GGBS-based Low Carbon Concrete Technologies for the Construction Industries of Hong Kong

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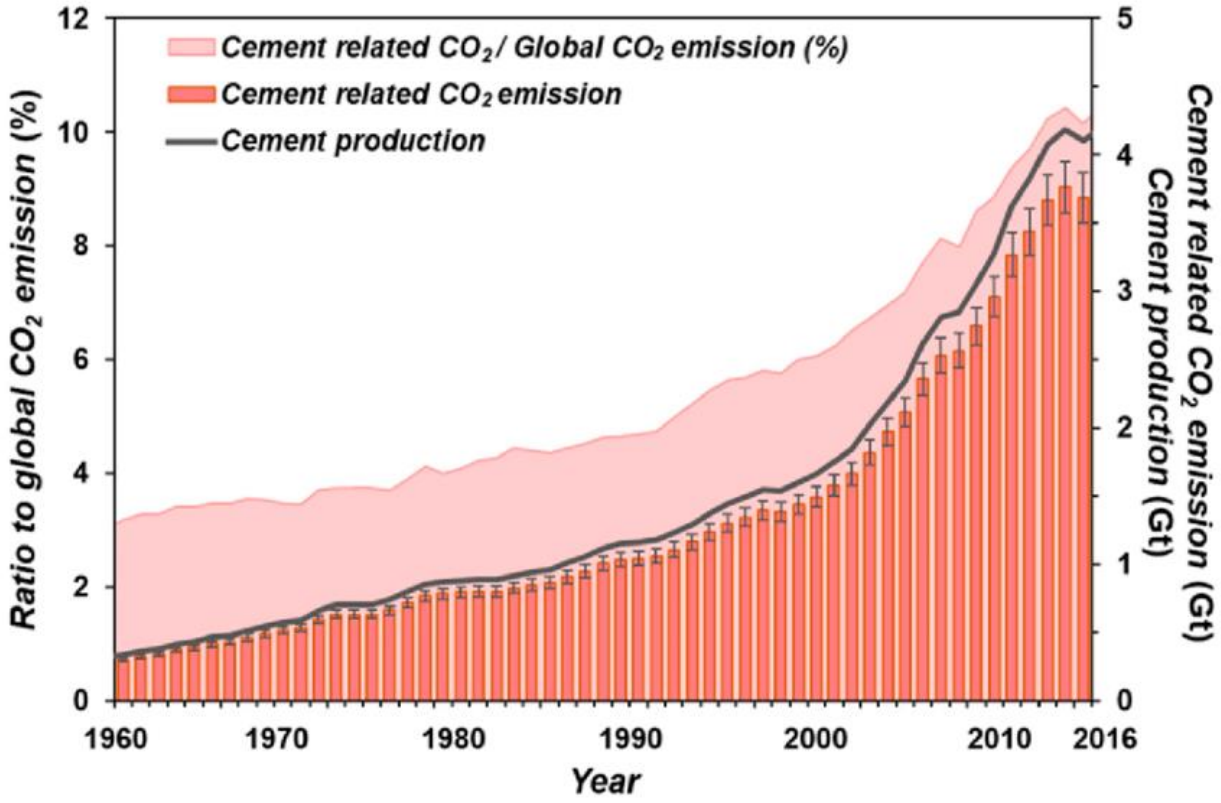
Nov 2022

Concrete and Carbon



8-10% Global CO_2 emission from cement production

Green concrete for lower carbon footprint buildings in HK

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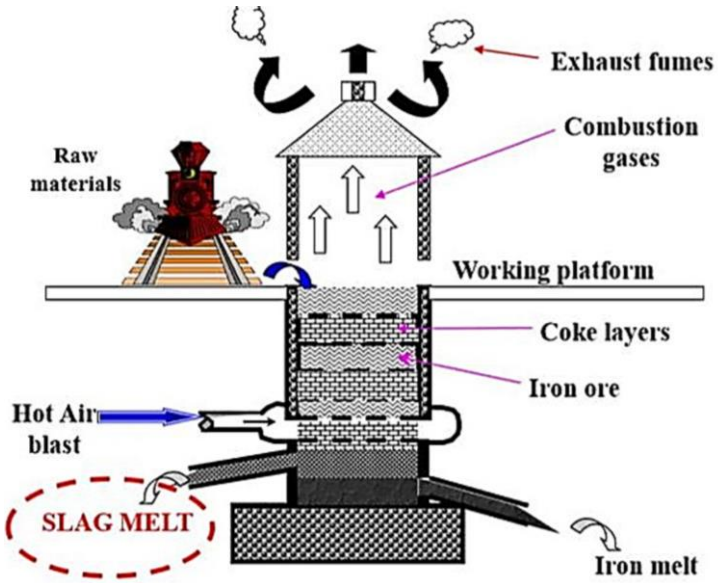
Partial OPC Replacement by GGBS

- GGBS: A green cementitious materials



Environmental issue	Measured as	Cement	GGBS
Climate change	CO_2 equivalent	0.95 *tonne*	0.066 *tonne*
Energy use	Primary energy	5000 *Mj*	1300 *Mj*
Mineral Extraction	Weight of ores	1.5 *tonne*	0
Water disposal	Weight of waste to be disposed	0.02 *tonne*	0
BRE Ecopoint Score	Eco-point	4.6	0.47

- ASTM C989: Standard Specification for Slag Cement for Use in Concrete and Mortars
- JIS A 6206 : 1997 Ground Granulated Blast-furnace Slag for Concrete
- BS EN 15167-1/2: Ground Granulated Blast Furnace Slag for use in concrete, mortar and grout
- GB/T 18046-2017 - Ground granulated blast furnace slag used for cement, mortar and concrete

Oversea applications of GGBS- concrete

Region	Projects & Usage	GGBS ratio (OPC replacement)
USA	Central Park Tower (76,000 m^3 concrete, 62-96 MPa)	30%-70% (Depending on application)
UK	Gatwick Airport station (3000 m^3 concrete)	70%
India	Bengaluru International Airport (50,000 t GGBS, for the runway)	40%
China	The Three Gorges Dam (28 million m^3) Cross-bay Bridge of Hangzhou Bay (35 km)	20-70%
Singapore	TUAS Undersea Cable Tunnel (23,520 t GGBS)	70%

Current Application Sweetspot of GGBS Concrete

- **Infrastructure & building near seashore**
- **Buildings requiring high performance, long life**
- **Underground tunnels, etc.**

GGBS cement producer

Application Examples of GGBS-concrete in HK

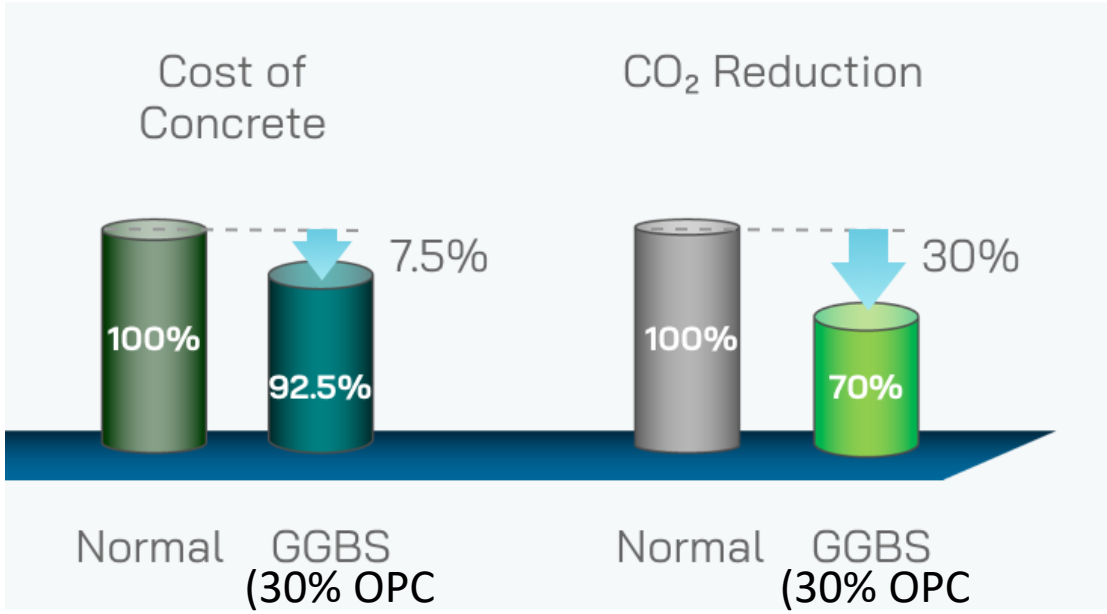
Project	Usage	GGBS ratio (OPC replacement)
Public Housing	15,000 units/yr Precast concrete facades	35%
Tsing Ma Bridge	The towers	65%
Stonecutters Island Bridge	Pile caps	60%
MTRC Infrastructures	Pile caps & piles in a landfill site	50-75%

- Recommended specification for reinforced concrete in the marine environment has been endorsed by SCCT in 2000
- Yet, wider applications are urging to further promote the use of GGBS concrete for low-carbon buildings

Pros & Cons of GGBS Concrete

Advantages in performance

- Improved workability with good pumpable and compaction characteristics
- Low heat of hydration
- High resistance to chloride penetration
- High resistance to sulphate attack
- Increased resistance to fire attack
- ……



Advantages in economy and environment

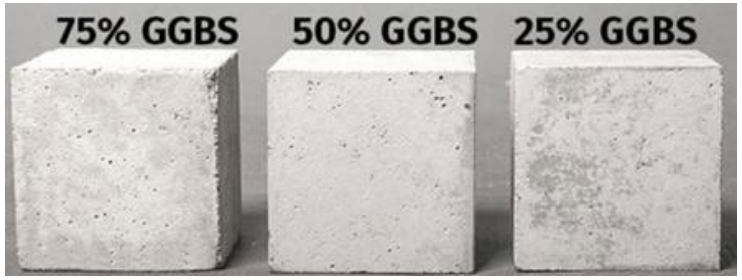
Disadvantages in performance

- Prolonged setting time at fresh stage
- Bleeding in the fresh state
- Lower early strength at initial hardening stage
- ……

Doubts from the Industries on Using GGBS-based Low-carbon Concrete

- Low early strength affecting demolding time?
- A “powdery” surface, and lower bonding strength?
- Bonding strength between existing OPC based normal concrete and new high volume GGBS concrete
- A concrete with lighter/different color, long term strength development
- Bleeding problem in the fresh state, so a specific admixture is to be developed

Our Strategy – To Provide a Holistic Study for the Industries



High volume GGBS

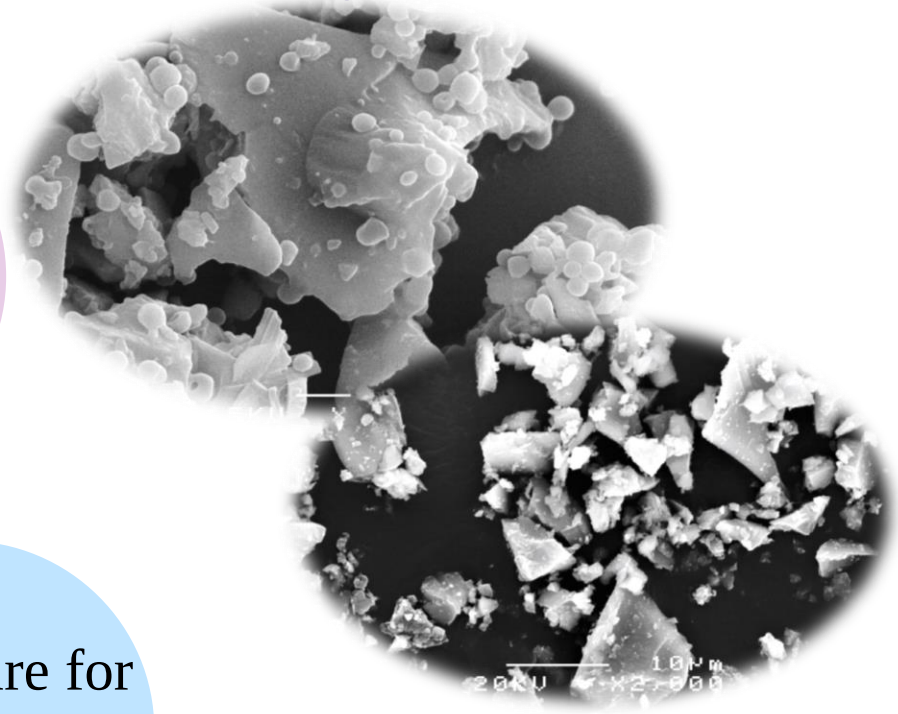
GGBS quality control

Low Carbon Concrete

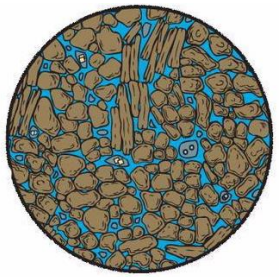
Mix and packing design for hardened properties

Admixture for fresh properties control

Satisfied concrete durability



Lower bulk density
Lower weight
More pore space



Higher bulk density
Higher weight
Less pore space

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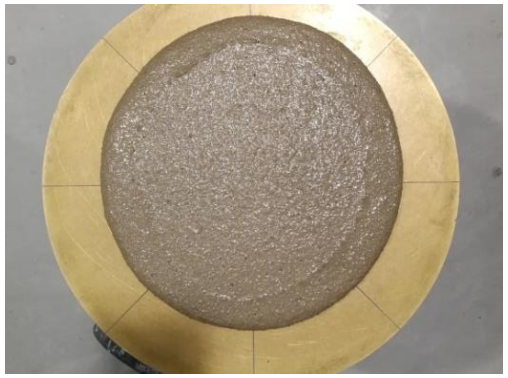
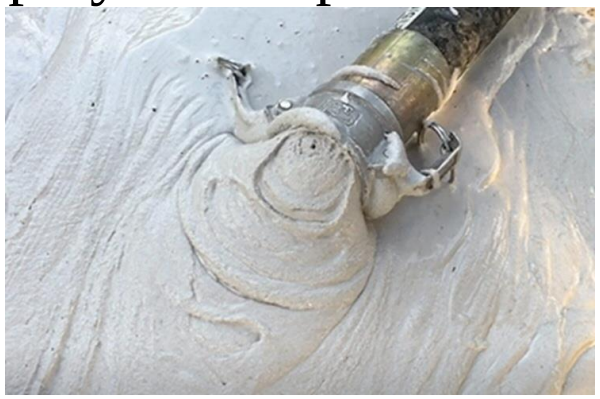
NAMI's Expertise in GGBS System

Geopolymerization



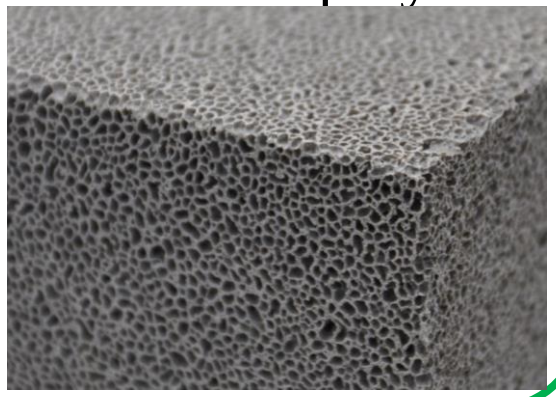
Dry-Mixed Repair Mortar

Sprayable Repair Mortar



Precast Concrete

Foamed Geopolymer



Others:

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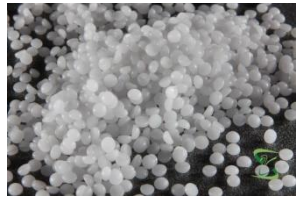
Geopolymerization Technology (GGBS >90%)

Functional admixtures

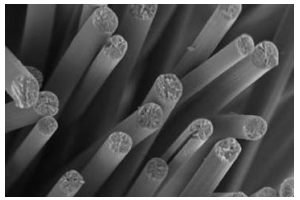
Hardener



Foaming agent, PCM, etc

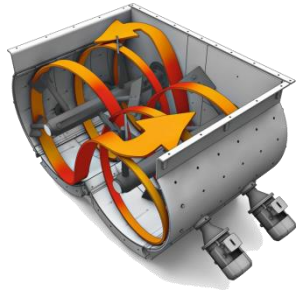
Fly ash, slag, metakaolin, fine sand, etc.

Cementitious materials & fine aggregate

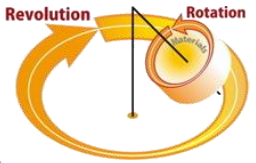


Superplasticizer, shrinkage compensator, etc.

Mineral admixtures



Optimization



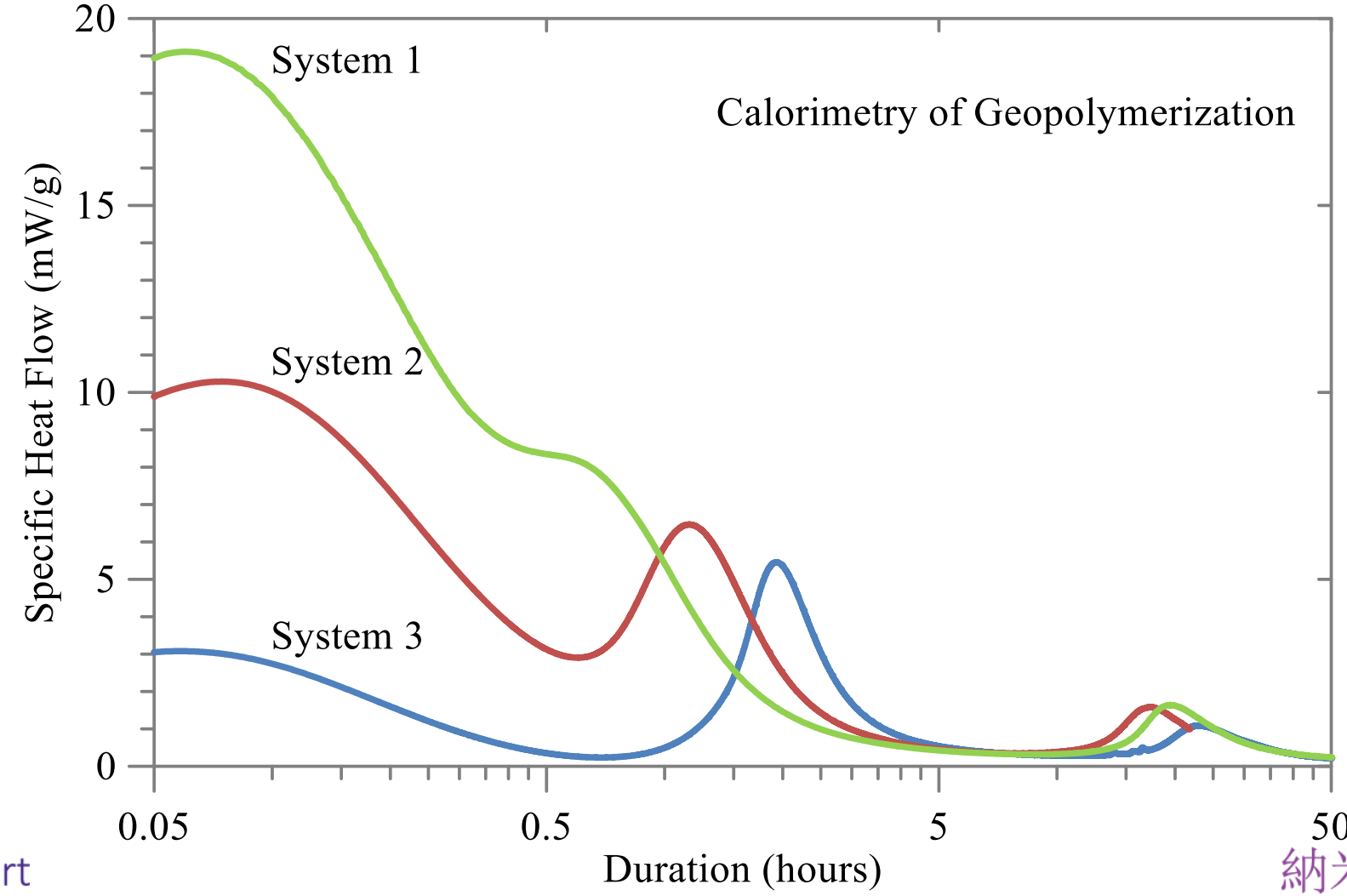
High-performance functional building material

Adjustable Performance

- Setting time & one-day strength optimized for different application scenarios
- One-day strength kept at ~20 MPa, setting time regulated from 30~180 min
- Setting time kept at ~90 min, one-day strength regulated from 20~40MPa

System Design

- Controlling setting & strength development

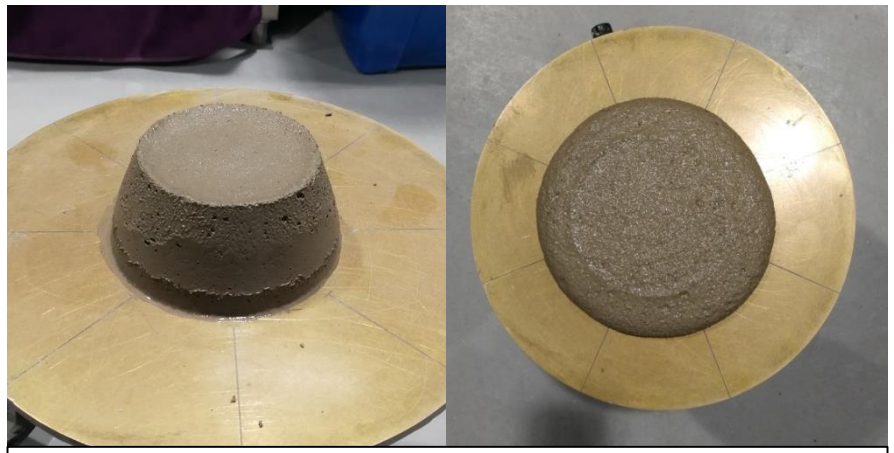


Admixtures for the GGBS System

- The three major performance areas in concern
  - Water usage reduction (strength & durability)
  - Workability enhancement (application scenarios)
  - Drying shrinkage minimization (consistency)

Water Reduction

- Water reduction in geopolymer mortar



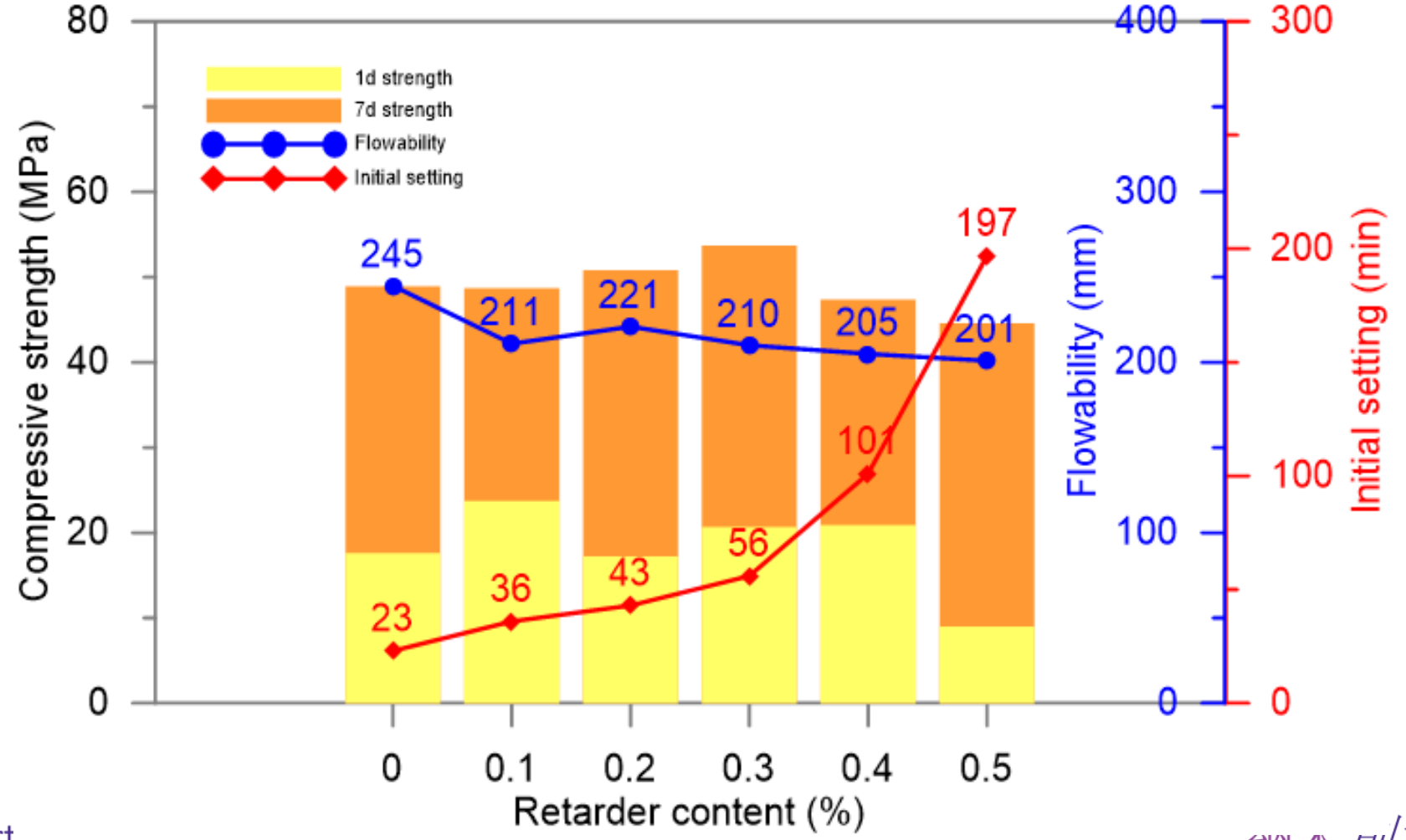
Control mortar

With water reducer

Specimen	Setting (min)	Flowability (mm)	Strength @1-d (MPa)
Control mortar	50	162	5.8
With water reducer	60	202	24.0

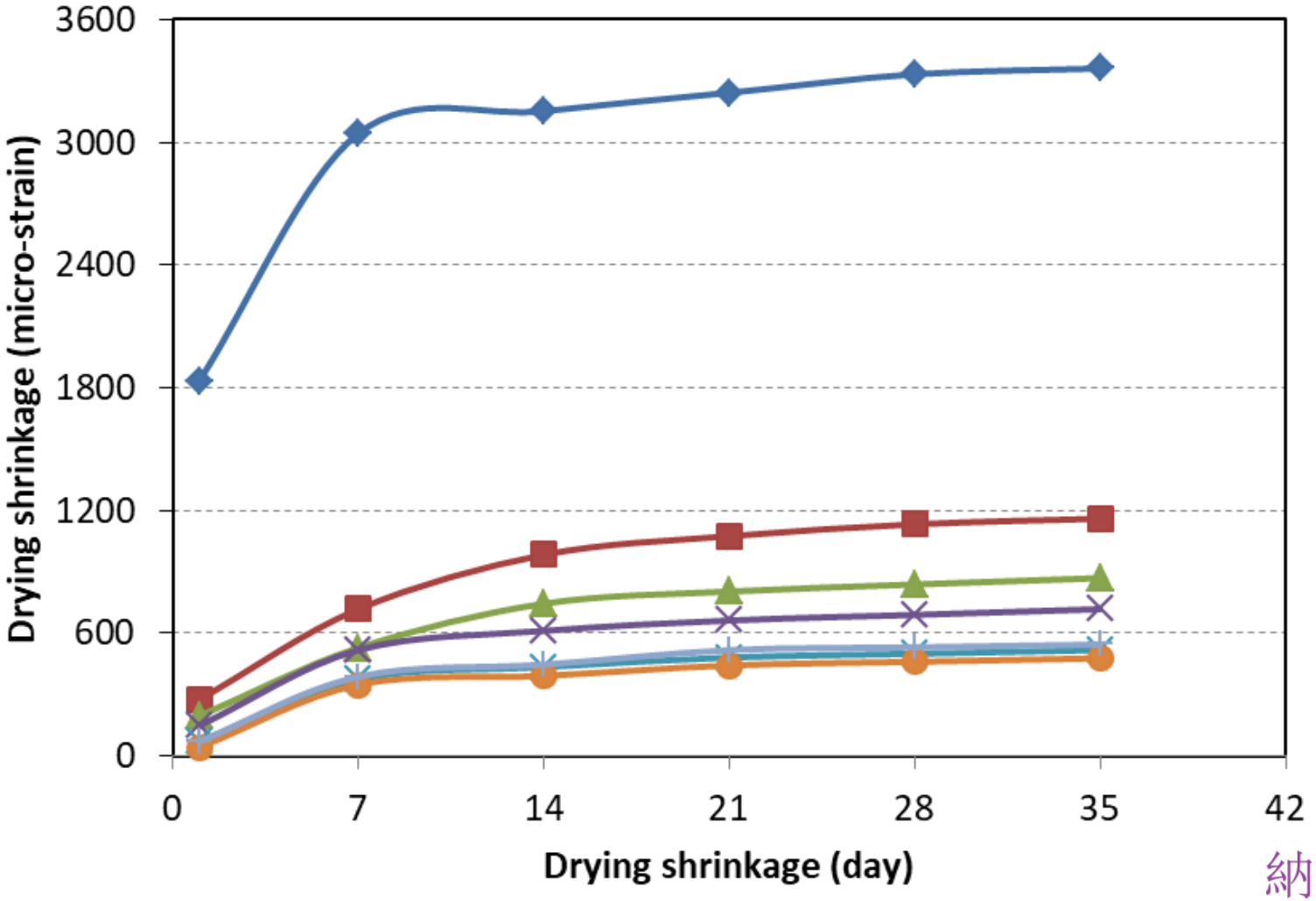
Retardation

- Retarder effects in geopolymer paste



Shrinkage Minimization

- Linear shrinkage measurement



Potential Applications

- Enhanced performance of OPC system blended with high volume of GGBS
- Raw materials control
- Geopolymer cement, mortar & concrete applications
- Precast geopolymer products
- Applications in thermal insulation & backfilling

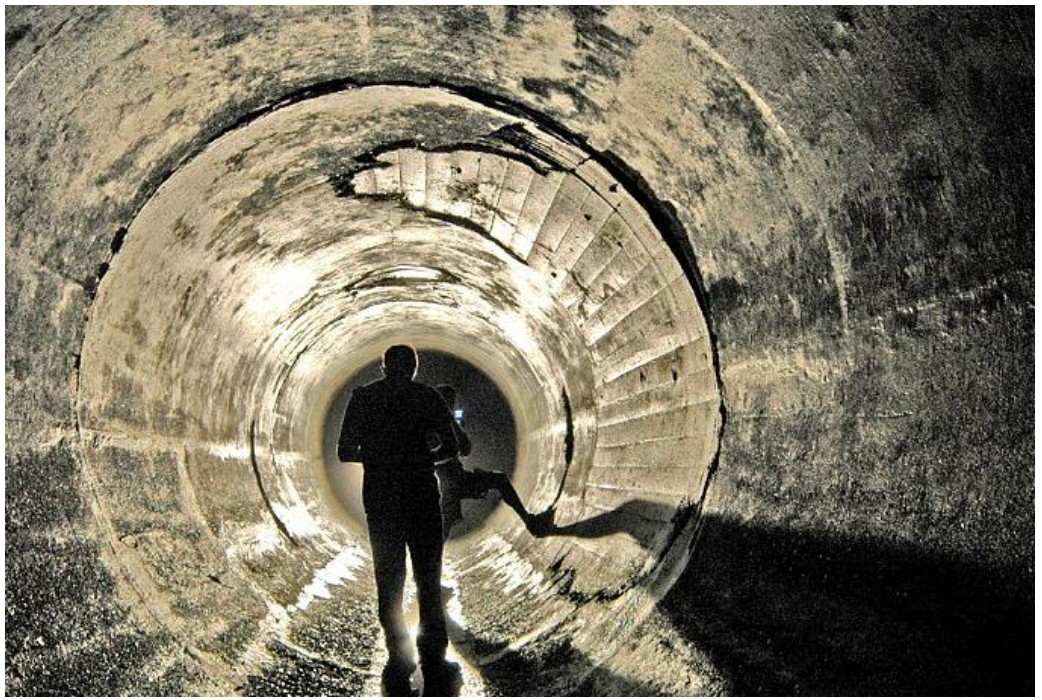
Dry-Mixed Repair Mortar

- OPC-free geopolymeric repair mortar
  - Setting time longer than 90 min
  - Wet density is ~2.0 g/cm^3
  - Compressive strength at 1-day > 20 MPa
  - Modulus of elasticity > 20 GPa
  - Weight loss (4 weeks in 5% H_2SO_4) < 5%
  - Chloride ion penetrability low
  - Drying shrinkage < 0.06%

Application Trials of Patch Repair

Partial Acid Submersion Test

- To imitate & accelerate the dynamic corrosive acidic environment inside a sewage pipe, with a 5% sulphuric solution of pH~0.5



Excellent Acid Resistance

- Dynamic partial submersion in 5% sulphuric solution (pH~0.5) for 14 days

Weight loss over 6%

Not measureable

Sprayable Repair Mortar

Adjustment for suitable rheology

Trials of Sewerage Repair

Setup for spraying

After spraying repair

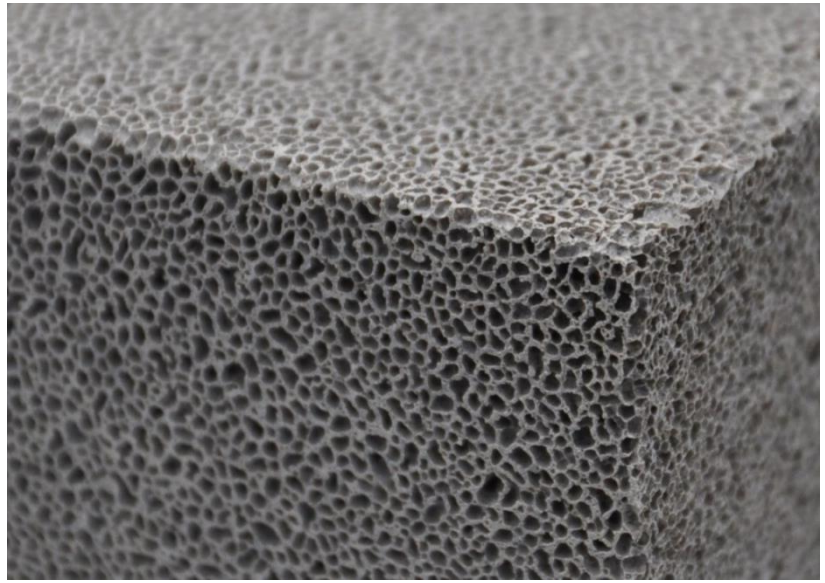
Foamed Geopolymer

- The engineered geopolymeric base prepared
- Foaming agent such as aluminum powder, CaH_2 or H_2O_2 etc. then added & well mixed
- A cellular structure formed within over time

Excellent for backfilling operations & thermal insulation works

Wide Range of Applications

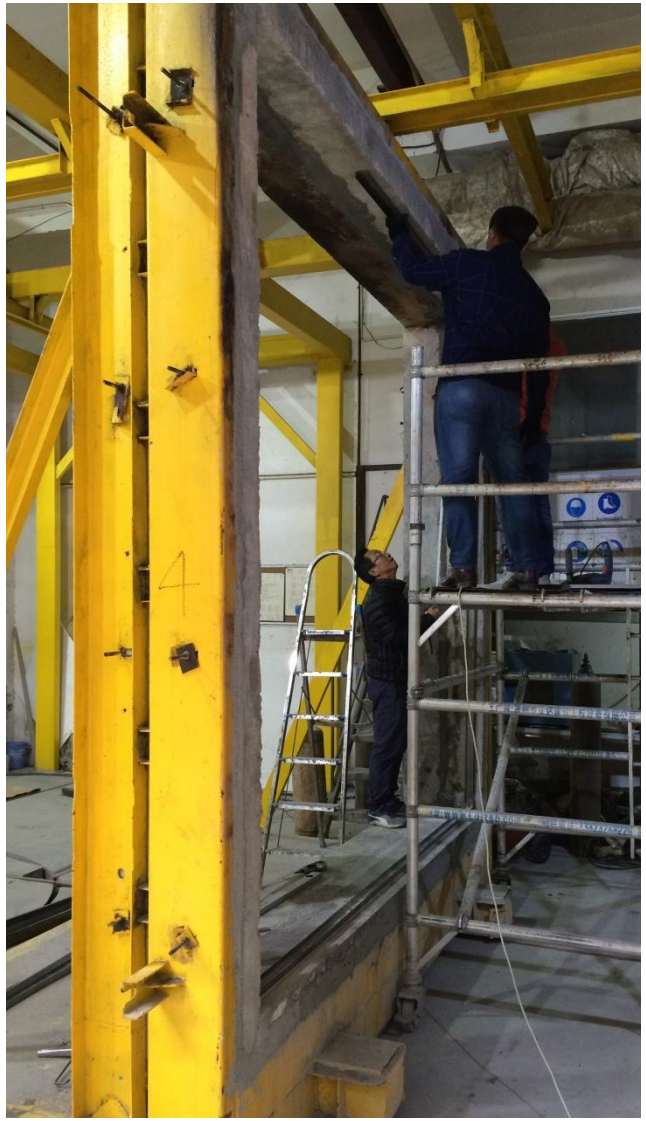
- Standard ultra-lightweight insulation core material (JC/T-2200)
  - Density < 180 kg/m^3
  - Compressive strength > 0.3 MPa
  - Thermal conductivity < 0.055 W/mK
- Geopolymeric blocks
  - Density 500~1,500 kg/m^3
  - Strength 3.5~35 MPa



Up-Scale Production Trial

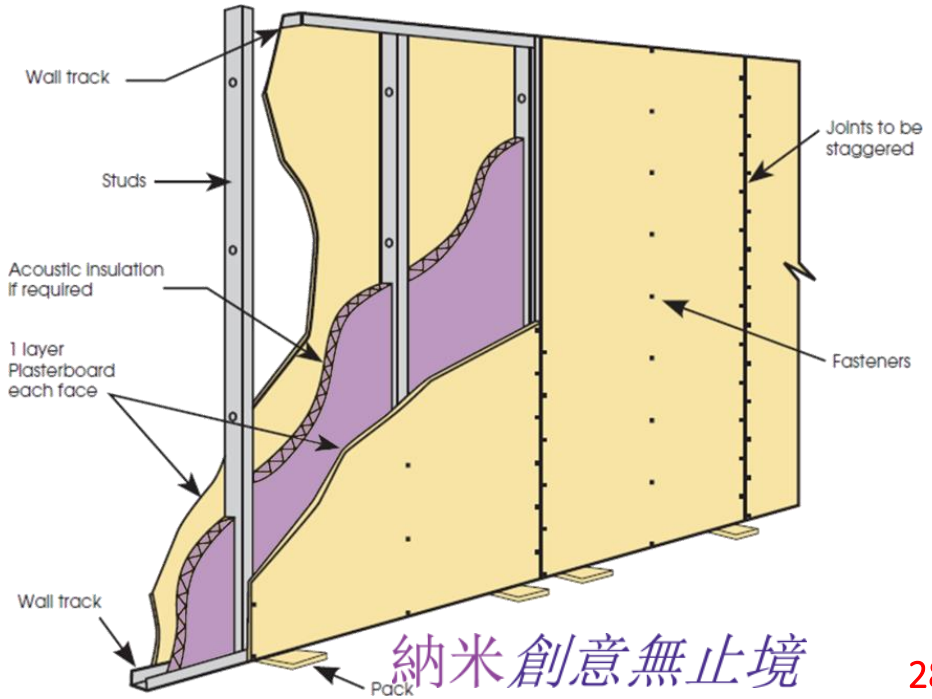
- Proper mixer & mixing procedures facilitating a homogeneous paste is critical

Installation of Dry Wall

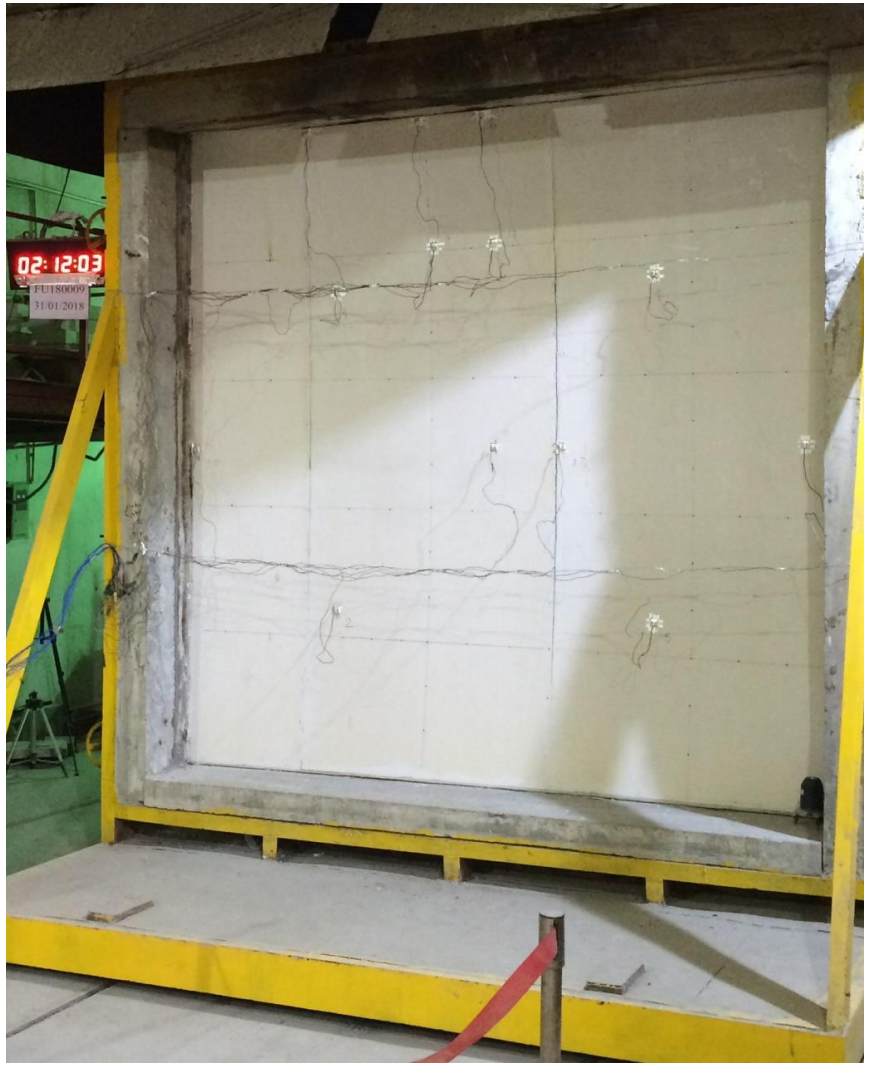


Fire Resistance Test

- For non-loadbearing wall to BS EN 1364-1
  - Ultra-lightweight thermal panel
    - Total 50 pcs each of 50 × 300 × 600 mm
  - Two layers of surface boards on both sides
    - Wall area of 10 m^2
  - Total wall thickness of about 85 mm
  - Total wall density of only 500 kg/m^3



FRR of 2-Hr Achieved



What's Next?

- Apart from some iconic examples of using GGBS concrete locally, ultra-high content of GGBS (>90%) has been researched & commercialized for drywall and repair mortar applications.
- Ready-mix, GGBS-based concrete can effectively reduce the carbon footprint of the concrete industry. Yet, we need a platform connecting the industries of the whole ecosystem to work together and demonstrate the viability of GGBS concrete for wide applications in HK.
- Focused application scenario(s) should also be identified to demonstrate the practicality & advantages of high contents GGBS concrete with reasonable performance and consistent supply by local concrete plants.
- This holistic study should be pursued as soon as possible!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