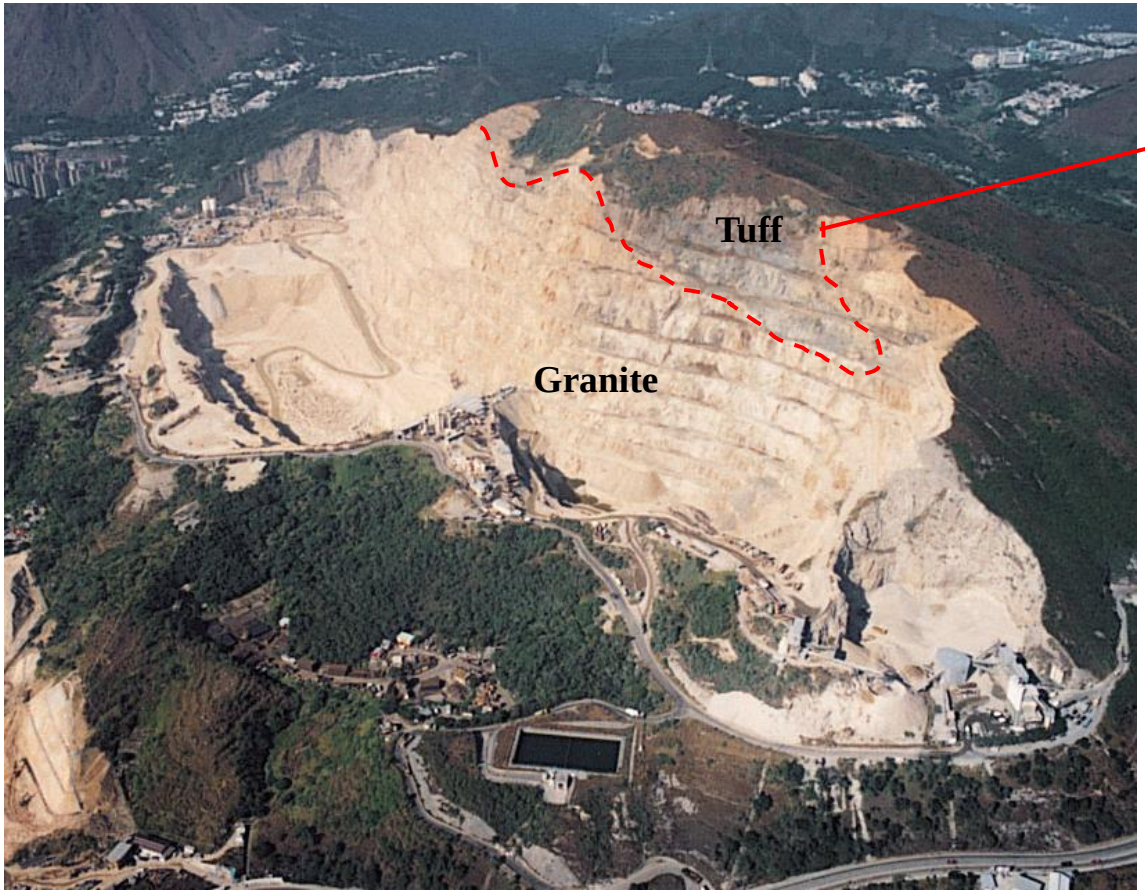


Local geology and aggregate suppliers



Lam Tei Quarry

Anderson Road Quarry



- The volcanic tuff from Anderson Road Quarry is highly alkali-reactive.

Volcanic aggregates used in concrete in Hong Kong

- Volcanic tuff aggregates have been used in ICC and IFC towers:
  - High concrete strength: 90+ MPa
  - High E-modulus value: 39+ GPa

By courtesy of: Alliance, CPA

To explore the use of volcanic rock as aggregates in concrete

- The volcanic tuff aggregate from tunnel / underground / cavern projects presents a Better utilization of local aggregate resources; and

- Offers engineering and environmental benefits by development of specialist high strength concrete of great potential to:
  1) Reduce structural member sizes,
  2) Use less concrete,
  3) Increase usable floor areas, and
  4) Improve structural performance.

Previous Study on ASR

- SCCT (2004) : Study on the Use of Volcanic Tuff Aggregates from Anderson Road Quarry in Concrete.

- Findings and recommendation:
  1. Volcanic tuff aggregates from Anderson Road Quarry can be used in concrete provided a minimum of 25% PFA is included;
  2. Volcanic tuff aggregates should not be used in concrete that will be exposed to aggressive marine conditions.

GEO's current study on mitigating ASR in concrete using supplementary cementitious materials

- Our objective:
  1. An indicative concrete design mix using SCM (GGBS, PFA, and CFS) to mitigate ASR in concrete with local volcanic aggregates; and
  2. A correlation between laboratory results and field measurements in the long term.

Supported by SCCT, HKCI, CPA, HKU, PolyU, Nanjing University of Technology, and Rilem Technical Committee AAA. (International Union of Laboratories and Experts in Construction Materials, Systems and Structures)

GEO's current study on mitigating ASR in concrete using supplementary cementitious materials

- Methodology

	Test Method	Test duration/remarks
1.	Petrographic examination Rilem AAR 1	Rock thin sections
2.	Ultra-accelerated Mortar Bar Test CS1:2010 (Rilem AAR 2)	14 days (extended to 3 months)
3.	Concrete Prism Test CS1:2010 (Rilem AAR 3)	52 weeks (to be extended to 2 years)
4.	Accelerated Concrete Prism Test (Rilem AAR 4)	20 weeks (extended to 26 weeks)
5.	Field works	Long term, say 10 years

GEO's current study on mitigating ASR in concrete using supplementary cementitious materials

Rilem AAR 1 - Petrographic examination

Thin section of rock

A petrographic microscope

To identify potentially reactive constituents in the rock

GEO's current study on mitigating ASR in concrete using supplementary cementitious materials

Rilem AAR2(UAMBT) , Rilem AAR3(CPT) & AAR4(ACPT):

- Basic concept behind:

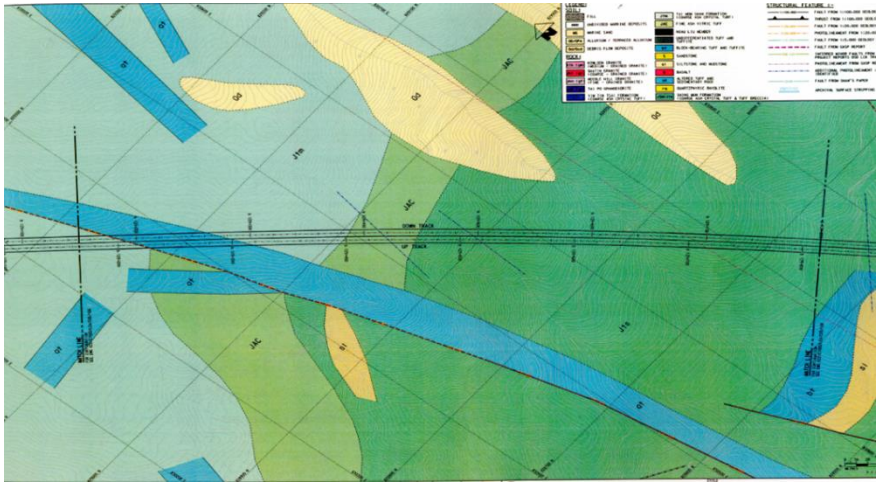
  To simulate the long term ASR effects by increasing the alkali level, temperature, and humidity to speed up the alkali-silica reaction (expansion) in the test specimens.

GEO's current study on mitigating ASR in concrete using supplementary cementitious materials

Materials:

- Norcem: Norway (alkaline content : 1.0)
- OPC: 青洲英泥(alkaline content : 0.5)
- GGBS: 廣東韶鋼
- PFA: CLP
- CSF: Elkem
- Volcanic Aggregates: (i) Anderson Road Quarry and
  (ii) Lam Tei Quarry
  (from XRL Tse Uk Tsuen to Shek Yam tunnel section)

Mix design by K. Wah and 144 concrete prism specimens produced in Alliance's laboratory in Hung Hom and subsequently tested in the laboratory of Fugro Technical Service Ltd.



GEO's current study on mitigating ASR in concrete using supplementary cementitious materials

Test Programme

Mix No.: PFA or GGBS replacement level	Norcem +PFA%	Norcem +GGBS%
M1: 0%	Norcem only as control	
M2: 35%	X	
M3: 30%+5%csf	X	
M4: 50%		X
M5: 70%		X
M6: 50%+5%csf		X

GEO's current study on mitigating ASR in concrete using supplementary cementitious materials

Study Programme

- Commencement: August 2014
- Petrographic examinations on rock samples: March 2015
- Ultra-Accelerated mortar bar tests (CS1:2010): May 2015
- Accelerated concrete prism tests (AAR4): June 2015
- Concrete prism tests (CS1:2010, AAR3): December 2015

Rilem AAR2, AAR3 and AAR4 Tests

- AAR2: Ultra-accelerated Mortar Bar Test

  To measure the expansion of the mortar bar after 14 days of immersion in 80℃ NaOH solution.

- AAR3: Concrete Prism Tests

  To measure the expansion of the concrete prism after 52 weeks under 38℃.

- AAR4: Accelerated Concrete Prism Tests

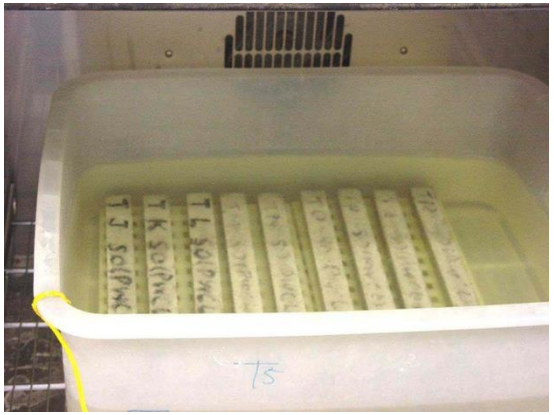
  To measure the expansion of the concrete prism after 20 weeks under 60℃, RH 90% or above.

- Long term on site exposure.

Accelerated mortar bar tests (CS1:2010, AAR2)

Making mortar bar

1 M NaOH solution



Oven, 80℃

Length measurement

Concrete Prism tests (CS1:2010, AAR 3)

Making concrete prism

Container for concrete prism

Humidity chamber, 38 ± 2℃

Test results – Rilem AAR 1 - Petrographic examination

- Volcanic Rock/Aggregate samples:
  1) Rock samples from Anderson Road Quarry: Alkali-reactive; and
  2) Aggregate samples from Lam Tei Quarry (from XRL Tse Uk Tsuen to Shek Yam tunnel section): Potentially alkali-reactive.

Interpretation of Results

- Ultra-accelerated Mortar Bar Test (AAR-2)

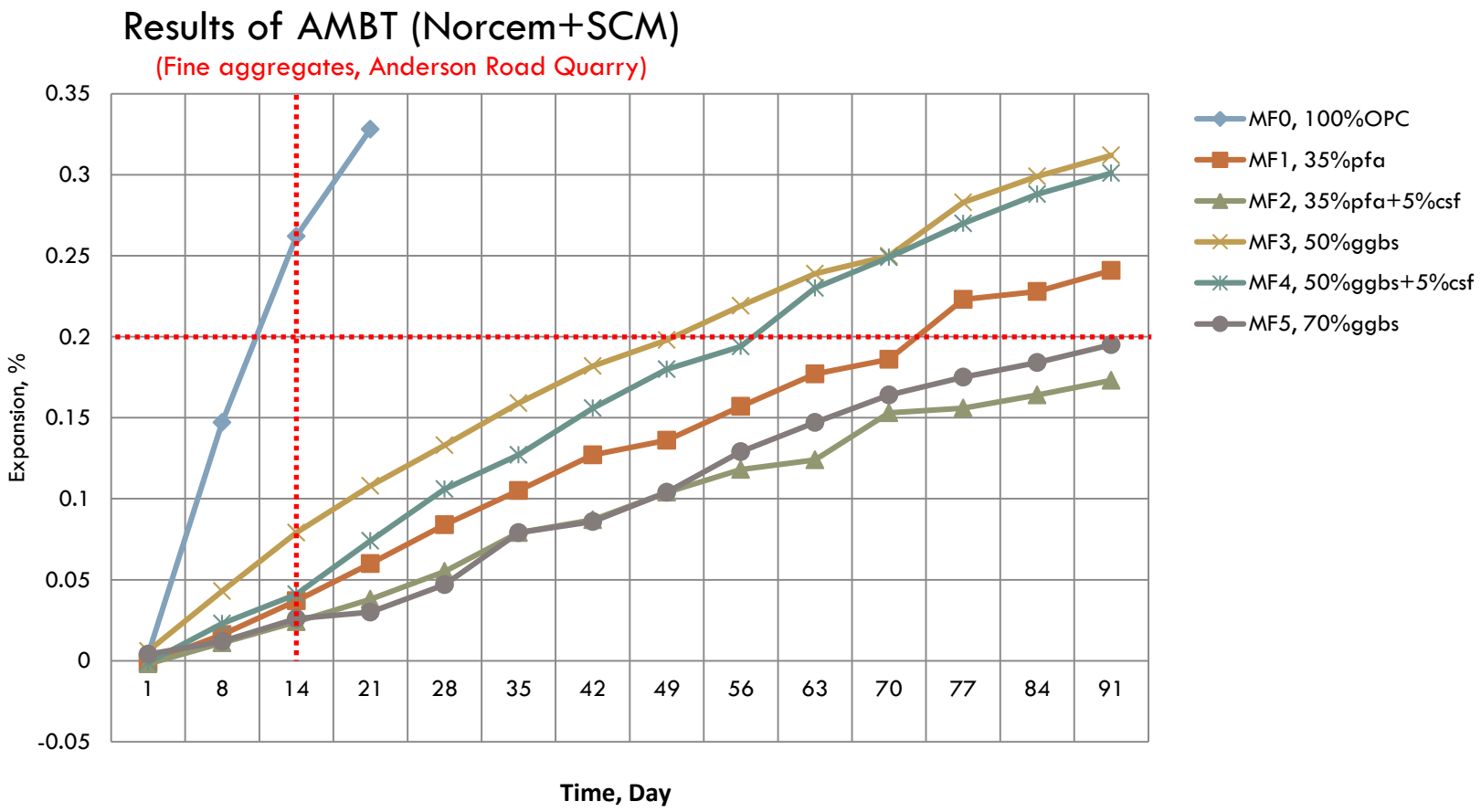
Expansion after 14 Days of Immersion in 1M NaOH solution (%)	Potential Reactivity
< 0.10	Non-reactive
0.10 to 0.20	Potentially reactive
> 0.20	Reactive

- Concrete Prism Test (AAR-3 and AAR-4)

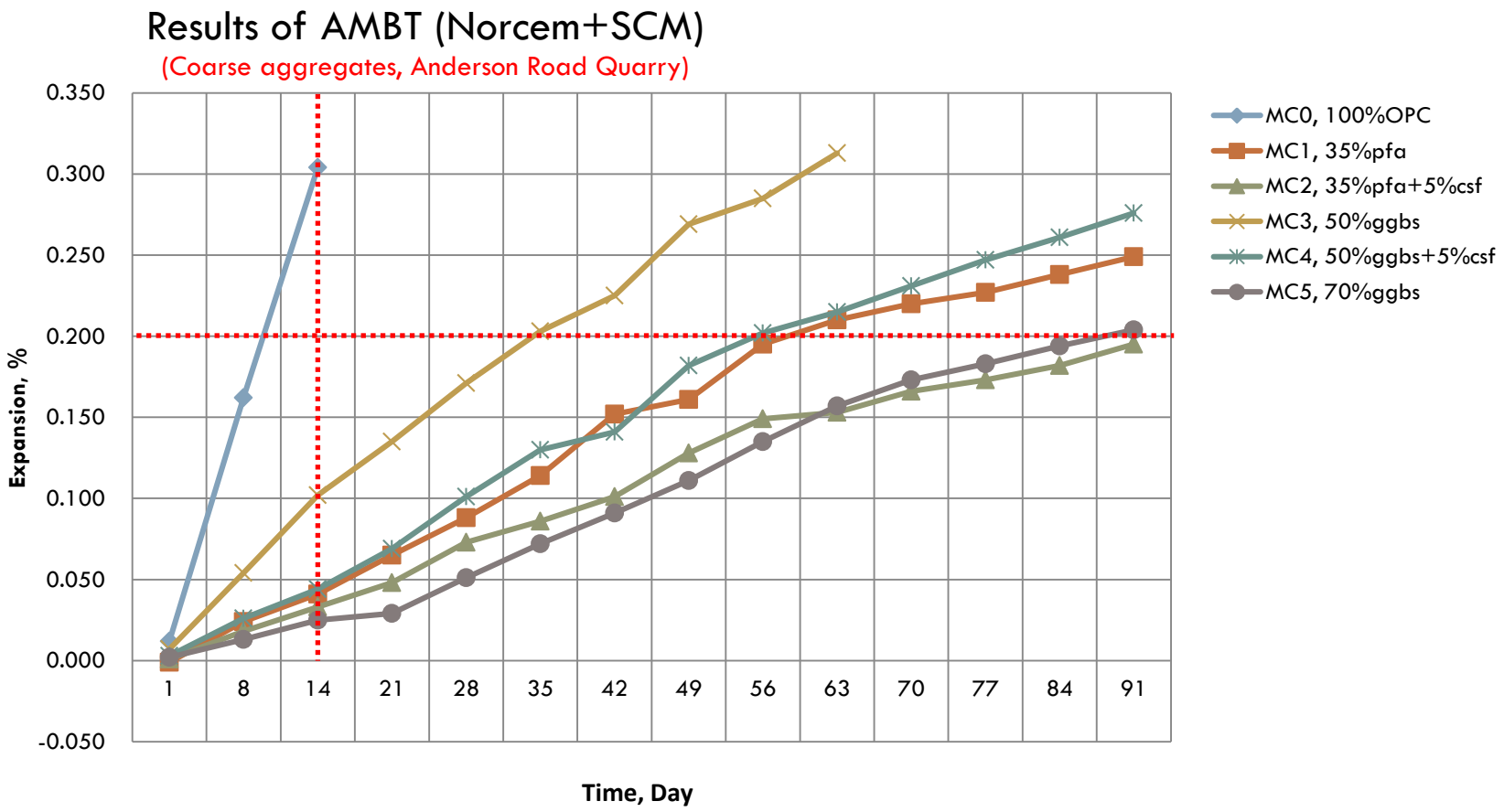
	Pass (No risk of deleterious ASR)*
AAR-3 :Expansion after 52 Weeks (%)	< 0.05 (<=0.04%)*
AAR-4 : Expansion after 20 Weeks (%)	< 0.03

*Civieltechnisch Centrum Uitvoering Research en Regelgeving (CUR) recommendation 89, the Netherlands

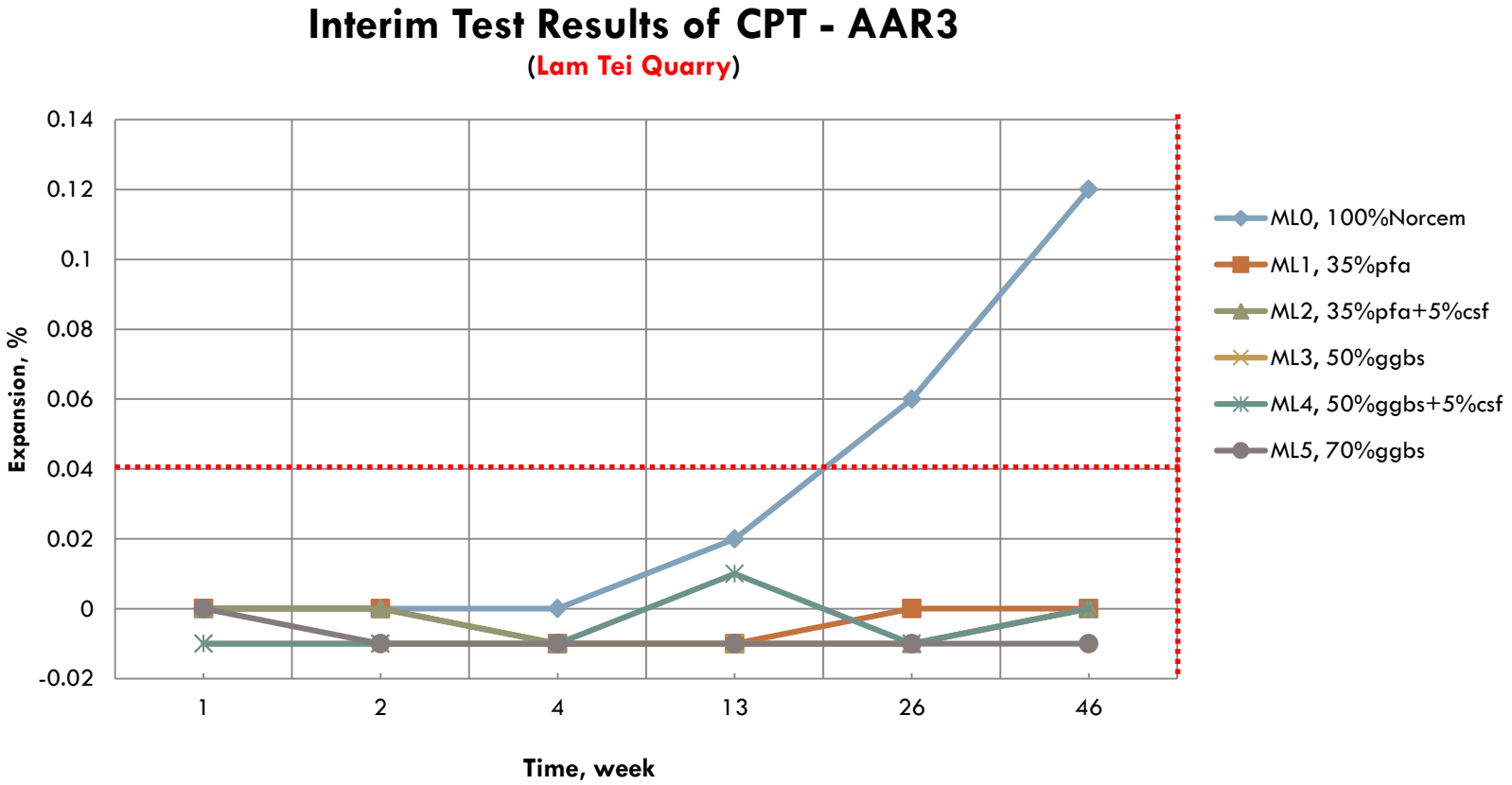
Test results – AAR2: AMBT



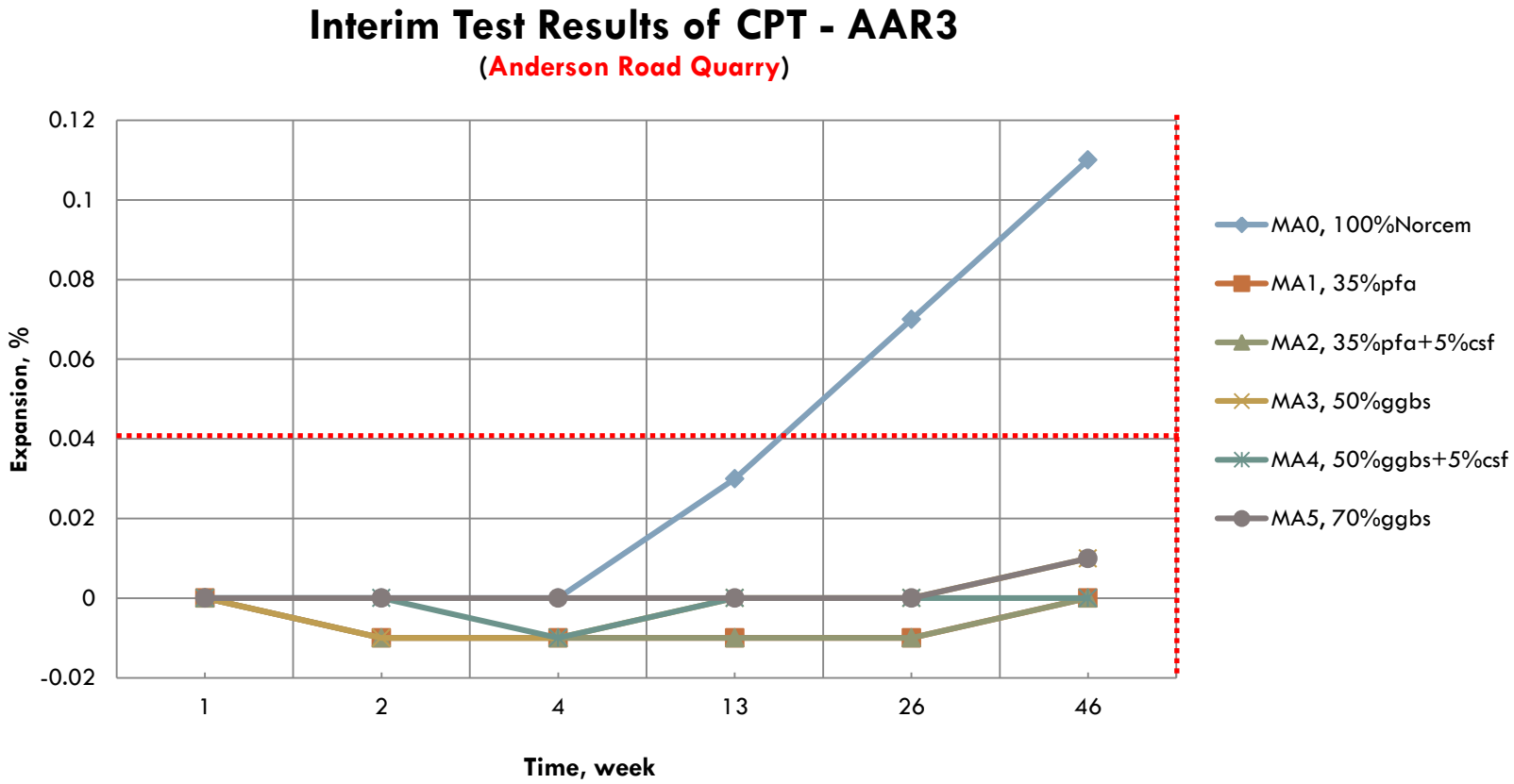
Test results – AAR2: AMBT



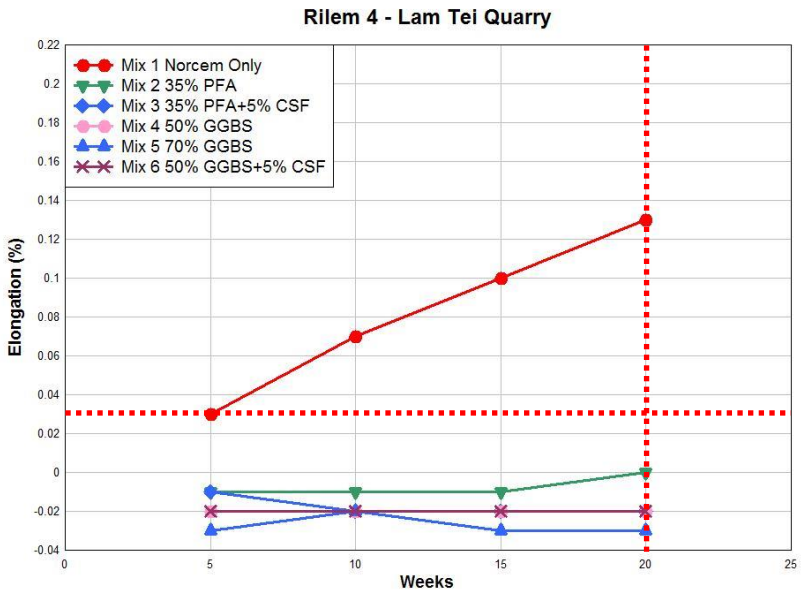
Test results (46 weeks) – AAR3: CPT (38℃)

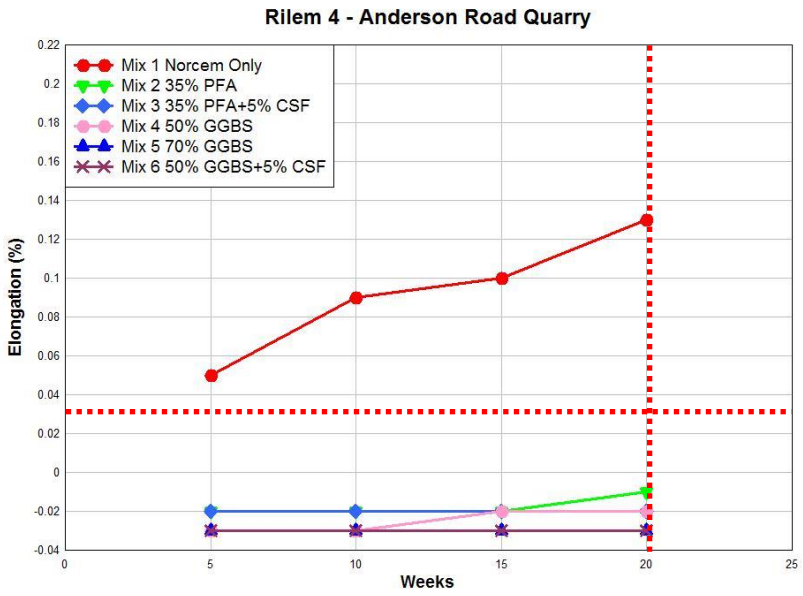


Test results (46 weeks) – AAR3: CPT (38℃)



Test results – AAR4: Accelerated CPT (60℃)





Closing Remarks

1. Use of local volcanic aggregates in concrete: Possible
2. Important engineering and environmental benefits
3. Indicative concrete mix design by using GGBS, PFA, and silica fume to mitigate ASR in volcanic aggregate concrete

In the long term,

- Find a correlation between laboratory test results and field measurements; and
- Draft guidelines/specification on the use of local volcanic aggregates for concrete production in Hong Kong.

Acknowledgements

- Hong Kong Concrete Institute
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- Prof. Duyou Lu (盧都友教授), Nanjing University of Technology
- RILEM Technical Committee (TC), AAA (2014 – 2019) : Avoiding Alkali Aggregate Reactions in Concrete - Performance Based Concept.

End of Presentation

Thank You!

Lam Tei Quarry

Mix	Compressive Strength 7-Day (MPa)	Compressive Strength 28-Day (MPa)	E-modulus (MPa)
ML0, 100%Norcem	69.25	78.20	-
ML1, 35%pfa	53.65	76.35	37750
ML2, 35%pfa+5%csf	58.55	77.80	35000
ML3, 50%ggbs	81.50	86.70	32250
ML4, 50%ggbs+5%csf	80.00	91.45	35500
ML5, 70%ggbs	69.90	81.35	34000

Anderson Road Quarry

Mix	Compressive Strength 7-Day (MPa)	Compressive Strength 28-Day (MPa)	E-modulus (MPa)
MA0, 100%Norcem	67.15	80.30	-
MA1, 35%pfa	58.20	81.70	47000
MA2, 35%pfa+5%csf	62.15	83.05	30500
MA3, 50%ggbs	82.75	93.55	38750
MA4, 50%ggbs+5%csf	80.45	95.50	34250
MA5, 70%ggbs	67.05	88.55	35750