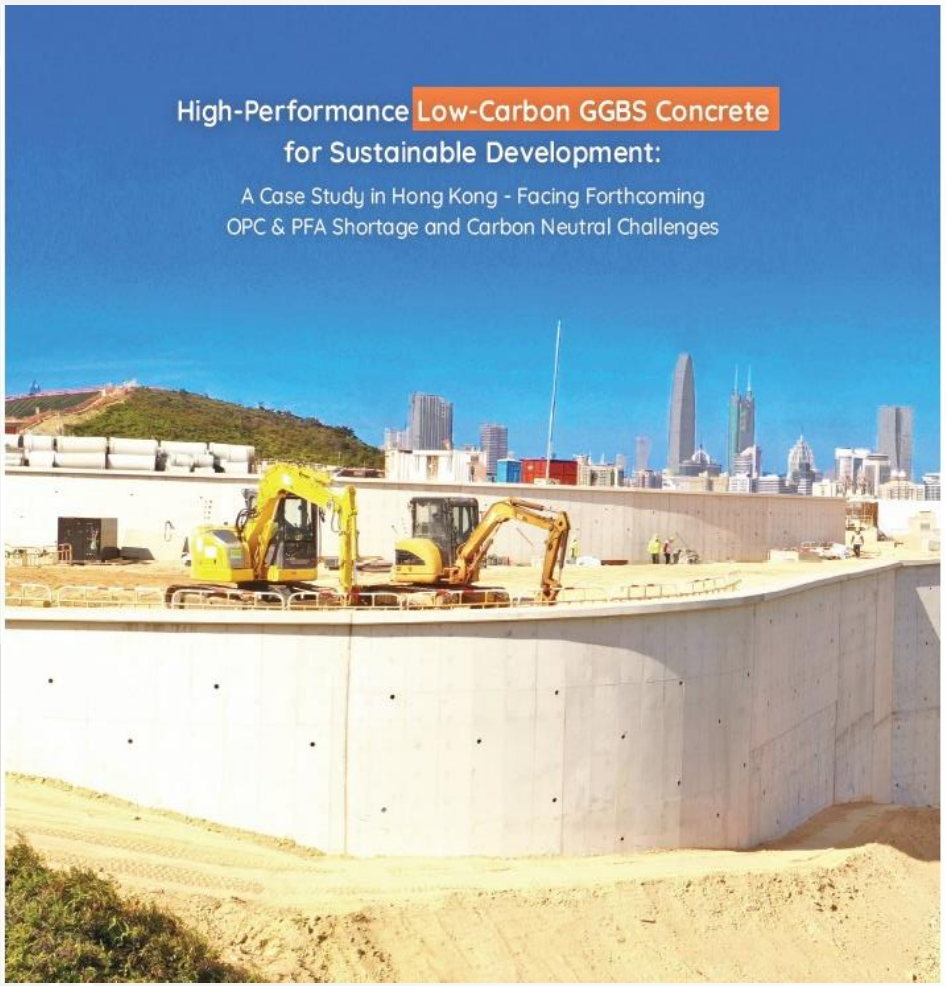

A Case Study in Hong Kong – High-performance Low-carbon GGBS Concrete for Sustainable Development

Content

- Background
- The use of GGBS concrete for Kong Nga Po Project
- Use of high-performance GGBS concrete for Kong Nga Po project and its comparison with PFA concrete
- Carbon footprint reduction
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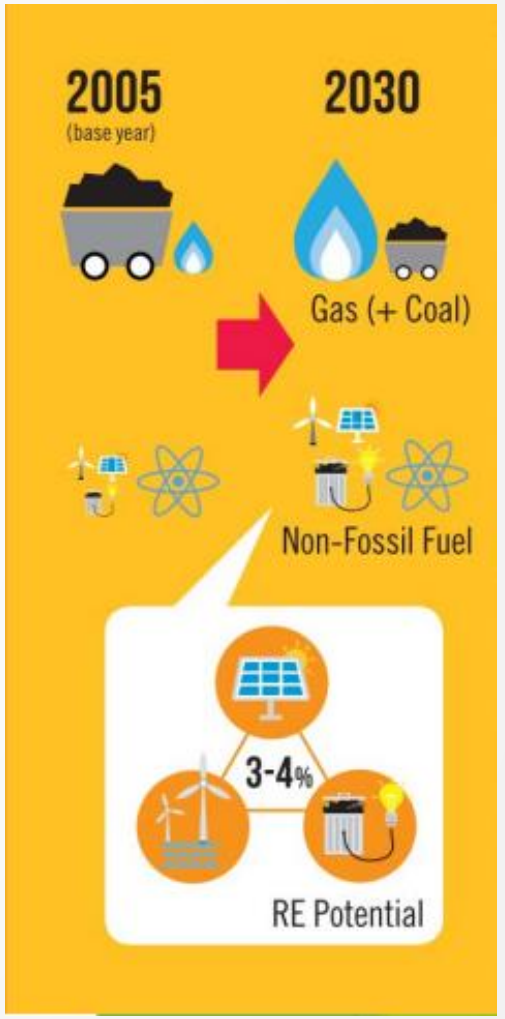
Background

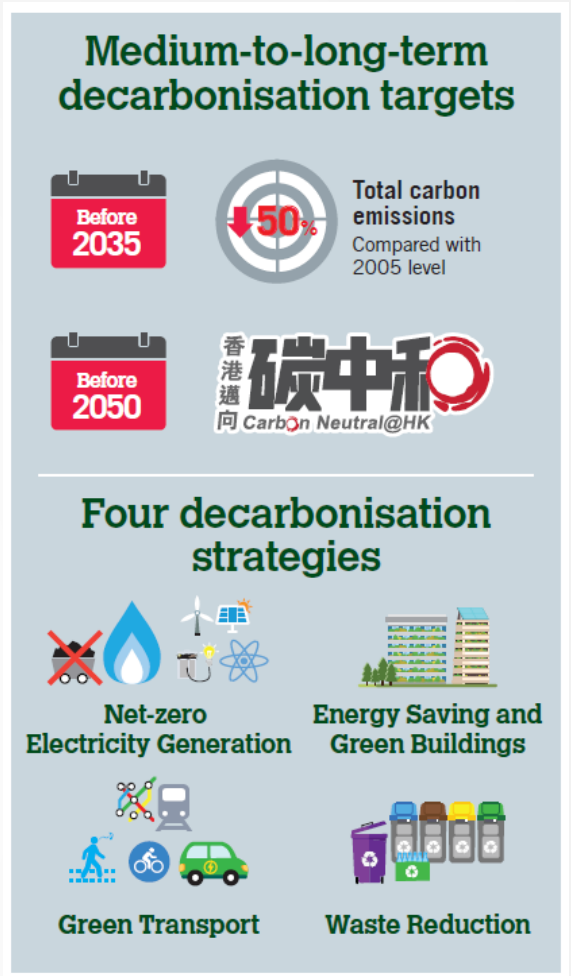
Challenges Ahead - Shortage of PFA

- PFA commonly used as a Supplementary Cementitious Material (SCM) to improve concrete performance
- PFA is a by-product of the combustion of pulverized coal in electricity generating stations
- Hong Kong is striving to promote the use of renewable/clean energy
- Gradually phase out coal as a source of power generation
- An estimated shortage of PFA amounting to more than 300 thousand tons in the years to come
- It is opportune to explore for alternative SCM, could Ground granulated blast-furnace slag (GGBS) be an alternative to PFA?



Government Incentives

- Cement production is the prime source of CO_2 emission
- In support of the HKSAR Government's environmental initiatives towards the goal of carbon neutrality before 2050
- Tally with CEDD's strategic plan on fostering innovation and advancing technical development in lowering carbon footprint
- Lack of data on using GGBS concrete in Hong Kong
- Trial use of newly-designed GGBS concrete mix



The use of GGBS concrete for Kong Nga Po Project

Kong Nga Po project

- **Project title:** Site Formation and Infrastructure Works for Police Facilities in Kong Nga Po

- **Client:** Civil Engineering and Development Department

- **Consultant:** AECOM Asia Co. Ltd.

- **Contractor:** Build King Construction Ltd.

Incentives to adopt GGBS concrete for Kong Nga Po Project

- Shortage of PFA

- Construction of stormwater storage tank
  - high workability
  - withstand chloride attack
  - mitigate thermal cracks

Overcoming low early strength of GGBS concrete
- new source of GGBS with relatively higher fineness and consistent quality
- newly available admixture

Use of high-performance GGBS concrete for Kong Nga Po project and its comparison with PFA concrete

Concrete supplier: Excel Concrete Ltd.

The Kong Nga Po project

Trial of GGBS concrete

Compliance criteria of plant trial:

- All values for slump during the period between minimum and maximum times for discharge of concrete: within ±20% or 20mm (whichever is the greater) of the designed value
- Values of slump at the estimated maximum time for discharge of concrete: ≥ than 80% of the slump at the estimated minimum time for discharge of concrete
- Maximum bleed at 1 hour: ≤ 0.5% of the net mixing water
- Maximum total bleed, until cessation of bleeding: ≤ 1.5% of the net mixing water
- The average 28-day strength of pairs of cubes taken from the same sample:

  ≥ specified characteristic strength + 14MPa

The Kong Nga Po project

Trial of GGBS concrete

Results of plant trial carried out with Kong Nga Po project:

Day of trial	Test items	1	2	3	4	5	6	Average Strength (MPa)
1	Slump test result (mm)	210	215	205	200	190	195	89.6
	28 days cube density (kg/m^3)	2440	2440	2430	2430	2420	2420	
	28 days cube result (MPa)	89.0	91.6	90.5	88.4	88.6	89.3	
2	Slump test result (mm)	220	220	205	195	210	210	104.1
	28 days cube density (kg/m^3)	2430	2430	2430	2440	2440	2440	
	28 days cube result (MPa)	105.1	104.6	100.0	106.7	103.1	105.3	
3	Slump test result (mm)	215	215	200	200	200	200	94.9
	28 days cube density (kg/m^3)	2440	2440	2440	2440	2430	2420	
	28 days cube result (MPa)	95.2	96.0	91.5	97.5	95.4	93.7	

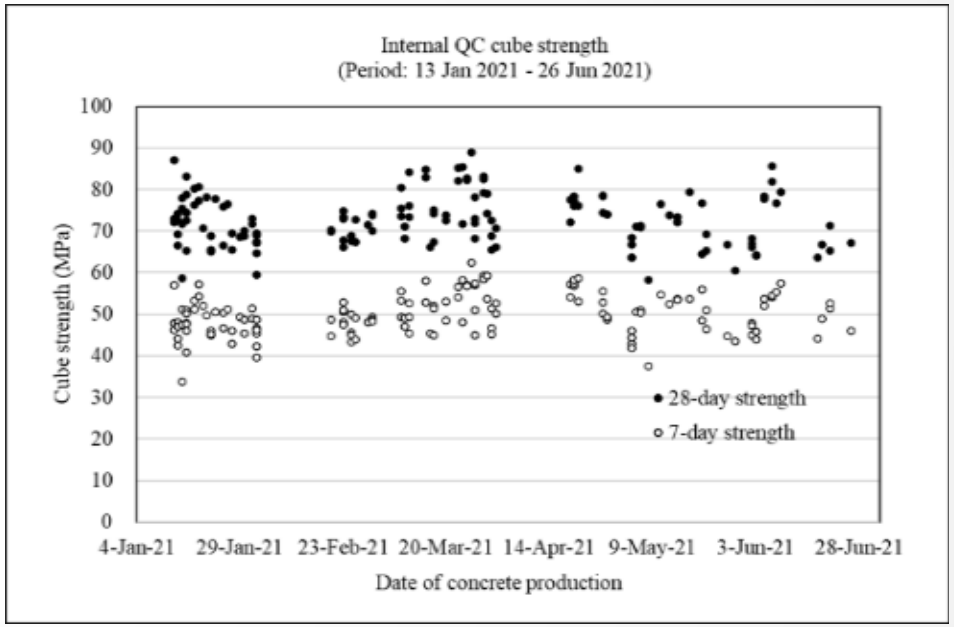
- Bleeding of concrete (ASTM C232): 0%
- Setting time of concrete (ASTM C403), on average

  - initial: 550 mins (9hrs 10 mins)
  - final: 660 mins (11 hrs)

Use of high-performance GGBS concrete for Kong Nga Po project (Excel's internal QC cube results)

Variations of 7-day and 28-day cube strengths:

- 7-day strength: varied within the range of 33.8MPa to 62.4MPa
- 28-day strength: varied within the range of 58.3MPa to 88.9MPa
- Moving-40 standard deviation of 28-day strength: varied from 3.86MPa to 6.82MPa



Variations of 7-day and 28-day cube strengths during production

Use of high-performance GGBS concrete for Kong Nga Po project and its comparison with PFA concrete

Comparison of GGBS (50%) concrete and PFA (35%) concrete (Excel's internal QC results)

- Concrete strength
- Workability control and production efficiency
- On-site measures during concreting
- Concrete appearance

	C40/20 GGBS (50%) W/C 0.40	C40/20 PFA (35%) W/C 0.38
7-day compressive strength	33.8MPa to 62.4MPa	37.4MPa to 56.7MPa
28-day compressive strength	58.3MPa to 88.9MPa	52.8MPa to 83.2MPa
Moving-40 S.D.	3.86MPa to 6.82MPa (Prod. Period: Jan 2021 to Jun 2021)	6.51MPa (36 results) (Prod. Period: Jan 2021 to Jun 2021)
Workability control	No particular difficulty	No particular difficulty
Production efficiency	Slightly better than PFA concrete	Poorer
On-site measures during concreting	Similar to PFA concrete	--
Concrete appearance	Refer to next photo	

Use of high-performance GGBS concrete for Kong Nga Po project and its comparison with PFA concrete

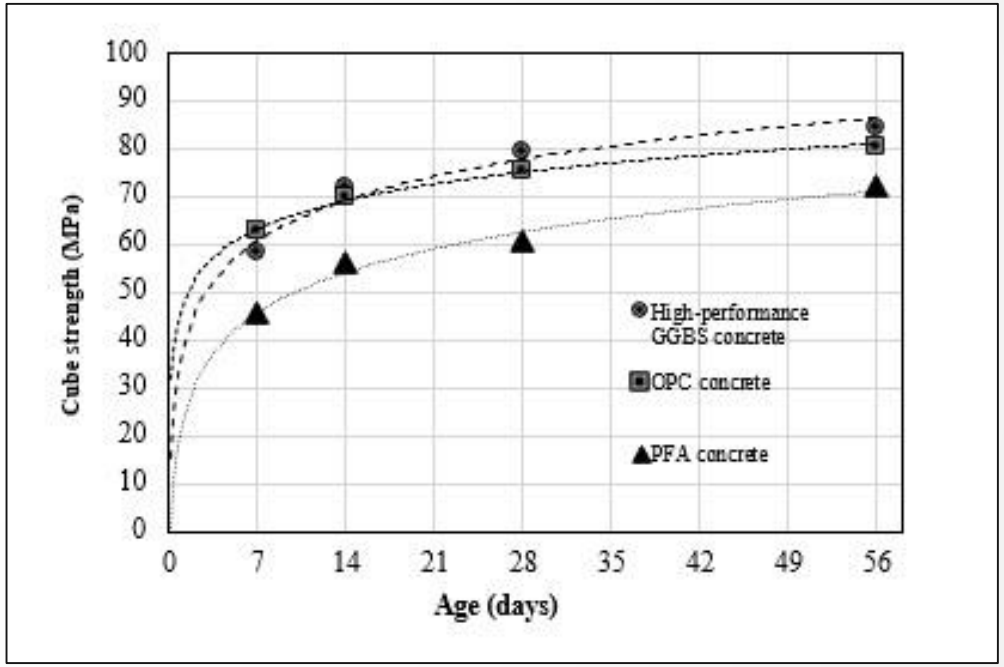
Colour variation between GGBS and PFA Concrete

Use of high-performance GGBS concrete for Kong Nga Po project and its comparison with PFA concrete

Strength development of OPC (100% OPC), PFA (25%) and GGBS (50%) concrete (W/C ratio 0.40):

- 7-day to 28-day strength ratios of OPC, PFA and GGBS concrete: 0.829, 0.748 and 0.734 respectively

- The 28-day strength of GGBS concrete: higher than OPC concrete and PFA concrete by 5% and 31.6% respectively

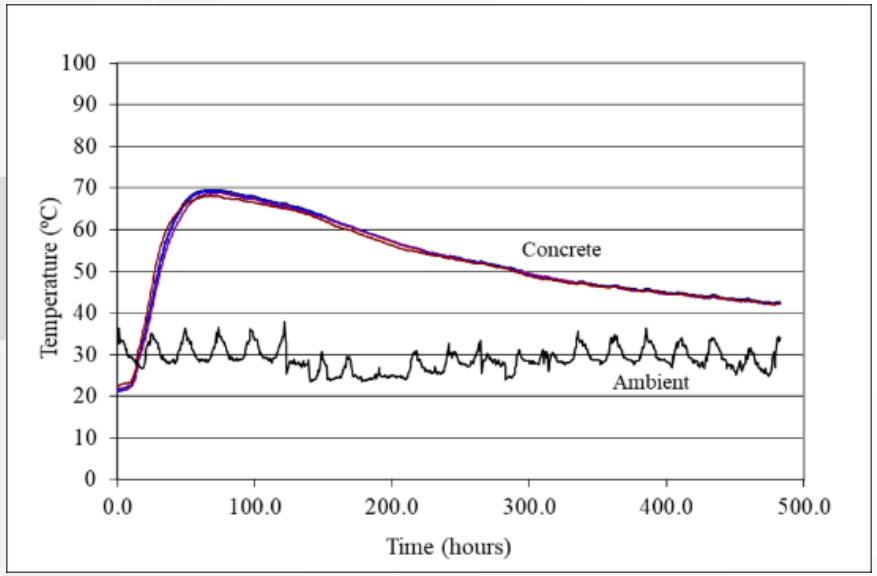


Strength development of OPC, PFA and GGBS concretes

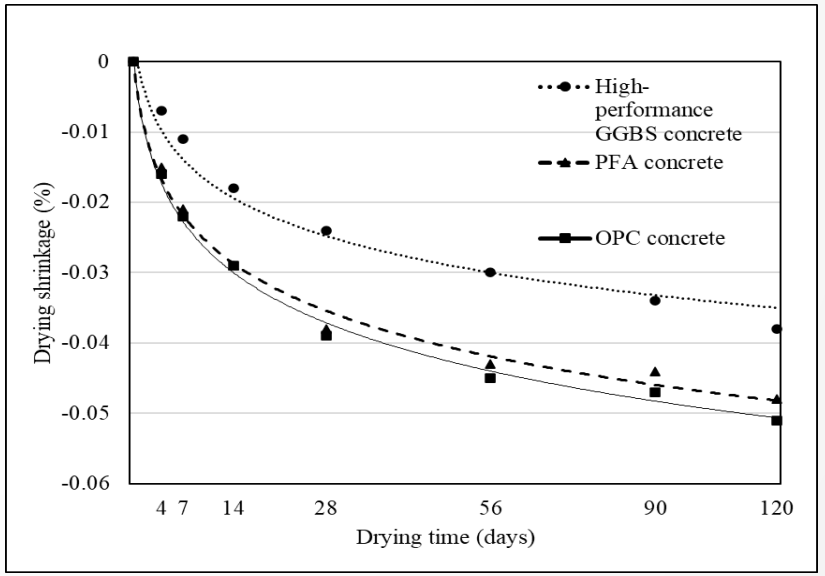
Use of high-performance GGBS concrete for Kong Nga Po project and its comparison with PFA concrete

TRET and shrinkage test results of the GGBS concrete:

- Maximum temperature rise: 48.5ºC reached at 73 hours (~15% lower than that of OPC concrete with similar grade strength and workability)
- Shrinkage strain after 120 days of drying: 380 micro-strain (~25% lower than that of ordinary OPC concrete, 21% lower than that of ordinary PFA concrete)



TRET results of the GGBS concrete



Shrinkage test results of the OPC, PFA and GGBS concretes

Use of high-performance GGBS concrete for Kong Nga Po project and its comparison with PFA concrete

RCPT results of the GGBS concrete:

- Mean value of total charge passed: 1271 Coulomb (specimens from the TRET block), 1207 Coulomb (additional specimens from 150mm concrete cube)
- Both are “low” according to ASTM C1202 or Hong Kong Construction Standard CS1
- Lower than that of OPC concrete by more than 50% (usually about 3000 Coulomb)

Use of high-performance GGBS concrete for Kong Nga Po project and its comparison with PFA concrete

Colour and surface finish of the GGBS concrete:

- More consistent and whiter colour than the PFA concrete
- No efflorescence on the surfaces

External Surface of U-trough

External Surface of Retaining Wall

General View of Surface Appearance

Carbon footprint reduction

Carbon footprint reduction

- CIC Carbon Labelling Scheme for Construction Products – Ready Mixed Concrete
- Verified by Hong Kong Quality Assurance Agency (HKQAA)
- Reduction of carbon footprint when compared with OPC concrete of same grade:

  Grade 40:

  - 18.3% by addition of PFA
  - 47.5% by addition of GGBS

  Grade 45:

  - 24.7% by addition of PFA
  - 47.4% by addition of GGBS

CO_2e of various concrete mixes produced in Excel's Lam Tei Plant	
Concrete mix	CO_2e (kg CO_2e/m^3)
Grade 30 OPC concrete	339.77
Grade 30 PFA concrete	256.60
Grade 40 OPC concrete	390.32
Grade 40 PFA concrete	318.92
Grade 40 GGBS concrete	204.88
Grade 45 OPC concrete	410.57
Grade 45 PFA concrete	309.27
Grade 45 GGBS concrete	215.96
Grade 60 OPC concrete	432.05
Grade 60 PFA concrete	310.36
Note: All GGBS concretes have a GGBS content of 50%	

Carbon footprint reduction

- CO_2 emission of Grade 45 OPC concrete = 410.57 × 50000 = 20,529 ton
- CO_2 emission of Grade 45 50% GGBS concrete = 215.96 × 50000 = 10,798 ton
- Total reduction in CO_2 emission = 20,529 – 10,798 = 9,731 ton

Conclusion

- GGBS is a good substitute of both OPC and PFA
- No particular difficulty in the quality control
- Have better early strength than PFA concrete
- Temperature rise during curing: around 15% lower than OPC concrete
- Drying shrinkage: around 20-30% lower than OPC and PFA concretes
- RCPT total charge passed: below 50% of that of OPC concrete.
- Significant carbon footprint reduction compared to OPC and PFA concrete

The End