HKSAR Standing Committee on Concrete Technology
Annual Concrete Seminar 2011
(23 March 2011)

Ground Granulated Blastfurnace Slag in Concrete

粒化高爐礦渣粉混凝土

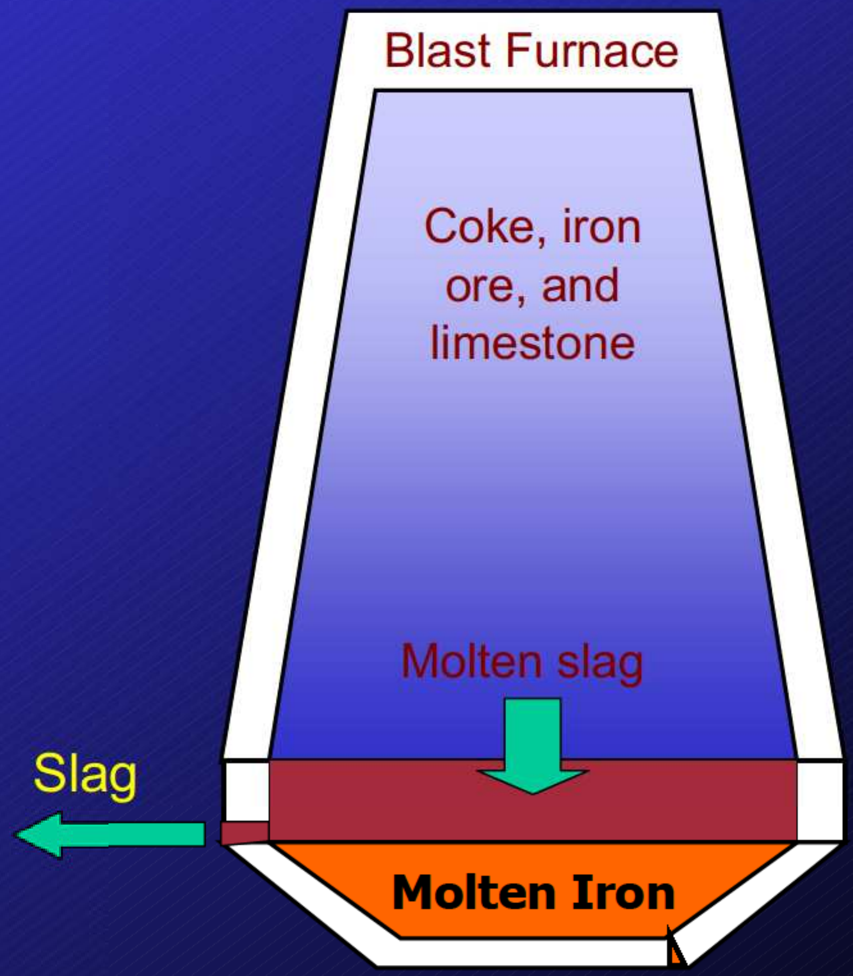
By Ir. H D Wong, E/PWCL
Standard & Testing Division
Geotechnical Engineering Office
Civil Engineering and Development Department

Outline

1. What is Ground Granulated Blastfurnace Slag (GGBS)?
2. Use of GGBS in Construction Projects
3. Benefits of Using GGBS in Concrete
4. Physical and Chemical Properties of GGBS
5. Typical Levels of Replacement
6. Study by Public Works Central Laboratory
7. Conclusions

What is Ground Granulated Blastfurnace Slag (GGBS)?

SLAG: A by-product of steel manufacturing industry.



What is Ground Granulated Blastfurnace Slag (GGBS)?

Slag

Granulated Blast Furnace Slag (GBFS) → **Further processed into a fine powder to produce Ground Granulated Blastfurnace Slag (GGBS)**

Air Cooled Blast Furnace Slag → **Slag aggregates, used in road construction**

What is Ground Granulated Blastfurnace Slag (GGBS)?

GBFS: Further milled into a fine powder of GGBS with required fineness.

In China, according to GB, there are three grades of GGBS: Grade S75: 300 m2/kg, Grade S95: 400 m2/kg; and Grade S105: 500 m2/kg.

Source: CPA

Typical Chemical Composition of GGBS, OPC and PFA (% by weight)

Oxides	GGBS	OPC	PFA
SiO_2	35	20	48
CaO	40	65	2
Al_2O_3	12	6	30
MgO	8	2	2
Fe_2O_3	0.5	4	8
Others	5	4	10

Typical Physical Properties of GGBS *vs* OPC

	GGBS	OPC
Colour	White	Grey
Density	2.9	3.2
Fineness	450 m^2/kg	340 m^2/kg

History of Using GGBS in Concrete

Discovered in Germany, 1862 and first commercially produced in 1865.

GGBS was used in Europe and North America for over 100 years.

Currently, GGBS has been widely used, particularly in China, Japan, Europe and USA.

Worldwide use of GGBS in construction projects

USA

- World Trade Centre in New York: 40% GGBS replacement.

- Minneapolis Airport, the airfield pavements: 35% GGBS replacement.

- Atlanta's Georgia Aquarium: 20% to 70% GGBS replacement.

Worldwide use of GGBS in construction projects

China:

- The Three Gorges Dam, concrete volume around 28 million m^3
- Cross-bay Bridge of Hangzhou Bay, length 35km

Currently in China, the GGBS replacement level is in general 40%.

Worldwide use of GGBS in construction projects

The Tsing Ma Bridge and Stonecutters Island Bridge, 60-70% GGBS.

Source: HyD

Benefits of Using GGBS in Concrete

Sustainability and Improve Durability of Concrete

- Reuse the iron industrial byproduct
- Avoid disposal
- Reduce ordinary cement in concrete
- Improving the durability of concrete

Benefits of Using GGBS in Concrete

Impact to environment from the manufacture of one tonne of products

Environmental issue	Measured as	Cement	GGBS	PFA
Climate change	CO_2 equivalent	***0.95 tonne***	***0.066 tonne***	***0.025 tonne***
Energy use	Primary energy	***5000 Mj***	***1300 Mj***	***NA***
Mineral extraction	Weight of ores quarried	***1.5 tonne***	***0***	***0***
Waste disposal	Weight of waste to be disposed	***0.02 tonne***	***0***	***0***
BRE Ecopoint Score	Eco-point	***4.6***	***0.47***	***0.07***

Sourced from published papers by D. Higgins and Building Research Establishment

Benefits of Using GGBS in Concrete

Environmental impacts for 1 tonne of concrete

Impact	100% PC	50 % ggbs	30% fly ash
Greenhouse gas (CO_2)	142 kg (100%)	85.4 kg (60%)	118 kg (83%)
Primary energy use	1,070 MJ (100%)	760 MJ (71%)	925 MJ (86%)
Mineral extraction	1,048kg (100%)	965 kg (92%)	1007 kg (96%)

Source: Denis Higgins

Benefits of Using GGBS in Concrete

Improve Concrete Durability

- Reducing the permeability of concrete.
- Mitigating sulphate attack.
- Mitigating Alkali-silica Reaction.
- Reducing thermal stress in mass concrete.

Typical Level of Replacement

- USA: 25% to 50% for high strength concrete.
- Canada: 50% for control of ASR and 60% to 85% for mass concrete.
- China: 30% to 40% for optimum strength performance.
- Hong Kong: 60% - 75% for normal applications and 60% - 90% for low heat applications.

National Standards

- BS EN 6699: 1992 (1992). Specification for ground granulated blastfurnace slag for use with Portland cement
- BS EN 15167-1: 2006 (2006). Ground granulated blastfurnace slag for use in concrete, mortar and grout. Definitions, specifications and conformity criteria
- GB/T 18046-2008 (2008). 用于水泥和混凝土中的粒化高炉矿渣粉.

Study by Public Works Central Laboratory

FINAL REPORT ON DURABILITY AND STRENGTH DEVELOPMENT OF GROUND GRANULATED BLASTFURNACE SLAG CONCRETE

GEO REPORT No. 258

Peter W.C. Leung & H.D. Wong

GEOTECHNICAL ENGINEERING OFFICE
CIVIL ENGINEERING AND DEVELOPMENT DEPARTMENT
THE GOVERNMENT OF THE HONG KONG
SPECIAL ADMINISTRATIVE REGION

http://www.cedd.gov.hk/eng/publications/geo_reports/geo_rpt258.htm

Study by Public Works Central Laboratory

Aim: to study

- The early age and long term strength development of concrete containing various proportions of GGBS under normal curing
- The effect of curing temperature on strength development
- The effect of curing duration on strength development
- The effect of GGBS content on durability
- The influence of silica fume and the source of GGBS

Study by Public Works Central Laboratory

Programme:

- Concrete Grade: 35 and 45
- Mixes: A OPC concrete mix, 4 GGBS concrete mixes with replacement levels: 30%, 50%, 70% and 80%, 3 GGBS mixes with 5% silica fume
- Source of GGBS: 東潤牌 and 廣東韶鋼
- Target slump: 100 mm – 200 mm
- Test ages: 3 days. 7 days, 28 days, 56 days, 182 days and 364 days
- Concrete panel of 1 m^3 to test peak temperature and durability of concrete

Study by Public Works Central Laboratory

Curing Environment	Description
E1	27°C water curing for 27 days after demoulding and then air curing
E2	27°C water curing for 7 day after demoulding and then air curing
E3	27°C water curing for 3 day after demoulding and then air curing
E4	Air curing
E5	10°C water curing for 3 days after demoulding and followed by 20°C water curing for 24 days and then air curing
E6	50°C water curing for 7 days after demoulding and followed by 27°C water curing for 20 days and then air curing
E7	75°C water curing for 7 days after demoulding and followed by 27°C water curing for 20 days and then air curing

Notes:
(1) The air cured cubes were stored in a room where the temperature was maintained at 20±5°C.
(2) The mean relative humidity of the room over the test period was within 75%±10%.

Study by Public Works Central Laboratory

Study Results:

Early age (3-day and 7-day) strength development under normal curing

- At 3 days, the GGBS mixes can achieve about 40% (control mix, 60%) of the strength of the OPC mix at 28 days
- At 7 days, the GGBS mixes can achieve about 60% (control 75%) of the strength of the OPC mix at 28 days
- Between 7 days and 28 days, rate of strength gain of GGBS mixes > control mix
- At 28 days, both GGBS mixes and control mix achieve target strength

Study by Public Works Central Laboratory

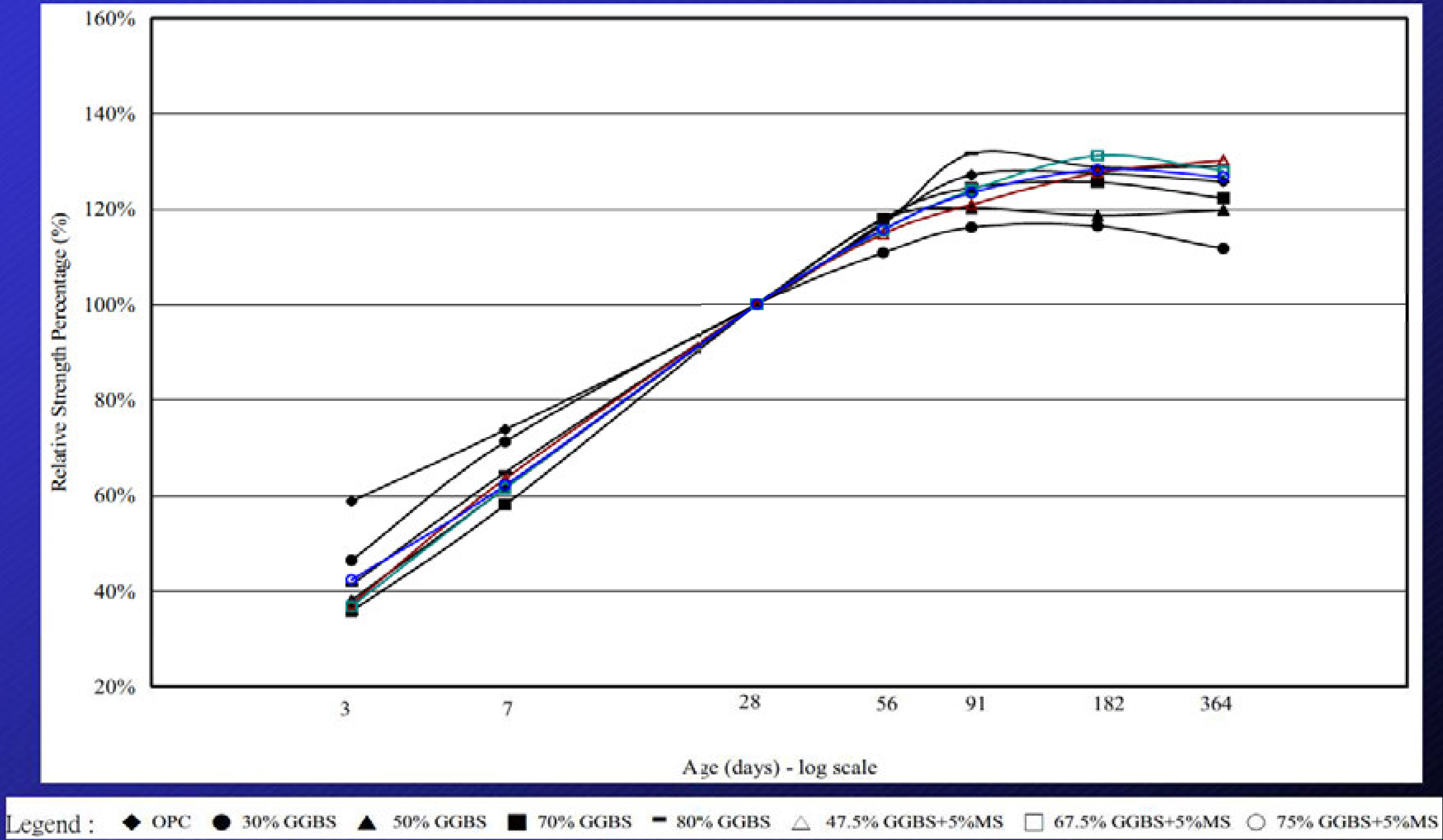
Study Results:

Long Term (28, 90, 182 and 364 days) strength development under normal curing

- Generally, GGBS concretes gain further strength (12-29%) after 28 days on wards
- There were cases of strength regression in some of the GGBS concrete mixes, in particular the mixes with 30% GGBS replacement

Study by Public Works Central Laboratory

Typical Strength Development of OPC and GGBS Concrete Cured under Normal Curing



Study by Public Works Central Laboratory

Study Results:

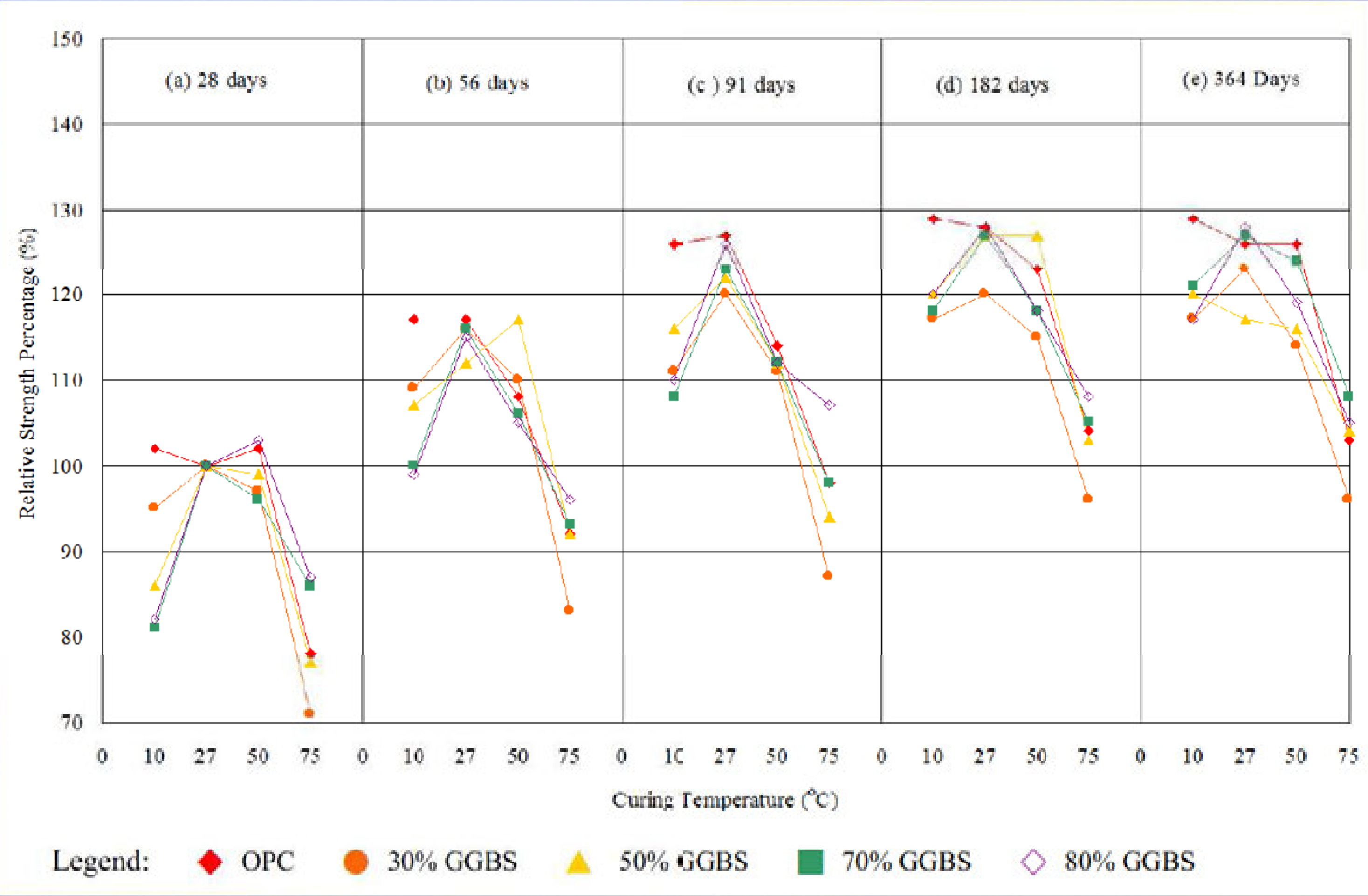
Effect of curing temperature on strength development

- At low curing temperature, 10°C, GGBS mixes suffered a 20% reduction in strength at 28 days, but they recovered to their target strengths at the age of 56 days

- At high curing temperature, 75°C, the 28-day strength of GGBS concrete fell between 71-94%. Some of the mixes cannot achieve their target strength even after one year.

Study by Public Works Central Laboratory

Influence of Curing Temperature on Strength Development of OPC and GGBS Concrete



Study by Public Works Central Laboratory

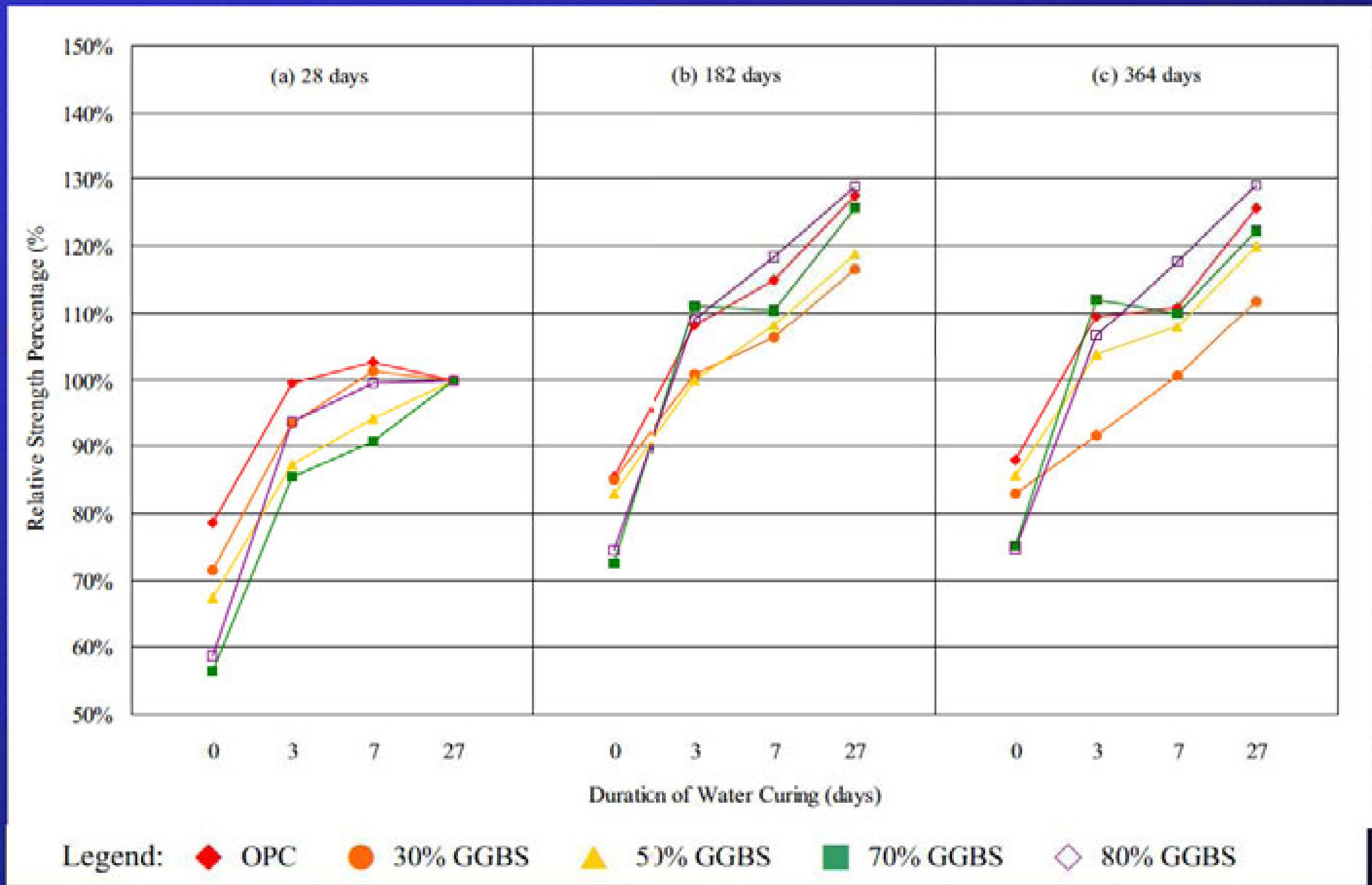
Study Results:

Effect of curing duration on strength development

- Air curing: GGBS mixes only achieve about 67% of target strength, OPC 79%
- 3-day curing: GGBS mixes achieve 87% of target strength, OPC 99%
- 7-day curing: GGBS mixes achieve 90-99% of target strength, OPC over 100%

Study by Public Works Central Laboratory

Influence of Curing Duration on Strength Development (Grade 35 Mixes, SG)



Study by Public Works Central Laboratory

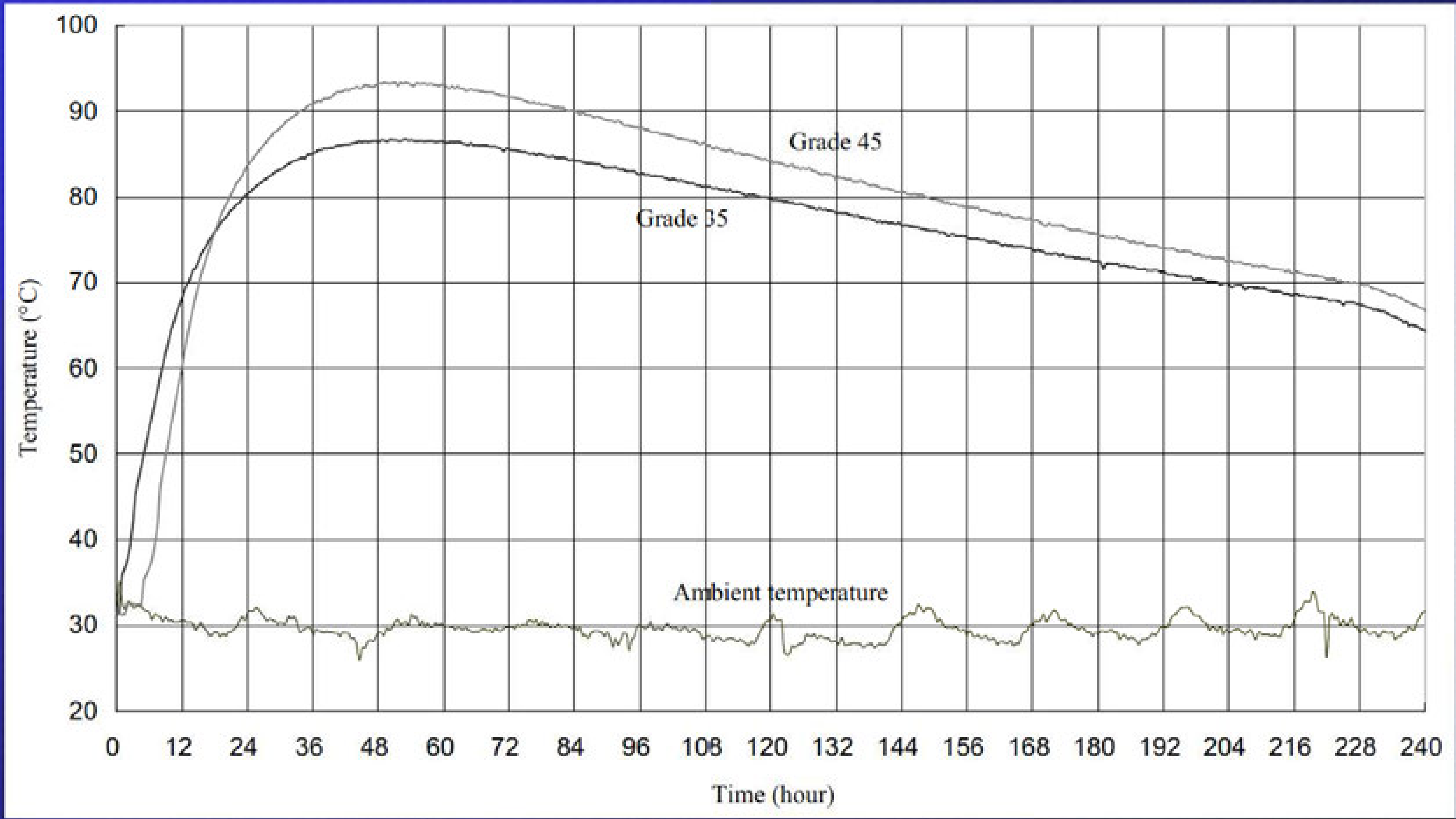
Study Results:

Temperature of large pour

- Peak temperature:
  - GGBS mixes with 50% GGBS replacement is about 16% higher than OPC mix
  - GGBS mixes with 80% GGBS replacement is about 14% lower than OPC mix
- With 5% of silica fume, peak temperature of GGBS mixes with 75% replacement is about 30% lower than that of OPC mix

Study by Public Works Central Laboratory

Typical Temperature Profile at Centre of 1 m^3 Panels



Study by Public Works Central Laboratory

Study Results:

Effect of GGBS on Durability (91-day RCPT results)

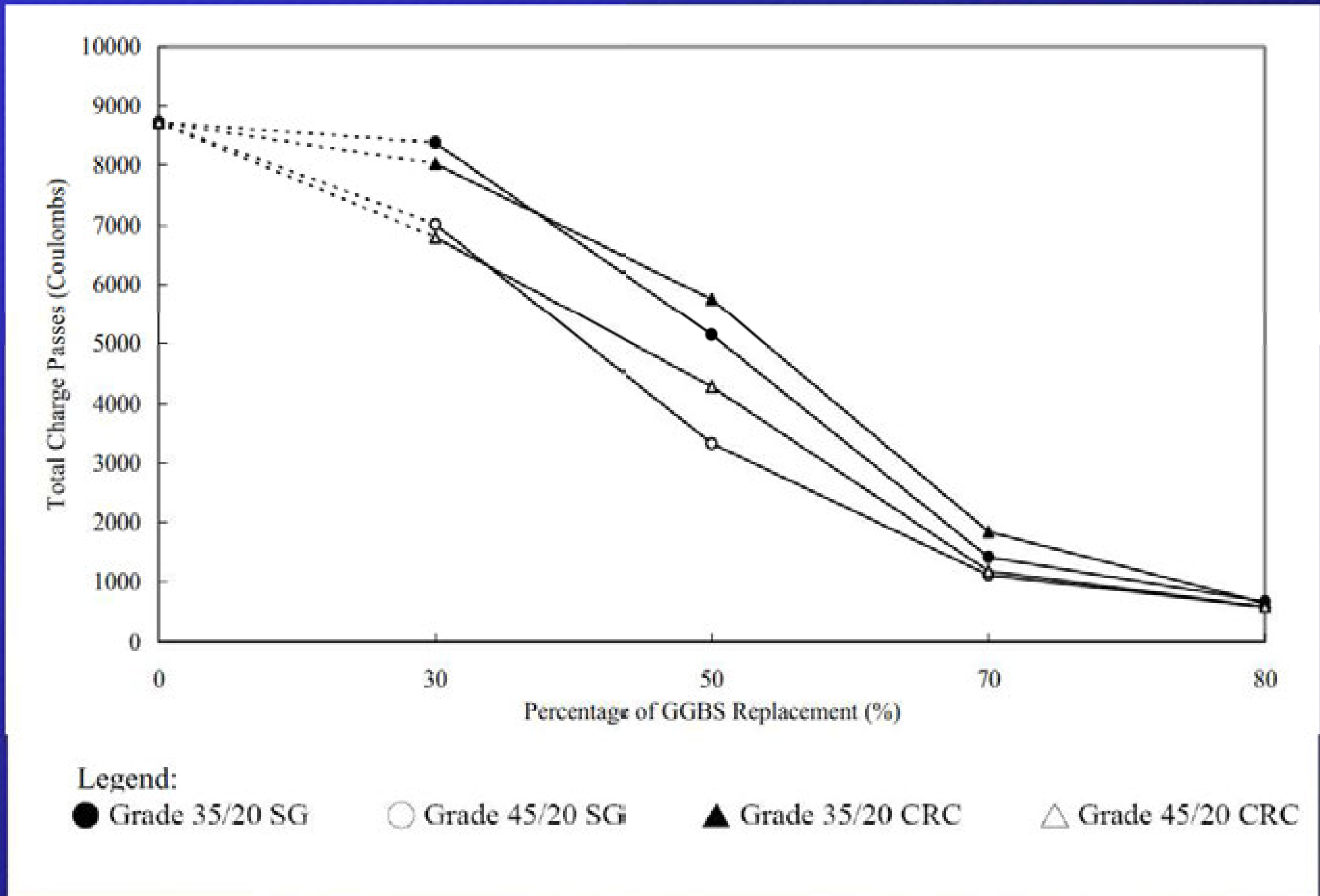
GGBS mixes:

- GGBS content <= 50%: average charge passed > 4600 Coulombs
- GGBS content = 70%: average charge passed: 1200-2200 Coulombs
- GGBS content = 80%: average charge passed < 700 Coulombs

- GGBS mixes with 5% silica fume:
  - Average charge passed: < 900 Coulombs

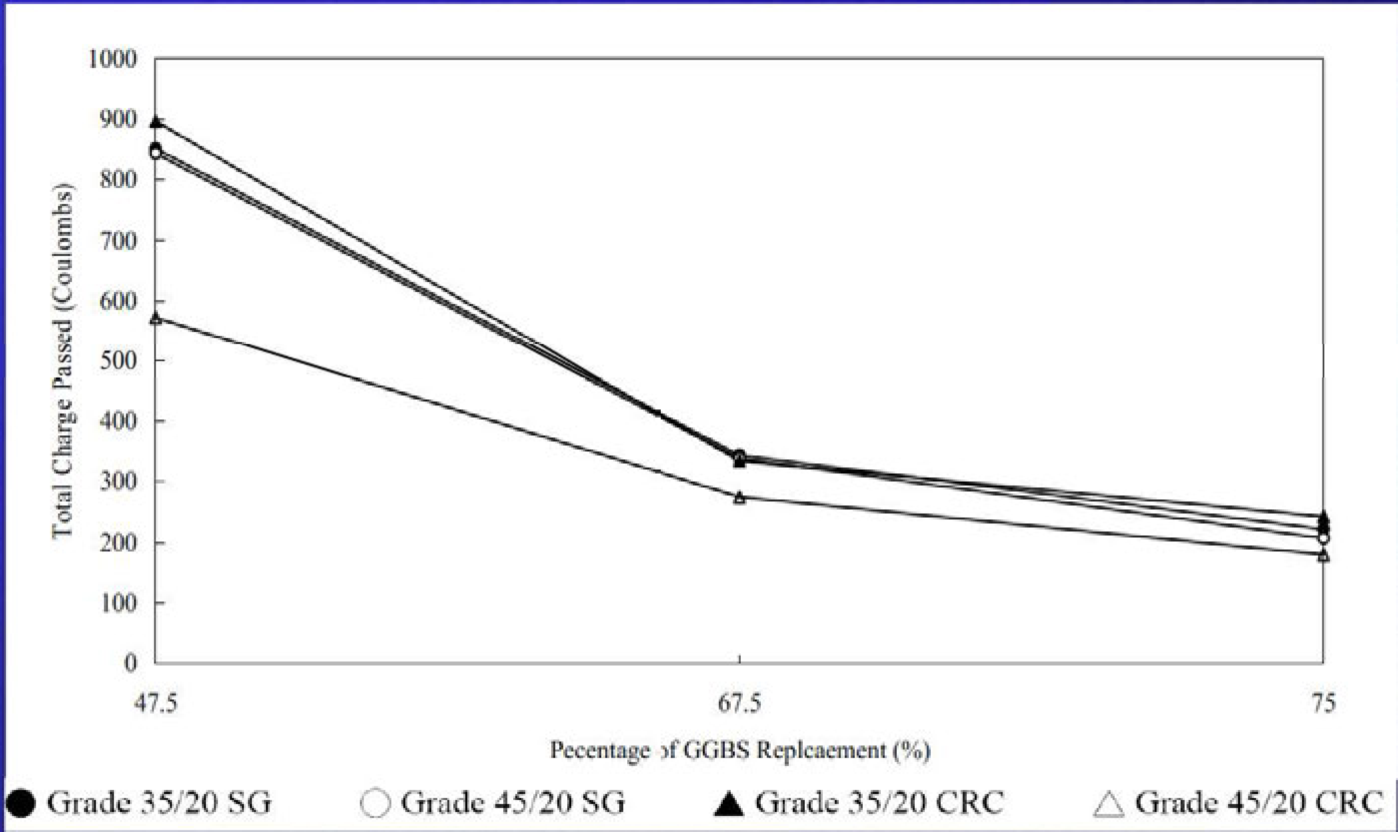
Study by Public Works Central Laboratory

Influence of GGBS Replacement on Durability at 91 days - without Silica Fume



Study by Public Works Central Laboratory

Influence of GGBS Replacement on Durability at 91 days - with Silica Fume



Study by Public Works Central Laboratory

Conclusions

- Bleeding of concrete is not affected significantly by the inclusion of GGBS.
- At a replacement percentage of 80%, there was a significant reduction in the peak temperature of GGBS concrete.
- There is a slight retarding effect on the early strengths of GGBS concrete.
- The GGBS concrete would require a longer curing period than that of Portland cement concrete.
- The strength development of GGBS concrete was affected by the curing temperature.

Study by Public Works Central Laboratory

Conclusion

- GGBS would improve the concrete's ability to resist chloride penetration.
- The inclusion of silica fume would significantly improve the concrete durability.
- GGBS replacement levels of between 30% and 40% were often adopted to give the optimal strength performance. For resistance to sulphate attack and lower early age heat generation, the replacement levels used were often from 60% to 85% for mass concrete construction.
- The source of GGBS does not appear to have a significant effect on the performance of GGBS concrete so long as the GGBS complies with the relevant standards.

End of Presentation

Thank You

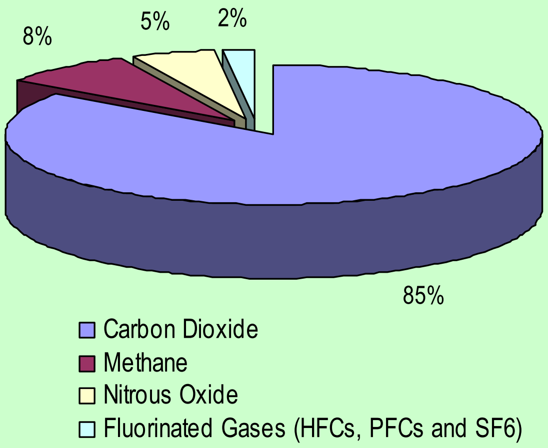
Ground Granulated Blastfurnace Slag (GGBS) in Concrete and Pilot Use of GGBS in the Precast Facades of a Housing Authority Project

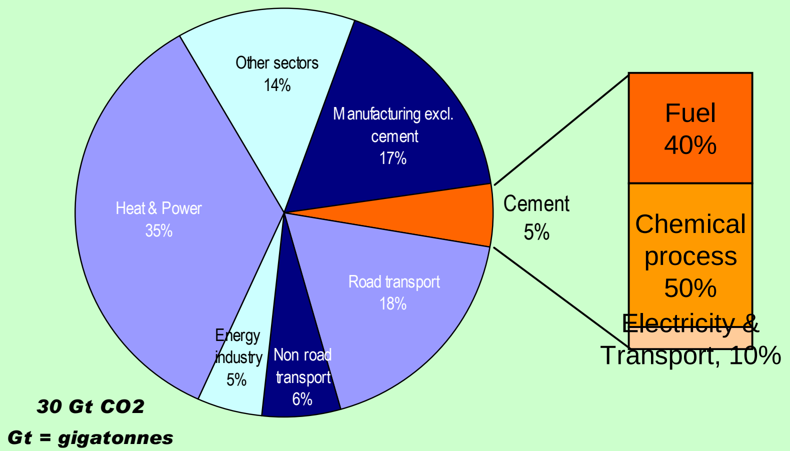
Ir. Joseph Y.W. Mak
Chief Structural Engineer/Development & Construction
Housing Department

SCCT Annual Concrete Seminar 2011
23 March 2011

Background

- In support of the HKSAR Government's environmental initiatives
  - Aiming to reduce the carbon dioxide (CO_2) emission by using less cement in concrete





Total Greenhouse Gas Emission by Volume

- 85% of greenhouse gas emitted to atmosphere is carbon dioxide
- *Source: Inventory of U.S. Greenhouse Gas Emissions and Sinks (2008), EPA.*

Global Carbon Dioxide Production

- The cement industry produces about 5% of global man-made CO_2
- *Source: The Cement Sustainability Initiative Progress Report, June 2005. www.WBCSD.org*

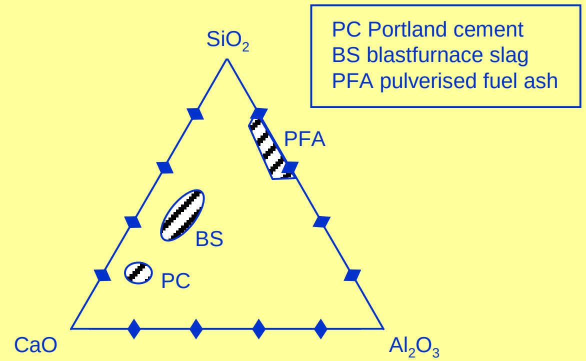
- Look for suitable cement replacement materials for elements of the superstructure with due consideration of the effect on construction cycle

Ground Granulated Blastfurnace Slag

GGBS (Ground Granulated Blastfurnace Slag) – by-product from steel mills

Chemically, a mixture of lime (CaO), silica (SiO_2) and alumina (Al_2O_3)

- Similar to ordinary cement but in different proportions



Schematic chemical composition in the ternary C-S-A system

Benefits of GGBS (1)

Benefits to concrete properties include:

- Higher long-term concrete strength

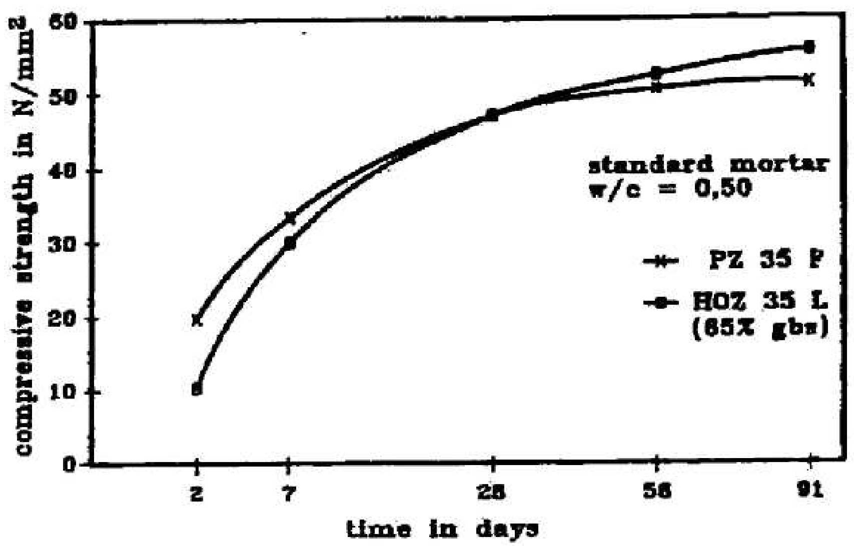


Fig. 1—Strength development of portland cement (PZ 35 F) and blast furnace cement (HOZ 35 L)

Benefits of GGBS (2)

Lower the risk of alkali-silica reaction

- A replacement of 50% is recognized as effective measure against ASR in technical reports and Standards*

Higher fire resistance

- In a study by a local university, a network of minor cracks found in GGBS concrete test specimens, as compared to major single crack in OPC concrete test specimens (suggesting spalling of concrete in a real structure) at about 800ºC

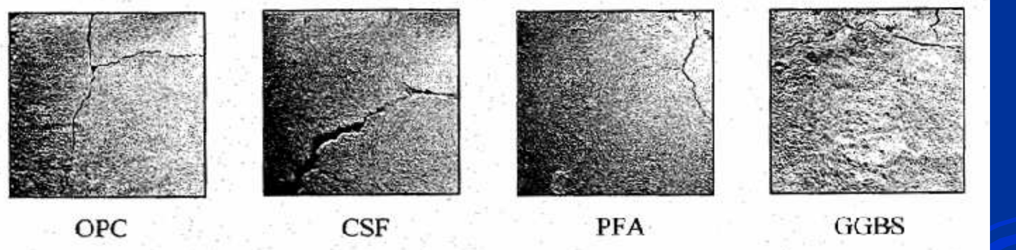


Fig. 12. Typical crack patterns observed in HSC at 800°C.

* Concrete Society Technical Report No.30 (1995); BRE Digest 330 (revised 1991); BS8110

Benefits of GGBS (3)

Lower heat of hydration, reduce occurrence of cracking

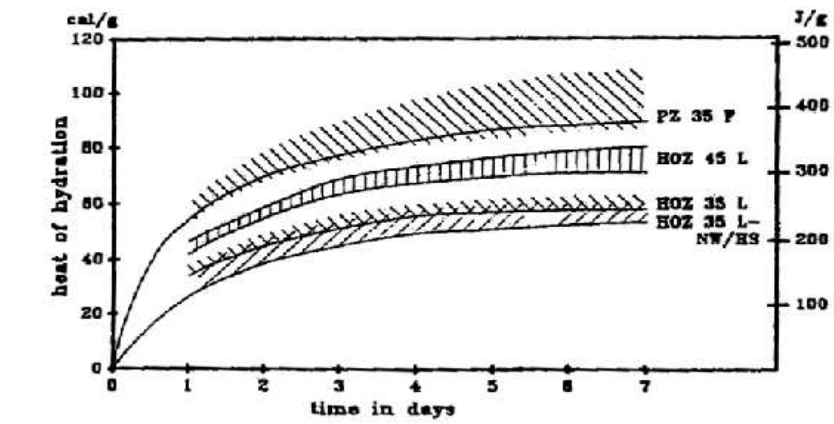


Fig. 4—Heat of hydration of portland cement (PZ) and blast furnace cement (HOZ) under adiabatic conditions[10]

Higher resistance against chloride ingress, reduce corrosion

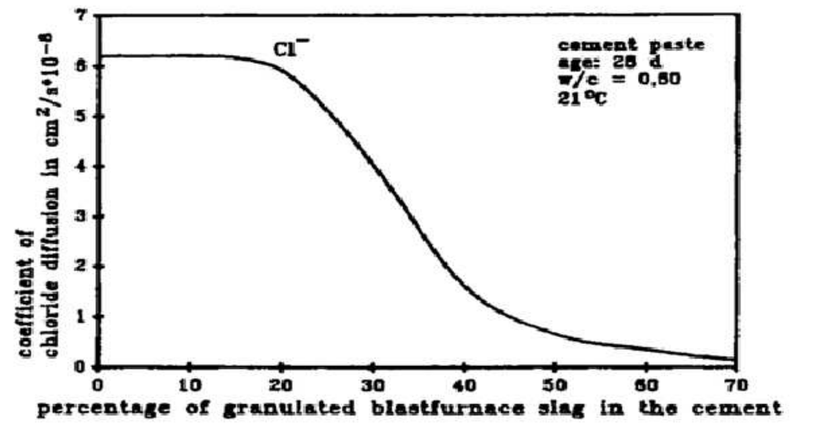


Fig. 8—Resistance against chloride diffusion as function of percentage of granulated blast furnace slag in cement[21]

Past Applications and Mainland Trend

- Overseas applications
  - North America: Canada, USA
  - Europe: UK, Germany, France
  - Rims of Pacific countries: Japan, Australia
- Local experience
  - Tsing Ma Bridge – Towers (65% GGBS)
  - Stonecutters Island Bridge – Pile caps (60% GGBS)
  - MTRC infrastructures – Pile caps & piles in a landfill site (50%-75% GGBS)
- Mainland trend
  - Rapid increase in production /demand
    - from 0.50M tonne per annum (tpa) in 1997 to 20.20M tpa in 2006
  - Slag grinding industry is becoming a stand-alone industry independent from cement industry

International Standards

Various national standards

British Standard

- BS 6699 : 1992 Specification for Ground Granulated Blastfurnace Slag for use with Portland Cement
- BS EN 15167-1 Ground Granulated Blast Furnace Slag for use in concrete, mortar and grout – Part 1: definitions, specifications and conformity criteria
- BS EN 15167-2 Ground Granulated Blast Furnace Slag for use in concrete, mortar and grout – Part 2: conformity evaluation

Chinese National Standard

- GB/T 18046-2000 Ground Granulated Blast Furnace Slag used for Cement and Concrete

Japanese Industrial Standard

- JIS A 6206 : 1997 Ground Granulated Blast-furnace Slag for Concrete

In 2005, SCCT endorsed BS 6699 as the standard for GGBS in Hong Kong

Specifications

Local specification

CEDD’s Particular Specification for marine structures

- 60% - 75% by mass of cementitious content for normal application and
- 60% - 90% by mass of cementitious content for low heat application

MTRC infrastructure projects

- 50% - 75% by mass of cementitious content

Preliminary Study on using GGBS in Precast Concrete Construction (1)

To determine the strength development against age by carrying out series of trial mixes

To assess the early strength in relation to demoulding at precast yard

To determine the effect of ambient temperature by trying out in both summer and winter time

To check the effect on tiles and paint finishes such that tiles /paints will not fall off

Preliminary Study on using GGBS in Precast Concrete Construction (2)

Early strength (strength at 18 hours)

Demoulding strength of 15.0 MPa is required

Various Mix Proportions of GGBS

Grade 35 – 22 mixes

- Direct partial replacement of cement of an approved OPC concrete (395 kg/m^3 cementitious content)
- Tests carried out in hot season, 28-day strength (about 61.5 MPa) and early strength (about 15.0 MPa) for 30%~40% replacement level
- Low strength of about 7.1 MPa at demoulding at 21ºC~22ºC without steam curing for 30%~40% replacement

Grade 45 – 10 mixes

- Cementitious content increased to around 470 kg/m^3
- Inadequate strength of about 12.0 MPa at demoulding at 20ºC without steam curing for 30%~40% replacement level

Pull-off tests on finishes

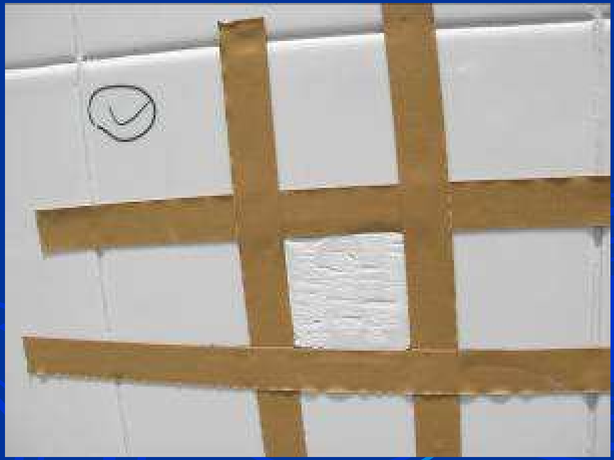
- 3 facades cast: 1 OPC concrete, 1 GGBS concrete, 1 PFA concrete
- Tile finishes at interior face, paint finishes at exterior face

Pull-out Test on Tile

Test method

HKHA in-house method





Pull-out Test on Paint

Test method

BS EN ISO 4624

Findings (1)

Replacement level

35% by mass of cementitious content is selected, based on

- Not all precast factories are currently equipped with steam curing facilities
- Steam curing is expected necessary for about 2 months in cold season

Early strength at demoulding

For higher ambient temperature, normal demoulding within 18 hours for grade 45 concrete is achieveable

For lower ambient temperature at around 20ºC, steam curing may have to be used

Strength at 28 days

Well above the required compressive strengths

- Mean strength of 70.8MPa for grade 45 concrete (57% above characteristic strength)

Findings (2)

Effects on finishes

Pull-off tests carried out in accordance with HA Specification, i.e. not more than 60 days after application of finishes

Performance better than that of ordinary Portland cement concrete

	Portland Cement (N/mm²)	GGBS (N/mm²)	PFA (N/mm²)	Minimum Pull off force (N/mm²)
Tile Finishes	0.816	1.097	1.012	0.5
Paint Finishes	0.97	1.38	0.75*	0.5

Estimated CO_2 emission

About 20% reduction as compared with ordinary Portland cement concrete mix (roughly 3,800 tonnes** each year if widely used in HA projects)

* 2 out of 6 results fail to meet requirement

** Using concrete volume of façade in standard block as basis and assuming annual production of 15,000 flats

Pilot Project

Major works

- Two 39-storeys domestic blocks on top of a 2-storey podium
- One 8-storey Welfare Retail Block
- Associated drainage and external works

Contract Period

- 30 months commencing in 6/2009

Contractor

- Yau Lee Construction Co Ltd

Precaster

- Yau Lee Wah Concrete Precast Products Co Ltd

Site general layout

Trial Mix

Concrete Mix Proportion proposed by contractor

Grade 45/20 (35% of total cementitious content), 75 mm slump

Cement		292 kg/m^3
GGBS*		158 kg/m^3
Coarse aggregate	(20 mm)	785 kg/m^3
	(10 mm)	325 kg/m^3
Fine aggregate		585 kg/m^3
Water		170 l/m^3
Admixture		5.72 l/m^3
w/c ratio		0.38

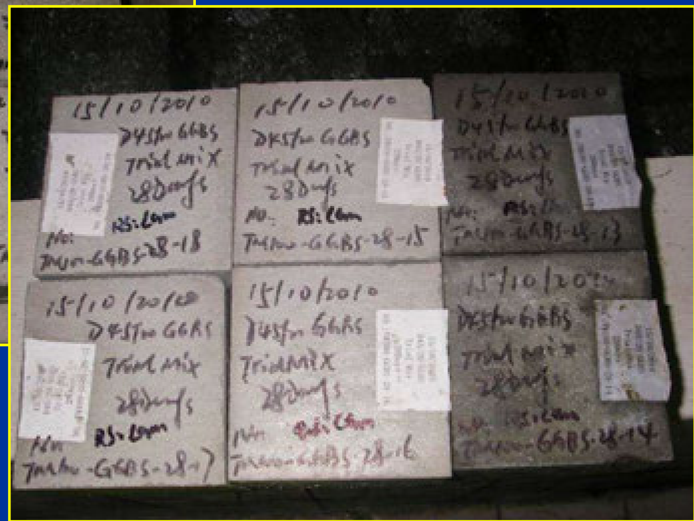
* source: Hua Run, Dongguan

Trial Mix (Plant Trial) …

Batching Control Panel

Silo for GGBS

Trial Mix (Plant Trial) …



Test cubes cast on 3 separate days

Trial Mix (Plant Trial)

Tests on concrete

In compliance with HKHA Specification

28-day compressive strength

- Mean of 18 cubes: 73.9 MPa (acceptance: 59 MPa min.)
- Min. individual cube: 69.0 MPa (acceptance: 52 MPa min.)

Slump

- Range of measured slump: 75 mm to 90 mm (acceptance range: 55 mm to 95 mm)

Tests on GGBS

In compliance with BS6699

- Physical: strength (7-d, 28-d), fineness, soundness etc.
- Chemical: loss-on-ignition, chemical moduli, chloride, sulphate etc.

Production Photos …

A spot sample of GGBS

Batching plant

Production Photos …

Steel mould for façade

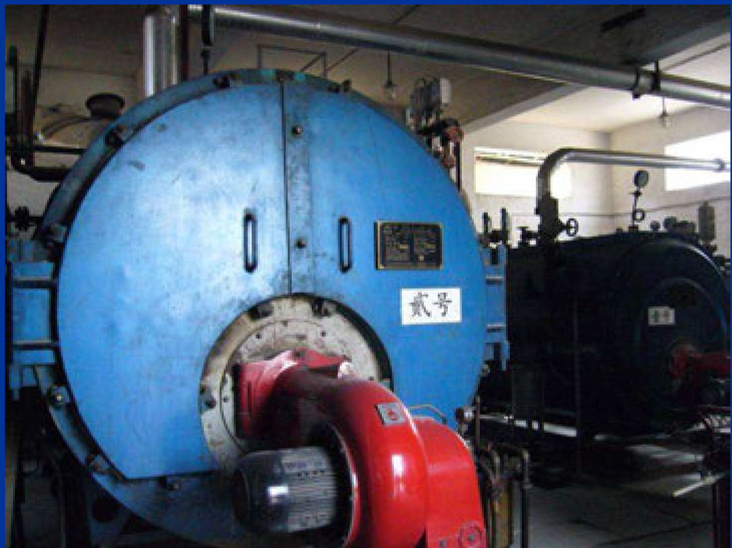
Concrete placement

Production Photos …

Trowelling concrete surface

Demoulding (after steam cured)

Production Photos …



Boilers for Steam Curing

Piping System from Boiler Room

Production Photos

Storage Area

Delivery to Site

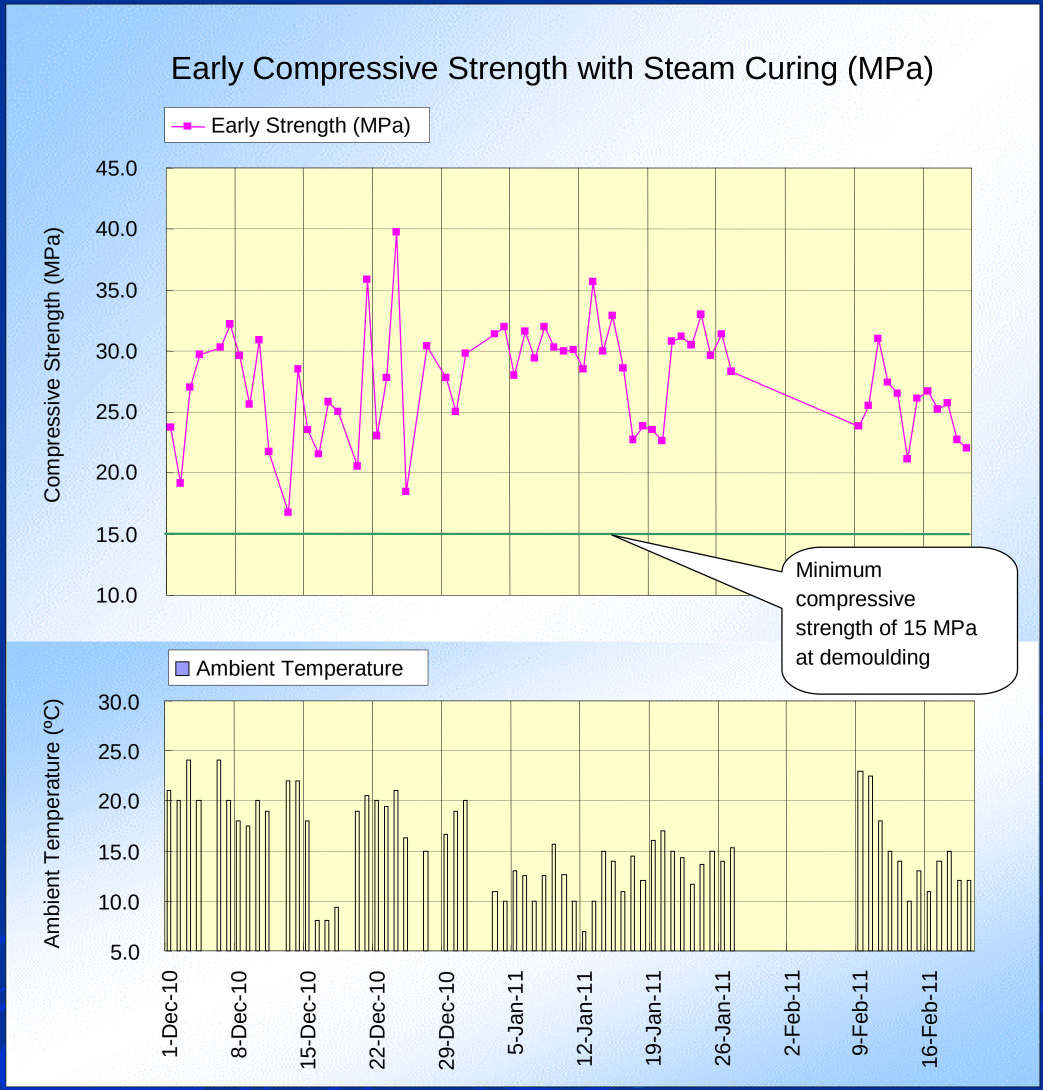
Observations

Early cube strength at demoulding from December 2010 to end February 2011 for façade (Grade 45 concrete)

- About 18~20 hours after casting
- Steam cured
- Ambient temperature ranges from 7ºC to 24ºC

28-day compressive cube strength

- Mean = 77.6 MPa
  - Max. = 82.0 MPa
  - Min. = 69.0 MPa
- SD = 4.4 MPa



Thank you