Evaluation of the Performance of GGBS Concrete used in Civil and Geotechnical Works

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doi: https://doi.org/10.21467/proceedings.159.26

ABSTRACT

The use of supplementary cementitious materials (SCM) such as Pulverised Fly Ash (PFA) and Ground Granulated Blastfurnace Slag (GGBS) has been proven effective in reducing the total carbon emission of the concrete production process by lowering the use of Ordinary Portland Cement (OPC). The general specifications published by the Government of the Hong Kong Special Administrative Region have allowed the use of PFA as SCM in concrete production for public work projects in the past three decades. From 2012 onwards, the use of GGBS as SCM has also been permitted. In recent years, the local electricity companies have been reducing their reliance on coal-fired plants for electricity generation. The local supply of PFA has been declining and is expected to deplete by the 2030s. Through the management of the concrete mix ID database, the Public Works Central Laboratory (PWCL) noted the trend of using GGBS concrete in public works contracts has been on the rise in the past two years.

The PWCL has recently conducted an in-house technical study on the performance of GGBS concrete mixes recently adopted in public works contracts. Based on the original concrete mix formulas and sources of materials, fresh concrete batches were made in laboratory environment. Furthermore, additional concrete test cubes were obtained from available on-going public works construction sites adopting GGBS concrete. Various performance aspects of the concrete mixes, such as the early strength development and shrinkage properties were evaluated. PWCL has also obtained the results of the recent "Low Carbon Concrete Trophy Competition 2022" initiated by the Standing Committee on Concrete Technology and organised by HKIE for comparison purposes. In view of the improved quality of GGBS available in the market in the past few years, PWCL is also planning to conduct a further study on the performance of GGBS concrete, focusing on the recent technological advancement in this area, and the feasibility of achieving higher replacement levels, higher grade strengths with the use of locally available raw materials.

This paper summarises our current work on evaluation of the performance of GGBS concrete used in recent public works contracts with the aim of facilitating the industry's consideration for wider adoption of GGBS concrete in civil and geotechnical engineering works.

Keywords: Ground Granulated Blastfurnace Slag (GGBS), Supplementary Cementitious Materials (SCM), Low Carbon Concrete

1 Introduction

1.1 Use of Supplementary Cementitious Materials (SCM)

Cement is one of the major constituent materials for the production of concrete. To produce cement, limestone, clay and other materials are heated in large kilns to high temperatures (about 1500 °C). During the process, greenhouse gases (e.g., carbon dioxide, nitrous oxides, sulphur dioxide) are emitted. Carbon dioxide (CO_2) accounts for the majority of the gas emissions, which comes from the calcination of limestone (breaking down into CO_2 and calcium oxide) and the combustion of fossil fuels for heating the kilns. The cement industry accounts for about 8% of the global CO_2 emission.

Proceedings DOI: 10.21467/proceedings.159; Series: AIJR Proceedings; ISSN: 2582-3922; ISBN: 978-81-965621-6-8

The use of supplementary cementitious materials (SCM) such as Pulverised Fly Ash (PFA) and Ground Granulated Blastfurnace Slag (GGBS) has been proven effective in reducing the total carbon emission of the concrete production process by lowering the use of Ordinary Portland Cement (OPC). The General Specification for Civil Engineering Works (HKSAR Government, 2006, 2020) published by the Government of the Hong Kong Special Administrative Region has allowed the use of PFA as SCM in concrete production for public work projects in the past three decades. From 2012 onwards, the use of GGBS as SCM has also been permitted. In recent years, the local electricity companies have been reducing their reliance on coal-fired plants for electricity generation. The local supply of PFA has been declining and is expected to deplete by the 2030s.

1.2 Low Carbon Concrete Trophy Competition 2022

The "Low Carbon Concrete Trophy Competition 2022" (LCCTC) initiated by the Standing Committee on Concrete Technology and organised by HKIE was completed in November 2022. The objective of the competition was to arouse the awareness and interest of stakeholders in the construction industry towards the benefits of low carbon concrete produced using GGBS. The competition had two categories, viz. the Students Category and the Practitioners Category. Each participating team was required to design a concrete mix using GGBS as SCM to achieve the target strength The teams were later required to produce their designed concrete mix in laboratory environment. Strength tests and durability tests were conducted on the produced concrete specimens and scores were given based on a set of pre-defined criteria. Under the Students Category (with a total 10 teams), most of the teams prepared concrete mixes with GGBS content from 70% to 75% for a target strength of 45MPa. Under the Practitioners Category (with a total 12 teams), most of the teams prepared concrete mixes with GGBS content from 80% to 85% for a target strength of 60MPa. From the results of the competition, it was observed that the ratio of 7-day strength / 28-day strength and 56-day strength / 28-day strength ranged from 0.65 to 0.81 and 1.05 to 1.13 respectively.

1.3 In-house Technical Study on GGBS

Through the management of the concrete mix database, the Public Works Central Laboratory (PWCL) noticed that the trend of using GGBS concrete in public works contracts has been on the rise in the past two years. The PWCL has recently conducted an in-house technical study on the performance of GGBS concrete mixes adopted in public works contracts in 2022. Based on the original concrete mix formulas and sources of materials, fresh concrete batches were made in laboratory environment. Furthermore, additional concrete test cubes were also obtained from available on-going public works construction sites adopting GGBS concrete. Various performance aspects of the concrete mixes, such as the early strength development and shrinkage properties were evaluated.

This paper summarises the above recent work conducted by the PWCL and presents some observations obtained thereby regarding the performance of GGBS concrete used in Hong Kong.

2 In-House Technical Study

2.1 Concrete Samples prepared by PWCL

PWCL identified the GGBS concrete mixes adopted in public works contracts in 2022 through the management of the concrete mix database. Amongst the GGBS concrete mixes from the database, the grade strengths and GGBS replacement ratios range from Grade 25 to Grade 60 and 35% to 65% respectively. It was observed that Grade 45 was the most common grade used. PWCL replicated 13 of these GGBS concrete mixes using the same cementitious content, aggregate content and W/C ratio in

laboratory environment from December 2022 to March 2023. The selected mixes cover various grade strengths and GGBS replacement ratios. Strength tests and shrinkage tests were conducted in laboratory conditions in accordance with Hong Kong Construction Standard CS1:2010 (HKSAR Government, 2010) and BS EN 12390-16 (BSI, 2019) respectively. For each of the replicated GGBS mix, a control OPC mix with the same W/C ratio was also prepared for comparison purpose.

In all concrete mixes, superplasticizer was added to achieve the target slump of each mix. In the preparation of the concrete mixes, OPC with strength class 52.5N in accordance with BS EN 197-1 (BSI, 2011) and GGBS in accordance with BS EN 197-1 (BSI, 2006) with fineness between 400 and 500 m^2/kg were used. A summary of the concrete mixes is shown in Table 1. The grade of concrete mixes ranged from Grade 25 to Grade 60. The total cementitious content ranged between 406 to 480 kg/m^3. The concrete mixes with higher grade strengths generally have lower W/C ratios.

Table 1: *Summary of Concrete Mixes prepared by PWCL.*

Mix Number	Grade	Total Cementitious Content, kg/m^3	GGBS Content %	A/C Ratio	W/C Ratio
1	25	410	60%	4.09	0.49
2	30	406	35%	4.26	0.45
3	30	450	60%	3.61	0.46
4	40	410	50%	4.44	0.38
5	45	450	35%	3.83	0.41
6	45	480	40%	3.52	0.36
7	45	450	60%	3.80	0.42
8	45	450	65%	3.91	0.36
9	45	410	65%	4.41	0.38
10	50	450	65%	3.91	0.36
11	55	430	65%	4.20	0.35
12	55	460	65%	3.76	0.35
13	60	460	50%	3.83	0.35

2.2 Concrete Cubes Obtained from Available On-going Public Works Construction Sites

In addition to the concrete specimens prepared by PWCL, extra GGBS concrete cubes were also obtained from available on-going public works construction sites for carrying out strength tests for comparison purpose. The concrete mixes include 5 GGBS concrete and 2 PFA concrete. A summary of the concrete mixes is shown in Table 2.

Table 2: *Summary of Concrete Samples obtained from Available On-going Public Works Construction Sites*

Mix Number	Grade	Total Cementitious Content, kg/m^3	SCM %	A/C Ratio	W/C Ratio
14	40	410	50% GGBS	4.44	0.38
15	45	480	40% GGBS	3.52	0.36
16	45	450	65% GGBS	3.91	0.36
17	45	450	65% GGBS with Shrinkage Reducing Agent	3.91	0.36

Proceedings DOI: 10.21467/proceedings.159
ISBN: 978-81-965621-6-8

Series: AIJR Proceedings
ISSN: 2582-3922

18	45	450	35% PFA + PP Fibre	3.83	0.35
19	60	500	40% GGBS + 8% CSF	3.35	0.32
20	60	450	35% PFA + 8% CSF	3.85	0.32

3 Results And Discussion

3.1 Concrete Samples prepared by PWCL – Concrete Strength

A total of 13 GGBS mixes and 13 OPC control mixes were prepared in this study. Concrete cube samples (100mm x 100mm x 100mm) were made for each mix. All cube samples were water cured at 27 +/- 3 ºC after demoulding at 1 day after casting until strength tests were carried out. Concrete cube strength tests were carried out at ages of 3, 7, 14, 28 and 56 days. While majority of the results at 56 days were not yet available at the time of writing, the results of the tests at 3, 7, 14 and 28 days are summarised in Table 3 and Figures 1 to 4.

Table 3: *Concrete Samples prepared by PWCL – Concrete Strength*

Mix Number		Grade	GGBS Content %	3-Day Strength, MPa	7-Day Strength, MPa	14-Day Strength, MPa	28-Day Strength, MPa	Ratio of 28-Day Strength (GGBS) / 28-Day Strength (Control), %
1	GGBS	25	60%	19.2	32.1	39.0	46.5	85%
	Control			34.6	44.0	47.6	54.5	
2	GGBS	30	35%	31.7	43.6	53.7	61.2	95%
	Control			43.1	54.1	59.7	64.7	
3	GGBS	30	60%	23.9	35.9	46.3	57.7	104%
	Control			36.1	45.7	51.1	55.5	
4	GGBS	40	50%	36.4	57.7	71.6	84.2	123%
	Control			49.9	58.6	65.5	68.6	
5	GGBS	45	35%	39.1	56.8	68.4	76.3	110%
	Control			49.9	60.2	65.7	69.2	
6	GGBS	45	40%	43.2	62.9	78.6	83.4	106%
	Control			55.9	67.4	74.4	78.4	
7	GGBS	45	60%	31.1	48.9	62.2	73.3	97%
	Control			51.4	62.0	69.8	75.5	
8	GGBS	45	65%	33.1	50.7	65.8	77.7	105%
	Control			54.4	63.3	71.4	73.9	
9	GGBS	45	65%	31.7	48.9	60.7	69.7	102%
	Control			49.9	58.6	65.5	68.6	
10	GGBS	50	65%	37.2	56.2	70.6	82.4	96%
	Control			64.8	76.9	81.2	85.9	
11	GGBS	55	65%	33.4	59.7	71.6	79.1	91%
	Control			62.6	76.8	79.9	87.0	
12	GGBS	55	65%	33.7	50.1	61.0	71.9	97%
	Control			53.9	65.1	71.4	74.1	
13	GGBS	60	50%	40.4	56.2	75.4	86.2	114%
	Control			53.8	62.0	71.6	75.9	

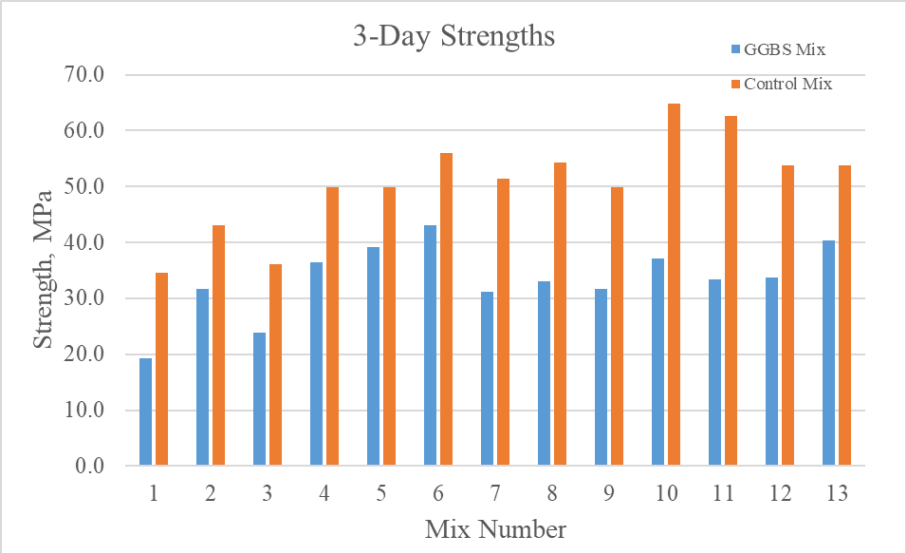

Figure 1: *3-Day Strengths*

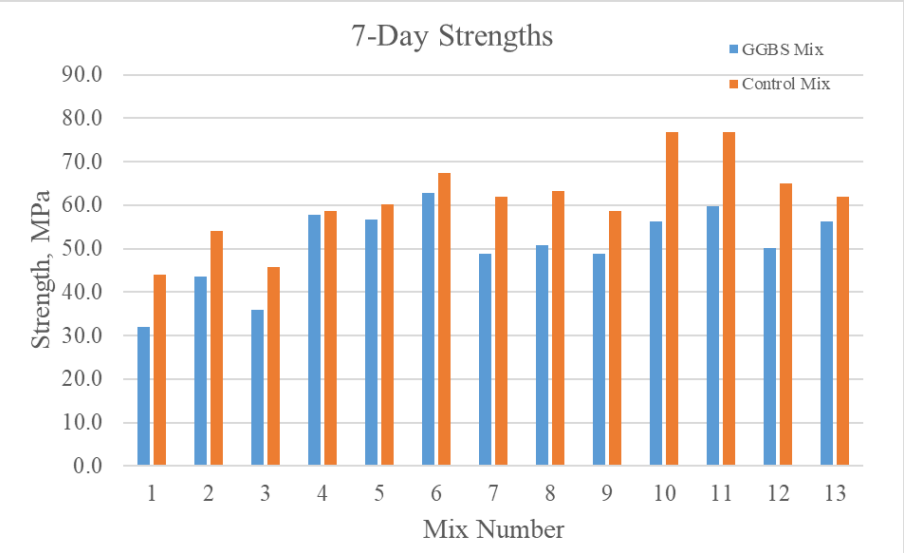

Figure 2: *7-Day Strengths*

Proceedings DOI: 10.21467/proceedings.159
ISBN: 978-81-965621-6-8

Series: AIJR Proceedings
ISSN: 2582-3922

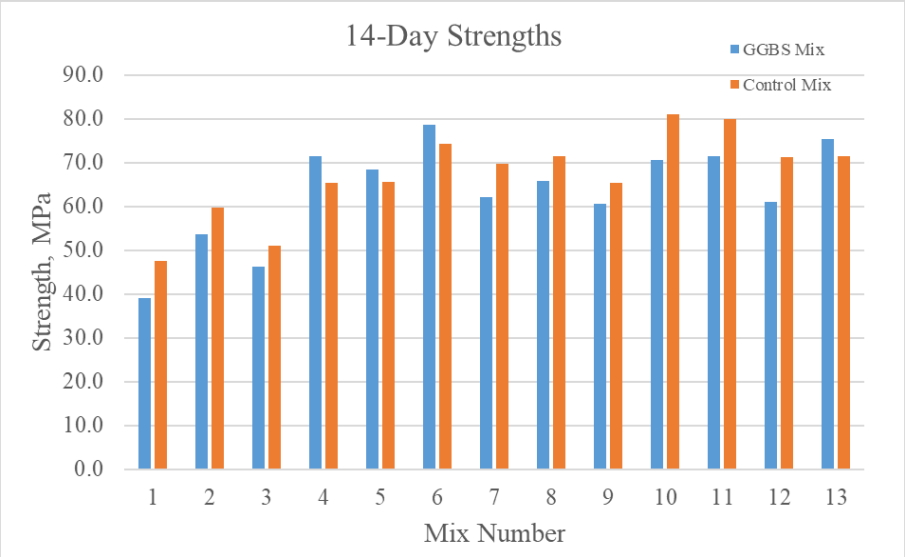

Figure 3: *14-Day Strengths*

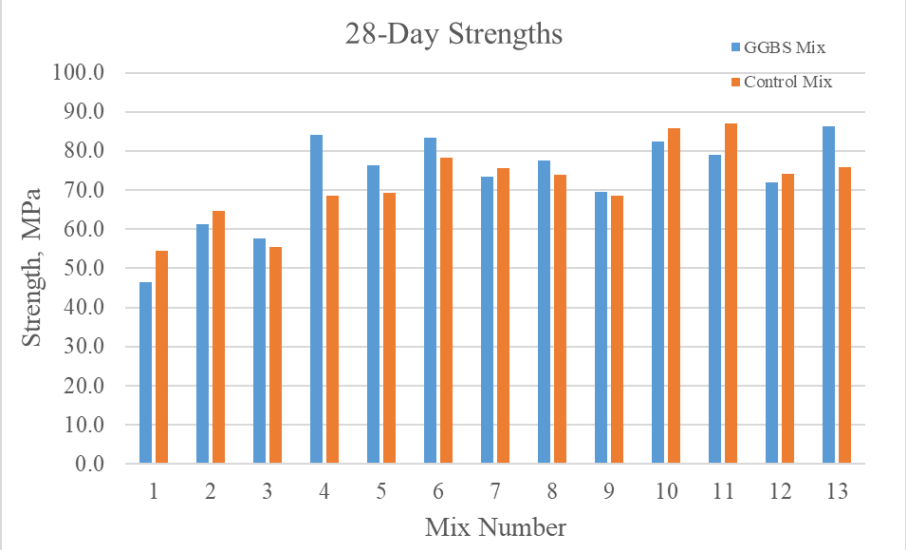

Figure 4: *28-Day Strengths*

To better illustrate the strength development of each mix, the results of tests were further computed in two ways: (1) as a percentage of the 28-day strength, as shown in Table 4 and (2) as a percentage of the grade strength, as shown in Table 5. The graphical representations of the results are shown in Figures 5 and 6.

The results show that all GGBS mixes have achieved greater than 40% of the 28-day strength at 3 days and greater than 60% of the 28-day strength at 7 days. When compared with the grade strengths, all GGBS mixes have achieved greater than 60% of the grade strength at 3 days and 90% at 7 days. The 7-day strength / 28-day strength of the GGBS mixes ranged from 0.62 to 0.76. The early strengths at 3 days and 7 days of all GGBS mixes were consistently lower than the control OPC mixes. Notwithstanding this, the actual strengths achieved by all GGBS mixes at 3 days and 7 days are considered sufficient for general civil and geotechnical engineering works.

The results show that 9 out of 13 GGBS mixes have lower 14-day strengths when compared to the corresponding control mixes. The remaining 4 GGBS mixes (Mix. Nos. 4, 5, 6 and 13) have higher 14-day strengths and the GGBS contents of such mixes range from 35% to 50%. Mix No. 2 with 35% GGBS content did not show the same trend. All GGBS mixes have comparable 28-day strengths when compared to the control mixes. The 4 mixes (Mix. Nos. 4, 5, 6 and 13) showing higher 14-day strengths also have higher 28-day strengths when compared to the corresponding control mixes (approximately 6% to 23% higher).

The following observations on the 28-day strengths of the GGBS concrete mixes, categorised by the GGBS replacement ratios, were made:

(a) When compared to the corresponding control mix, Mix No. 5 with 35% GGBS content has higher 28-day strength while Mix. No. 2 also with 35% GGBS content has a lower 28-day strength.

(b) All mixes with 40% to 50% GGBS content (Mix Nos. 4, 6 and 13) have higher strengths at 28 days when compared to the corresponding control mix (6% to 23% higher).

(c) Mix Nos. 1, 7, 8, 9, 10, 11 and 12 with 60% to 65% GGBS content have 85% to 105% of the 28-day strength of the corresponding control mix.

The authors noted the above observations were made based on small sample sizes only and might not reflect the actual characteristics of the various GGBS replacement ratios.

Table 4: *Concrete Samples prepared by PWCL – Comparison against 28-day Strength.*

Mix Number		Grade	GGBS Content %	3-Day Strength, %	7-Day Strength, %	14-Day Strength, %	28-Day Strength, %
1	GGBS	25	60%	41%	69%	84%	100%
	Control			63%	81%	87%	100%
2	GGBS	30	35%	52%	71%	88%	100%
	Control			67%	84%	92%	100%
3	GGBS	30	60%	41%	62%	80%	100%
	Control			65%	82%	92%	100%
4	GGBS	40	50%	43%	69%	85%	100%
	Control			73%	85%	96%	100%
5	GGBS	45	35%	51%	74%	90%	100%
	Control			72%	87%	95%	100%
6	GGBS	45	40%	52%	75%	94%	100%
	Control			71%	86%	95%	100%
7	GGBS	45	60%	42%	67%	85%	100%
	Control			68%	82%	92%	100%
8	GGBS	45	65%	43%	65%	85%	100%
	Control			74%	86%	97%	100%
9	GGBS	45	65%	45%	70%	87%	100%
	Control			73%	85%	96%	100%
10	GGBS	50	65%	45%	68%	86%	100%
	Control			75%	89%	94%	100%
11	GGBS	55	65%	42%	76%	91%	100%

Proceedings DOI: 10.21467/proceedings.159
ISBN: 978-81-965621-6-8

Series: AIJR Proceedings
ISSN: 2582-3922

	Control			72%	88%	92%	100%
12	GGBS	55	65%	47%	70%	85%	100%
	Control			73%	88%	96%	100%
13	GGBS	60	50%	47%	65%	87%	100%
	Control			71%	82%	94%	100%

Table 5: *Concrete Samples prepared by PWCL – Comparison against Grade Strength*

Mix Number		Grade	GGBS Content %	3-Day Strength, %	7-Day Strength, %	14-Day Strength, %	28-Day Strength, %
1	GGBS	25	60%	77%	128%	156%	186%
	Control			138%	176%	190%	218%
2	GGBS	30	35%	106%	145%	179%	204%
	Control			144%	180%	199%	216%
3	GGBS	30	60%	80%	120%	154%	192%
	Control			120%	152%	170%	185%
4	GGBS	40	50%	91%	144%	179%	211%
	Control			125%	146%	164%	171%
5	GGBS	45	35%	87%	126%	152%	170%
	Control			111%	134%	146%	154%
6	GGBS	45	40%	96%	140%	175%	185%
	Control			124%	150%	165%	174%
7	GGBS	45	60%	69%	109%	138%	163%
	Control			114%	138%	155%	168%
8	GGBS	45	65%	74%	113%	146%	173%
	Control			121%	141%	159%	164%
9	GGBS	45	65%	70%	109%	135%	155%
	Control			125%	146%	164%	171%
10	GGBS	50	65%	74%	112%	141%	165%
	Control			130%	154%	162%	172%
11	GGBS	55	65%	61%	109%	130%	144%
	Control			114%	140%	145%	158%
12	GGBS	55	65%	61%	91%	111%	131%
	Control			98%	118%	130%	135%
13	GGBS	60	50%	67%	94%	126%	144%
	Control			90%	103%	119%	127%

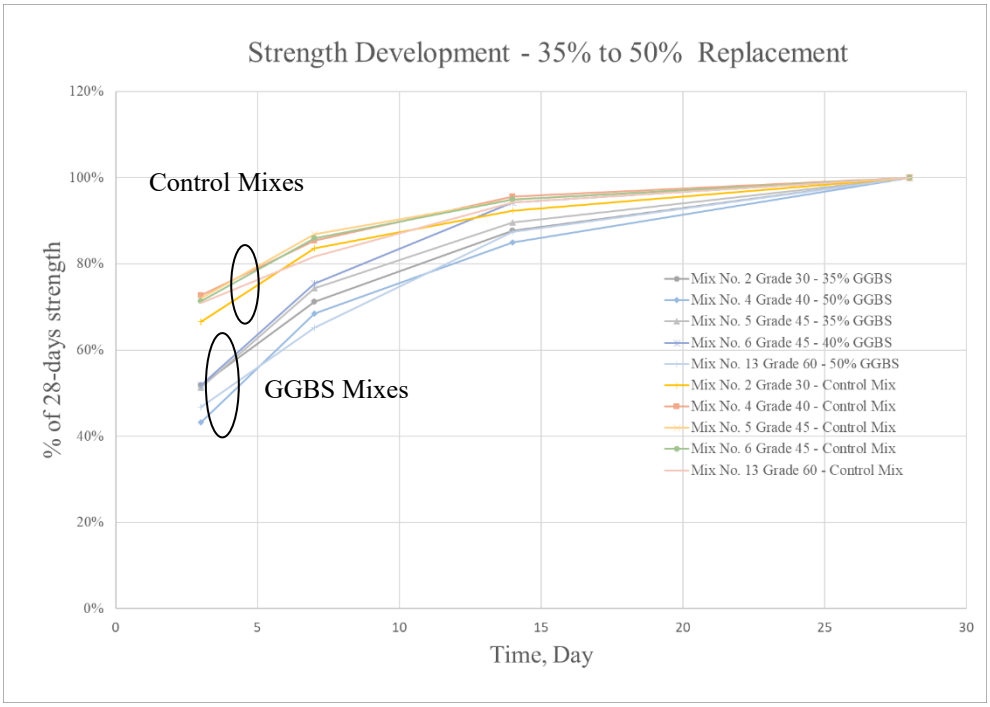

Figure 5: *GGBS Mix Strength Development – 35% to 50% Replacement*

Figure 6: *GGBS Mix Strength Development – 60% to 65% Replacement*

3.2 Concrete Samples prepared by PWCL – Shrinkage

Two numbers of 75mm x 75mm x 285 mm specimens for each GGBS mix and control mix were also prepared for evaluating their shrinkage performance at 20+/-2ºC and 60+/-5% relative humidity. The total shrinkage of the specimens was determined in accordance with BS EN 12390-16 (BSI, 2019). The results of the total shrinkage at 7 days, 14 days and 28 days as compared with the value at demoulding 1 day after casting are shown in Table 6. As observed from the results, 9 out 13 GGBS mixes (Mix Nos.

Proceedings DOI: 10.21467/proceedings.159
ISBN: 978-81-965621-6-8

Series: AIJR Proceedings
ISSN: 2582-3922

1, 2, 3, 5, 8, 10, 11, 12, 13) showed less total shrinkage than the corresponding control mixes, while the remaining mixes (Mix Nos. 4, 6, 7 and 9) showed the opposite result. No consistent trend on the influence of GGBS on shrinkage performance could be observed in this exercise. Further study on the influence of GGBS on the autogenous shrinkage and drying shrinkage, as well as to cover longer measurement periods is recommended.

Table 6: *Concrete Samples prepared by PWCL – Total Shrinkage*

Mix Number		Grade	GGBS Content %	7-Day Shrinkage, microstrain	14-Day Shrinkage, microstrain	28-Day Shrinkage, microstrain
1	GGBS	25	60%	210	317	406
	Control			226	340	459
2	GGBS	30	35%	237	319	420
	Control			221	326	430
3	GGBS	30	60%	264	408	456
	Control			249	394	480
4	GGBS	40	50%	155	247	357
	Control			222	284	307
5	GGBS	45	35%	288	348	418
	Control			322	441	574
6	GGBS	45	40%	276	319	409
	Control			274	326	409
7	GGBS	45	60%	300	370	434
	Control			167	263	395
8	GGBS	45	65%	260	356	398
	Control			259	350	467
9	GGBS	45	65%	235	287	328
	Control			222	284	307
10	GGBS	50	65%	250	312	388
	Control			256	362	504
11	GGBS	55	65%	223	256	295
	Control			245	316	388
12	GGBS	55	65%	299	361	404
	Control			260	373	462
13	GGBS	60	50%	242	284	306
	Control			243	334	406

3.3 Additional Concrete Samples obtained from On-going Public Works Construction Sites

Additional concrete cube samples were obtained from available on-going public works construction sites for testing at PWCL. The exercise involved a total of 7 mixes including 5 GGBS mixes and 2 PFA mixes. All concrete involved were ready-mix concrete produced by concrete batching plants. Cube strength tests were conducted at 3, 7, 14, 28 and 56 days, where applicable. The results available at the time of writing are summarised in Table 7. Similar to the previous exercise (PWCL mix replication exercise), the strength results were normalised as a percentage of the 28-day strengths and grade strengths, which are summarised in Table 8 and 9 respectively.

The formulas for Mix Nos. 14, 15 and 16 (produced by concrete batching plants) are similar to those of Mix Nos. 4, 6 and 8 (prepared in laboratory scale by PWCL) respectively. The results of the tests on these mixes are extracted and shown in Table 10. The results of strength tests from the two exercises at 3, 7, 14 and 28 days for the various mixes are found generally aligned, providing the authors confidence with the consistency of the results.

The PFA mixes (Mix Nos. 18 and 20) exhibit relatively high early strength gain (3-day) when compared to the GGBS mixes. However, it should be noted that for Mix. No. 20, this was possibly due to the use of 8% Condensed Silica Fume (CSF). The results of this mix was also found comparable to GGBS Mix. No. 19, which also involves the use of 8% CSF. Also, Mix No. 18 with 35% PFA involves the use of 1.5 kg/m^3 polypropylene fibre. The effect of the addition of fibres to the strength behaviour of concrete is outside the scope of this study.

The 7-day strength / 28-day strength of GGBS mixes range from 0.60 (Mix No. 17) to 0.88 (Mix No. 15), while the 56-day strength / 28-day strength ranged from 1.05 (Mix No. 17) to 1.20 (Mix No. 15).

Table 7: *Concrete Samples obtained from on-going Public Works Construction Sites – Results of Tests*

Mix Number	Grade	SCM %	3-Day Strength, MPa	7-Day Strength, MPa	14-Day Strength, MPa	28-Day Strength, MPa	56-Day Strength, MPa
14	40	50% GGBS	32.6	50.5	65.7	74.7	80.6
15	45	40% GGBS	-	66.1	71.7	75.1	90.2
16	45	65% GGBS	34.2	55.0	65.8	79.7	87.5
17	45	65% GGBS with Shrinkage Reducing Agent	29.3	40.7	51.8	67.3	70.7
18	45	35% PFA + PP Fibre	49.8	68.5	78.6	87.9	-
19	60	40% GGBS + 8% CSF	50.0	77.1	92.8	97.4	103.6
20	60	35% PFA + 8% CSF	48.7	74.4	91.5	91.2	101.6

Table 8: *Concrete samples obtained from on-going Public Works Construction Sites – Comparison by 28-Day strength.*

Mix Number	Grade	SCM %	3-Day Strength, %	7-Day Strength, %	14-Day Strength, %	28-Day Strength, %	56-Day Strength, %
14	40	50% GGBS	44%	68%	88%	100%	108%
15	45	40% GGBS	-	88%	96%	100%	120%
16	45	65% GGBS	43%	69%	83%	100%	110%
17	45	65% GGBS with Shrinkage Reducing Agent	44%	60%	77%	100%	105%
18	45	35% PFA + PP Fibre	57%	78%	89%	100%	-
19	60	40% GGBS + 8% CSF	51%	79%	95%	100%	106%
20	60	35% PFA + 8% CSF	53%	82%	100%	100%	111%

Proceedings DOI: 10.21467/proceedings.159
ISBN: 978-81-965621-6-8

Series: AIJR Proceedings
ISSN: 2582-3922

Table 9: *Concrete samples obtained from On-going Public Works Construction Sites – Comparison by Grade Strength*

Mix Number	Grade	SCM %	3-Day Strength, %	7-Day Strength, %	14-Day Strength, %	28-Day Strength, %	56-Day Strength, %
14	40	50% GGBS	81%	126%	164%	187%	201%
15	45	40% GGBS	-	147%	159%	167%	200%
16	45	65% GGBS	76%	122%	146%	177%	194%
17	45	65% GGBS with Shrinkage Reducing Agent	65%	90%	115%	149%	157%
18	45	35% PFA + PP Fibre	111%	152%	175%	195%	-
19	60	40% GGBS + 8% CSF	83%	128%	155%	162%	173%
20	60	35% PFA + 8% CSF	81%	124%	152%	152%	169%

Table 10: *Comparison of tests on samples prepared by PWCL vs samples obtained from on-going public works construction sites.*

Mix Number		Grade	GGBS Content %	3-Day Strength, MPa	7-Day Strength, MPa	14-Day Strength, MPa	28-Day Strength, MPa
4	GGBS Mix	40	50%	36.4	57.7	71.6	84.2
14	GGBS Mix			32.6	50.5	65.7	74.7
6	GGBS Mix	45	40%	43.2	62.9	78.6	83.4
15	GGBS Mix			-	66.1	71.7	75.1
8	GGBS Mix	45	65%	33.1	50.7	65.8	77.7
16	GGBS Mix			34.2	55.0	65.8	79.7

4 Observations And Recommendation

4.1 Key Observations

The key observations of the recent in-house study are summarised below: -

(a) In terms of the 28-day strength and total shrinkage, the performance of the GGBS mixes considered in this study are similar to the corresponding OPC control mixes. For certain ranges of GGBS replacement, the 28-day strengths even performed better than the corresponding OPC control mixes.

(b) The early strength development (3-day and 7-day strengths) of the GGBS mixes are slower than the OPC control mixes. Notwithstanding this, the actual strengths achieved at such early stages are considered sufficient for general civil and geotechnical engineering works.

(c) The 7-day strength / 28-day strength of the GGBS mixes ranged from 0.60 to 0.88, which are in line with the results of the LCCTC (0.65 to 0.81).

(d) The 56-day strength / 28-day strength of the GGBS mixes ranged from 1.05 to 1.20, which are in line with the results of the LCCTC (1.05 to 1.13).

(e) Some of the GGBS mixes exhibited smaller total shrinkage than the corresponding OPC control mixes, while the remaining mixes produced opposite results. No definitive relationship could be observed.

4.2 Recommendation and further work

The purpose of this study is to evaluate the performance of GGBS concrete used in recent public works contracts. Through testing of concrete specimens made by replication of the concrete mixes in laboratory environment and additional specimens collected from on-going public works construction sites, the performance of the GGBS concrete mixes considered were found to be on-par with OPC concrete mixes and are suitable for general civil and foundation works.

The scale of this study was relatively confined and its scope only covered strength tests and total shrinkage tests. More verification / study on the performance, including but not limited to the durability (e.g. chloride resistance) and heat evolution, is therefore recommended. A more focused study on the early strength development of GGBS concrete, with due consideration on the construction cycles of building works, is also recommended. PWCL is planning to conduct a further study on the performance of GGBS concrete, focusing on the recent technological advancement in this area, and the feasibility of achieving higher replacement levels, higher grade strengths with the use of locally available raw materials.

5 Declarations

5.1 Acknowledgements

This paper is published with the permission of the Head of the Geotechnical Engineering Office and the Director of Civil Engineering and Development, the Government of the Hong Kong Special Administrative Region of the People's Republic of China. The input and support from the various public works contracts in providing additional concrete specimens for this study are gratefully acknowledged.

5.2 Publisher's Note

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How to Cite

Kwok & Leung (2023). Evaluation of the Performance of GGBS Concrete used in Civil and Geotechnical Works. *AIJR Proceedings*, 316-328. https://doi.org/10.21467/proceedings.159.26

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