Performance Evaluation of Ordinary Portland Cement with GGBFS and Portland Slag Cement at Same GGBFS Replacement Level in Concrete

Ramesh Babu Chokkalingam^{1,*} and Manikandan Rajakannu²

¹ Department of Civil Engineering, Kalasalingam Academy of Research and Education, Krishnankoil, Virudhunagar, India

² Customer Support Service (Technical), ACC Cements Pvt. Ltd. Bangalore, India

Abstract. Literature review indicates that the usage of mineral admixtures (Fly ash, Ground Granulated Blast Furnace Slag, Silica Fume and Rice Husk ash) significantly improves the durability of concrete structures. Though it is reported as best alternative materials for improving durability of concrete structures, it was not very well received in government projects in India till 1990. However, for the past two decades, the usage of mineral admixtures directly or in the form of blended cement in concrete have significantly increased. Major concern of using mineral admixtures which was persisting among majority of the Ordinary Portland Cement (OPC) users are (i) delayed setting and strength gain, affecting the rate of construction, (ii) inconsistent in quality of mineral admixtures, mostly happened in site blending (iii) no established results pertains to Indian condition. In India, mostly the usage of mineral admixtures in concrete are used as a replacement for OPC, specifically in Ready Mix Concrete and site batching plant. However, few literature have reported that usage of mineral admixtures in the form of blended cement which is made at cement manufacturing plant by either intergrinding or blending will exhibits better concrete properties due to consistent quality and better quality control practice followed. Hence, the authors have undertaken this study to investigate the performance of mineral admixtures (only GGBFS) as direct replacement materials and as blended cement in concrete. In order to understand in detail, both as replacement of OPC and in the form of PSC, was undertaken on various cement content in concrete, i.e., 300, 320, 340, 360, 380 kg/m³. Results of compressive strength at various age of curing indicates that usage of GGBFS in the form of Portland Slag Cement (PSC) shows better performance than as a replacement of OPC in concrete.

1 Introduction

Literature review indicates that the usage of mineral admixtures (Fly ash, GGBFS, Silica Fume and Rice Husk ash) significantly improves the durability of concrete structures. Though it is reported as best alternative materials for improving durability of concrete

* Corresponding author: c.rameshbabu@klu.ac.in

structures, it was not very well received in government projects in India till 1990. However, for the past two decades, the usage of mineral admixtures directly or in the form of blended cement in concrete have significantly increased. Major concern of using mineral admixtures which was persisting among majority of the Ordinary Portland Cement (OPC) users are (i) delayed setting and strength gain, affecting the rate of construction, (ii) inconsistent in quality of mineral admixtures, mostly happened in site blending (iii) no established results pertains to Indian condition. In India, mostly the usage of mineral admixtures in concrete are used as a replacement for OPC, specifically in Ready Mix Concrete and site batching plant. However, few literature have reported that usage of mineral admixtures in the form of blended cement which is made at cement manufacturing plant by either intergrinding or blending will exhibits better concrete properties due to consistent quality and better quality control practice followed. Blended cements are produced by inter grinding or blending Portland cement clinker, gypsum and mineral admixtures, i.e., fly ash or GGBFS depending on the type of cement. GGBFS is a by-product from Iron ore processing industry by quenching the molten slag with water to get the sand like glassy particles. When this glassy granulate are grind to very fine particles (mostly less than 10 micron), the reactivity of particles increases and thus ground particles are called as Ground Granulated Blast Furnace Slag (GGBFS). Due to its superior property of converting the liberated calcium hydroxide from Portland cement into Calcium-Silicate-Hydrate during the secondary reaction, it exhibits the superior concrete properties such as low permeability, resistance to chloride and sulphate and corrosion [1]. Literature have reported that up to 80% of OPC can be replaced with GGBFS to achieve the superior durability performance in concrete subjected to very aggressive environment. Blended cement using GGBFS called as Portland Slag Cement (PSC) are being produced with combination of Portland cement clinker, Gypsum (5%) and GGBFS (25 to 70%) as specified in IS 455 – 2015. One of major concern as mentioned above, with usage of GGBFS in concrete is low strength gain as compared to OPC concrete leading to slow in construction activity. However, few researchers have reported that this low strength gain can be overcome by using low water-cement ratio for given replacement level [2]

Qiang et al.[3] reported that the compressive strength of concrete significantly improved after 28 days of curing for the GGBFS replacement level of 15% and 30% respectively. Khatri et al. [4] also stated that 35% GGBFS replacement shows better compressive strength at 28 days. However, Akçaozoglu and Atis[5] have found only marginal improvement in 28-days cured mortar compressive strength for 50% GGBS replacement. Guneyisi et al.[6] also reported similar observation for 40% and 60% replacement level of GGBFS. Few researchers also reported from their research studies that GGBFS in concrete improves the fluidity, reduces bleeding, reduces pore volume and hence better resistance to sulphate and chloride attack on concrete exposed to aggressive environment [7, 8]

1.1 Research Significance

Most of research studies have focused on usage of GGBFS as a replacement of OPC in concrete. However, there is no studies reported on performance of PSC in concrete. This research deals with the evaluating the performance of concrete with OPC and GGBFS and PSC at the same GGBFS level in the concrete. PSC used in this study is composed of 40% Portland cement clinker, 5% gypsum and 55% GGBFS. Hence, OPC plus GGBFS combination in concretes were kept at 45% OPC + 55% GGBS. Water cement ratio has been fixed for comparison purpose.

2 Experimental programme

2.1 Material Used

Ordinary Portland Cement (OPC-53 conforming to IS: 269 -2015), Portland Slag Cement (PSC conforming to IS: 455 – 2015) and GGBFS having the physical and chemical composition as shown in the Table 1 have been used for the present investigation. River sand and coarse aggregate (both 20 mm and 12.5mm) used in this investigation have been procured locally from Srivilliputhur, Tamilnadu, India. Aggregate properties, specific gravity, bulk density and sieve analysis are determined as per the procedures mentioned in IS 2386 (shown in Table 2 and 3). Commercially available Sulphonated Naphthalene Formaldehyde (SNF) based high range water reducer was used to maintain the workability in the concrete mix.

Table 1. Chemical composition of OPC, PSC and GGBFS

Chemical Analysis	OPC 53	PSC	GGBS
SiO ₂ %	20.52	25.66	31.86
Al ₂ O ₃ %	5.58	9.78	14.97
Fe ₂ O ₃ %	3.84	2.6	0.768
CaO%	62.40	49.0	33.75
MgO%	1.40	4.22	8.92
Actual SO ₃ %	3.18	3.42	2.45
K ₂ O%	1.07	0.61	0.55
Na ₂ O%	0.08	0.14	0.24
TiO ₂ %	-	0.41	0.34
P ₂ O ₅ %	-	0.11	0.03
MnO ₃ %	-	0.18	0.19
Cl%	0.007	0.01	0.05
Sulfate		0.28	1.08
Physical Analysis			
Blaine m ² /kg	277	340	458
R-45 Micron%	19.12	10.78	7.85

Table 2. Properties of aggregates

Materials	River sand	Coarse aggregate	
		20 mm	10 mm
Specific gravity	2.65	2.80	2.80
Water absorption, %	1.40	0.40	0.40
Fineness modulus	2.58	-	-

Table 3. Sieve analysis of River sand and Coarse aggregate

IS sieve	Weight retained (g)	Cumulative % retained	Cumulative % passing
River sand			
4.75	25	2.5	97.5
2.36	25	5	95
1.18	96	14.6	85.4
600	313	45.9	54.1
300	448	90.7	9.3
150	86	99.3	0.7
Pan	7	-	-
Coarse aggregate 20 mm			
40	0	0	100
20	1406	46.17	53.13
10	1520	97.53	2.47
4.75	74	100	0
Coarse aggregate 12.5 mm			
16	0	0	100
12.5	85	2.83	97.17
10	1995	69.33	30.67
4.75	850	97.67	2.33

2.2 Mix Proportions

The performance of GGBFS in the form of cement, i.e., PSC and as a replacement for OPC in concrete have been studied under two different mix proportions as shown in the Table 4 and 5. For both the mix proportions, various cementitious content have been used, i.e., 300, 320, 340, 360 and 380 kg/m³. The GGBFS percentage in the second study is arrived based on the GGBFS percentage in PSC which is approximately 55%. Concrete were made using drum mixer and the slump of concrete after mixing was maintained between 100 to 120 mm. The water content for both the mix were kept constant to study the strength gain tendency. However, the resultant slump drop is being addressed by addition of admixtures, to achieve the target slump. The admixture dosage in the each mix was varied to achieve the target slump of 100 to 120mm. The compressive strength of concrete was evaluated using 150 mm cube and each results are average of three specimen. Concrete cubes were demoulded after 24hrs and the specimens were cured in water tank till testing date. Compressive strength tests were carried out at the end of 1, 3, 7, and 90 days for the concrete cube specimens, using a Compression Testing Machine (CTM) as per IS: 516-1959.

Table 4. Mix proportion for PSC concrete

Mix ID	Cement content, kg/m ³	Water, kg/m ³	Coarse aggregate, kg/m ³		Sand, kg/m ³	Admixture, kg/m ³
			20 mm	12.5 mm		
PSC300	300	156	722	482	777	2.70
PSC320	320	160	712	475	766	2.88
PSC340	340	163	703	468	756	3.06
PSC360	360	162	698	465	750	3.24
PSC380	380	152	750	412	754	3.42

Table 5. Mix proportion for OPC+GGBS concrete

Mix ID	Cement content, kg/m ³	GGBFS, kg/m ³	Water, kg/m ³	Coarse aggregate, kg/m ³		Sand, kg/m ³	Admixture, kg/m ³
				20 mm	12.5 mm		
OPC-G300	135	165	156	774	516	833	2.70
OPC-G320	144	176	160	705	470	758	3.84
OPC-G340	153	187	163	696	464	748	4.08
OPC-G360	162	198	162	690	460	742	4.32
OPC-G380	171	209	152	693	462	745	4.56

3 Results and Discussions

Figure 1 shows the compressive strength development of PSC300 and OPC-GOPC-G300 concretes at 3, 7, 28 and 90 days. At 3 days, the strength development of PSC concretes was lower than that of OPC-GOPC-G. However, after 7 days, the compressive strength of PSC concrete was higher than that of OPC-G concretes. At 90 days, there is no significant difference in compressive strength of PSC and OPC-G concretes.

Figure 2 shows the compressive strength development of PSC320 and OPC-G320 concretes at 3, 7, 28 and 90 days. At 3 days, the strength development of PSC concretes was lower than that of OPC-G. However, after 7 days onwards, the compressive strength of PSC concrete was higher than that of OPC-G concretes. At 90 days, there was not much difference in compressive strength of PSC and OPC-G concretes. The strength development pattern is very similar for both 300 and 320 kg/m³.

Fig. 1. Compressive strength results of PSC and OPC-G concretes at 300 kg/m³ cementitious content

Fig. 2. Compressive strength results of PSC and OPC-G concretes at 320 kg/m³ cementitious content

Figure 3 shows the compressive strength development of PSC340 and OPC-G340 concretes at 3, 7, 28 and 90 days. At 3 days, the strength development of PSC concretes was slightly higher than that of OPC-G. But from 7 days onwards, the compressive strength of PSC concrete was higher than that of OPC-G concretes. The strength development of PSC concretes was always higher than that of OPC-G concretes at 340kg/m³ cementitious content.

Fig. 3. Compressive strength results of PSC and OPC-G concretes at 340 kg/m³ cementitious content

Fig. 4. Compressive strength results of PSC and OPC-G concretes at 360 kg/m³ cementitious content

Figure 4 shows the compressive strength development of PSC360 and OPC-G360 concretes at 3, 7, 28 and 90 days. Similar to 340kg/m³ cementitious content mix, the strength development of PSC concretes was always higher than that of OPC-G concretes at 360kg/m³ cementitious content.

Figure 5 shows the compressive strength development of PSC380 and OPC-G380 concretes at 3, 7, 28 and 90 days. The same trend was followed like 360kg/m³ cementitious content. The strength development of PSC concretes was higher at all ages than OPC-G concretes. The difference in strength at 90 days between PSC and OPC-G was higher in cementitious content 360 and 380kg/m³. From the results, it has been revealed that at lower cementitious content 300 and 320kg/m³ there was not much difference between PSC and OPC-G concretes. But at higher cementitious content such as 340, 360 and 380 kg/m³, the PSC concrete shows higher strength at later ages. From this study, it has been concluded that PSC concretes performs better than OPC+GGBS combination, when the replacement level was same in both cases.

Fig. 5. Compressive strength results of PSC and OPC-G concretes at 380 kg/m³ cementitious content

3 Conclusions

The conclusions drawn from this experimental studies and summarised below are applicable to the properties of raw materials used and methodology of investigation adopted.

1. Replacement of OPC with GGBFS in concrete shown relatively low strength development for most of cement content in the concrete as compared to PSC concrete.
2. Use of PSC as cement directly in concrete mix, shown significant strength development for age of curing up to 28 days for most of the cement content.
3. However, at the low cement content i.e., 300 and 320 kg/m³, the rate of strength development for PSC concrete cured at 3 days shown marginally low strength gain as compared to OPC and GGBFS concrete.

At higher level of cement content, between 340 to 380 kg/m³, the compressive strength development at all age of curing, exhibits significant strength development over OPC plus GGBFS concrete. This is mainly attributed to reduced

vairation in cement quality and optimised quantity of gypsum in the resultant concrete for better strength development.

References

1. A. Abdel Rahman, S. A. Abo-El-Enein, M. Aboul-Fetouh and K. H. Shehata, Characteristics of Portland blast furnace slag cement kiln dust and active silica, *Arabian Journal of Chemistry* ,pp1-6. (2011)
2. S. Teng, T.Y.D. Lim, and B.S. Divsholi, Durability and mechanical properties of high strength concrete incorporating ultra fine ground granulated blast furnace slag, *Construction and Building Materials*, **40**, pp875-881 (2013)
3. W. Qiang, Y. Peiyu, Y. Jianwei, and Z. Bo., Influence of steel slag on mechanical properties and durability of concrete, *Construction and Building Materials*, **47**, pp1414-1420 (2013)
4. R. Khatri, V. Sirivivatnanon, and W. Gross, Effect of different supplementary cementitious materials on mechanical properties of high performance concrete, *Cement and Concrete Research*, **25**, 1, 209-220. (1995)
5. S. Akcaozoglu, and C.D. Atis, Effect of granulated blast furnace slag and flyash addition on the strength properties of light weight mortars containing waste PET aggregates, *Construction and Building Materials*, **25**, pp4052-4058(2011)
6. E. Guneyisi, M. Gesoglu. and E. Ozbay, Strength and drying shrinkage properties of self-compacting concretes incorporating multi-system blended mineral admixtures, *Construction and Building Materials*, **24**, pp1878-1887 (2010)
7. J.M. Gao, C.X. Qian, H.F. Liu, B. Wang, and L. Li, ITZ microstructure of concrete containing GGBS, *Cement and Concrete Research*, **35**, 7, pp1299-1304 (2005)
8. R. Luo, Y. Cai, C. Wang, and X. Huang, Study of chloride binding and diffusion in GGBS concrete, *Cement and Concrete Research*, **31**, 8, pp1-7. (2003)
9. IS 383, Specification for Coarse and Fine Aggregate from Natural Sources for Concrete, Bureau of Indian Standards, New Delhi, India
10. IS 516-1959, Methods of Tests for Strength of Concrete, Bureau of Indian Standards, New Delhi, India
11. IS 2386, Methods of Test for Aggregate in Concrete, Bureau of Indian Standards, New Delhi, India
12. IS 10262-2009, Recommended Guidelines for Concrete Mix Design, Bureau of Indian Standards, New Delhi, India
13. IS 455-1989, Portland Slag Cement - Specifications, Bureau of Indian Standards, New Delhi, India
14. IS 12269-2013, Ordinary Portland Cement, 53 Grade- Specifications, Bureau of Indian Standards, New Delhi, India