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Mechanical Properties of Fly-Ash and GGBS Partial Cement Replacement in Reinforced High Strength Self-Compacting Concrete

Balachandu koya

Research Scholar & Civil and Structural Engineering Department & Sri Chandrasekharendra Saraswathi Viswa Mahavidyalaya, Kancheepuram, Tamilnadu, India

N. Seshadrisekhar

Associate Professor and HOD & Civil and Structural Engineering Department & Sri Chandrasekharendra Saraswathi Viswa Mahavidyalaya, Kancheepuram, Tamilnadu – 631561, India

Abstract - The mechanical parameters of high strength self-compacting concrete (HSSCC) made with various cement replacement combinations including cementitious material such as fly ash and ground granulated blast furnace slag GGBS, namely Strengths in compression, flexural stiffness, and split tensile strength, were investigated. In addition, steel reinforcement was added to examine the improvement in mechanical strength. The self-compacting concrete (SCC) is first tested for its basic qualities and filling ability, flow-ability, and passing ability. Concrete specimens that have been hardened are subjected to additional tests for Strengths in compression, flexural stiffness and split tensile strength. In order to investigate the changes in the fresh and hardened characteristics of high strength self-compacting concrete with different cementitious material replacements, various proportions of GGBS, fly-ash, and GGBS+ fly-ash are used in the production of various mixes. Compressive strength of 68.97 MPa, tensile strength of 7.5 MPa, and flexural strength of 8.9 Mpa were found in the mixture containing 20% GGBS and 0.28 water-cement ratio. Furthermore, the results showed that the load-displacement behavior improved significantly with varied cementitious material replacement contents (0 percent, 10% Fly ash, 10% GGBS, 10%Fly-ash+GGBS and 20%Fly-ash+GGBS). The results showed that the workability of HSSCC with Steel Reinforcement is strongly influenced.

Keywords - High strength self compacting concrete, Fly ash, Ground granulated blast-furnace slag, Mechanical properties

I. INTRODUCTION

Concrete that can flow and compact under its own weight without the aid of external vibrations is known as self-compacting concrete (SCC). It can also fill formwork while maintaining homogeneity and preventing the migration or separation of its large components, even in the presence of heavily reinforced concrete[1,2]. Several researchers [3-6] have described SCC in nearly identical terms to a highly flow-able concrete that must fulfil the flow-ability, passage ability, and segregation resistance characteristics. To improve SCC, several supplementary cementitious materials (SCMs) such as fly ash (FA) [7-14] and ground granulated blast-furnace slag (GGBS) [9] have been used throughout the past two decades. The adoption of different SCMs can have a significant impact for both the fresh and hardened stages [7-14]. Their particle size is less than or equal to that of portland cement (PC) and they display pozzolanic activity during hydration processes. All SCMs generally share these two characteristics. Cementitious value is minimal or nonexistent for pozzolans. These include silica (SiO_2) in reactive form. When finely divided and in the presence of moisture at normal temperatures, they chemically react with calcium hydroxide (CH) to produce cementitious compounds [15,16].

Ground granulated blast-furnace slag (GGBS) is a by-product of the iron-making blast furnaces. Using it in numerous nations throughout the world has yielded a number of technological advantages in the building sector [17,18]. There are several benefits of adding GGBS to self-compacting concrete that include enhancing its compactability and consistency while preserving the cement against both chloride, and sulphate attack [19]. Substituting PC for the same amount of cement with GGBS results in a larger paste volume, which considerably improves the flowability of the finished product. Oner and Akyuz [20] found that the water to binder ratio decreases for the same consistency as GGBS concentration increases, suggesting GGBS has a positive effect on the consistency. They also stated that the compressive strength of concrete mixtures containing GGBS rises as the GGBS replacement level increases.

A byproduct of coal-fired power stations is fly ash (FA) or pulverized fuel ash (PFA). In SCC, pozzolanic characteristics allow it to be used as a partial alternative for cement. FA may replace up to 30% of the bulk of PC while improving both the fresh and hardened characteristics of SCC. It takes longer for FA concretes to reach their full strength potential than typical PC based concretes. Because of its compact spherical form, FA can improve the rheological properties of SCC while also lowering water consumption [21]. Further investigations have shown that adding FA to super flowing concrete and substituting 30% of the cement with it can produce a material with exceptional workability [22]. SCC's reactivity can also be enhanced by the addition of fly ash. Increased compressive strength, greater durability, and decreased drying time can result from this phenomenon [23]. Another benefit of using fly ash is that it reduces bleeding and promotes stability [24].

The primary goal of this present study was to incorporate two types of SCMs such as fly ash and ground glass fibre reinforced concrete (GGBS) into SCC. And also investigate their effects on microstructure, and hardened at different replacement levels of cement (10 and 20 weight percent for FA and GGBS, respectively). It has been reported in the previous studies that the concrete blended with SCMs exhibits improved strength and pore structure in many cases [26-30]. And also in this study, investigates the behavior of HSSCC in compressive strength, splitting tensile strength, and flexural strength to learn about the current situation in the concrete industries of Fly ash and GGBS combination

II. EXPERIMENTAL STUDY

Raw Materials and its properties

Cementitious materials used in this study include OPC [43 Grade] conforming to IS: 269 – 2015, Fly-ash [8]class F (Type II) and GGBS [9]. Table1 shows the chemical, physical, and mechanical properties of OPC, fly ash, and GGBS [32]. Fine aggregates were made from a mixture of river sand with a specific gravity of 2.85 and coarse aggregates with a specific gravity of 2.84. HI-FORZA864, poly-carboxylate based super plasticizers were added to all mixes to fulfil ASTM C 494-13 workability limitations. The main reinforcement was made of 12 mm diameter thermal mechanically treated (TMT) bars that confirmed IS 1786:2000 standards, and the stirrups were made of mild steel rods 8mm in diameter. The mechanical properties of steel are shown in Table 2. Fresh, clean, and potable water should be used in the mixing process. Mixing was done with water that was safe to drink.

Table 1

Physical Properties of Material

S. No.	Material	Specific Gravity
1	Cement	3.15
2	Fly-ash	2.4
3	GGBS	2.62
4	Fine Aggregate	2.56
5	Coarse Aggregate	2.66

Table 2

Mechanical Properties of Steel

S.No.	Parameter	As Per 1786:2008 Specifications
1	Grade of Steel	Fe500
2	Ultimate Tensile Strength (Mpa.)	545
3	Yield Stress (Mpa.)	500
4	Elongation (%)	12

Casting and testing of concrete mixtures

There are seven different cementitious replacement content percentages in this mix. They are 0%, 10% fly ash, 20% fly ash, 10% GGBS, 20% GGBS, 10% fly ash and GGBS, and 20% fly ash + GGBS by volume. The mixture designs are shown in Table 3 for this concrete grade 60 mix with a w/c ratio of 0.28. Concrete mixture proportions were determined to meet an air content requirement according to EFNARC guidelines and the results are shown in Table 4. They were made into cubes, beams, and cylindrical samples for M60 concrete. Materials and mix proportions can have a significant impact on a material's ability to self-compact. IS:516-1959 compression tests were carried out at 3, 7, and 28 days, while IS 14858:2000 was used to verify equipment specifications. The tensile and flexural tests were performed for 3, 7, and 28 days for each mixture, and the average values were reported [32].

III. RESULTS AND DISCUSSIONS

Self compacting test results for fresh concrete

The self-compacting experiment was conducted for the fresh concrete based on the suitable concrete mix proportions which was shown in table 3. IS 7325:1974 specifications and regulations are used to build the experimental equipment for testing fresh self compacting concrete characteristics such as slump flow, V-funnel, L-box, and U-Box [7,14]. Initially, the equipments were checked thoroughly for these tests to identify whether they are functioning as expected or not. The study focuses mostly on concrete in its natural state. To determine if concrete is SCC or not, fresh-concrete behavior is used, and the fluid is the vital factor in determining whether or not the concrete is SCC. Slump flow, V-funnel, L-box, and U-Box, and T 50 cm slump test are conducted for all mixes in this experiment [32-33]. and shown in Table 4.

Table 3

MIX PROPOTIONS

Items	**0%**	**10% Fly Ash**	**20% Fly Ash**	**10% GGBS**	**20% GGBS**	**10% (Flyash+ GGBS)**	**20% (Flyash + GGBS)**
Cement	450	405	360	405	360	405	360
Fly-Ash	0	45	90	0	0	22.5	45
GGBS	0	0	0	45	90	22.5	45
Fine Aggregate	900	900	900	900	900	900	900
Coarse Aggregate	900	900	900	900	900	900	900
W/c Ratio	0.28	0.28	0.28	0.28	0.28	0.28	0.28
SP (%)	0.5	0.5	0.5	0.5	0.5	0.5	0.5

Table 4

Fresh Concrete Properties

Test		**Slump Flow**	**T50 Slump**	**V - Funnel**	**L - Box**	**U - Box**
Unit		**mm.**	**Sec**	**Sec**	**%**	**mm.**
EFNARC Values Limits		650-800	2-5	6-12	0.8-1.0	0-30
Replacement	**0%**	700	3	7.0	0.9	25
	10% Fly Ash	745	2.7	9	0.85	27
	20% Fly Ash	765	2.7	9	0.85	28
	10% GGBS	740	2.5	8	0.8	29
	20% GGBS	770	2.6	8.5	0.8	28
	10% (Fly Ash + GGBS)	740	2.9	10	0.84	28
	20% (Fly Ash + GGBS)	745	3.0	10	0.8	28

B. Hardened Concrete test results.

All of the HSSCC mixtures' compressive strengths are shown in Fig.1. These graphs compare the compressive strength (CS) of concrete with different percentages of admixture replacement [16]. The average CS of concrete cubes with 0% replacement at 3 days is 34.2 N/mm^2, at 7 days is 56.4 N/mm^2 and at 28 days is 65.9 N/mm^2. The average CS of concrete cubes with 10% replacement of fly ash at 3 days is 32.5 N/mm^2, at 7 days is 56.4 N/mm^2 and at 28 days is 63.73 N/mm^2. The average CS of concrete cubes with 10% replacement of GGBS at 3 days is 33.49 N/mm^2, at 7 days is 56 N/mm^2 and at 28 days is 65.38 N/mm^2. The average CS of concrete cubes with 10% replacement of fly ash + GGBS at 3 days is 31.29 N/mm^2, at 7 days is 53.66 N/mm^2 and at 28 days is 66.8 N/mm^2. The average CS of concrete cubes with 20% replacement of fly ash + GGBS at 3 days is 36.3 N/mm^2, at 7 days is 58.9 N/mm^2 and at 28 days is 67.6 N/mm^2. At 3 days, 7 days, and 28 days, it shows that the strength of admixtures at 20% replacement of fly ash + GGBS is slightly greater than 0% replacement. However, the strength gained by substituting fly ash + GGBS for 20% of the original amount is acceptable.

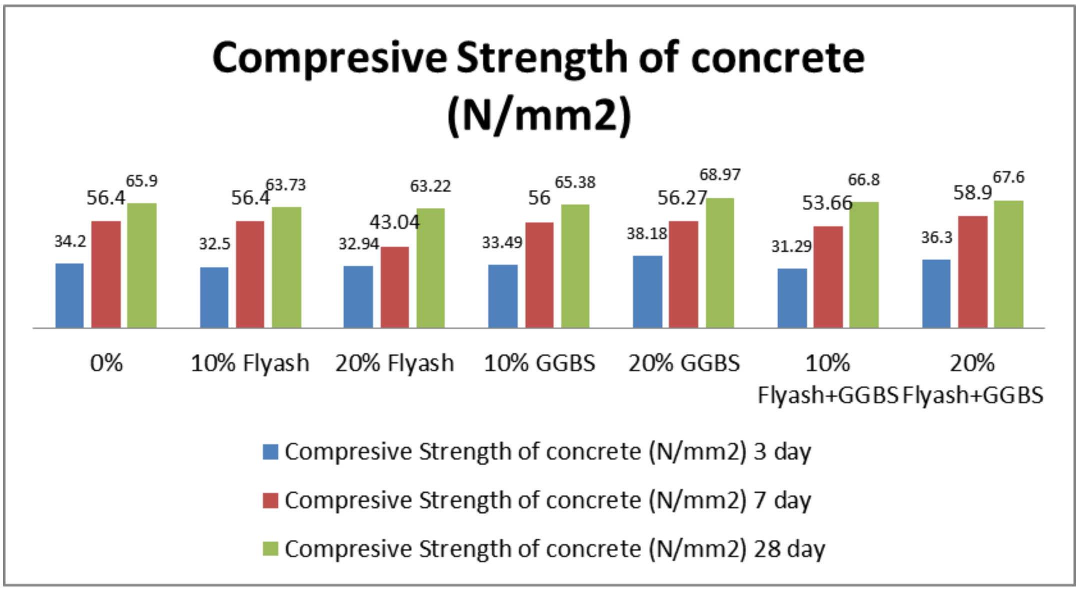

Figure1

Compressive Strength

Fig.2 shows the split tensile strength (STS) values for HSSCC mixtures. Comparing the STS of concrete at varying percentages of cement replacement with admixtures is depicted in this graph. The average STS of concrete cubes with 0% replacement at 3 days is 3.87 N/mm^2, at 7 days is 4.5 N/mm^2 and at 28 days is 6.4 MPa. The average STS of concrete cubes with 10% replacement of fly ash at 3 days is 3.32 MPa, at 7 days is 4.4 N/mm^2 and at 28 days is 6.4 N/mm^2. The average STS of concrete cubes with 10% replacement of GGBS at 3 days is 3.47 N/mm^2, at 7 days is 5.2 N/mm^2 and at 28 days is 7.2 N/mm^2. The average STS of concrete cubes with 10% replacement of fly ash + GGBS at 3 days is 3.31 N/mm^2, at 7 days is 4.2 N/mm^2 and at 28 days is 6.9 N/mm^2. The average STS of concrete cubes with 20% replacement of fly ash + GGBS at 3 days is 4.05 N/mm^2, at 7 days is 5.4 N/mm^2 and at 28 days is 7.4 N/mm^2. First, the strength of admixtures 0 percent replacement is lower than the strength of admixtures 20 percent replacement. Since at the end of 28 days the 20% fly ash + GGBS concrete split tensile strength was higher than the 0% replacement. However, the strength gained by substituting fly ash + GGBS for 20% of the original amount is acceptable.

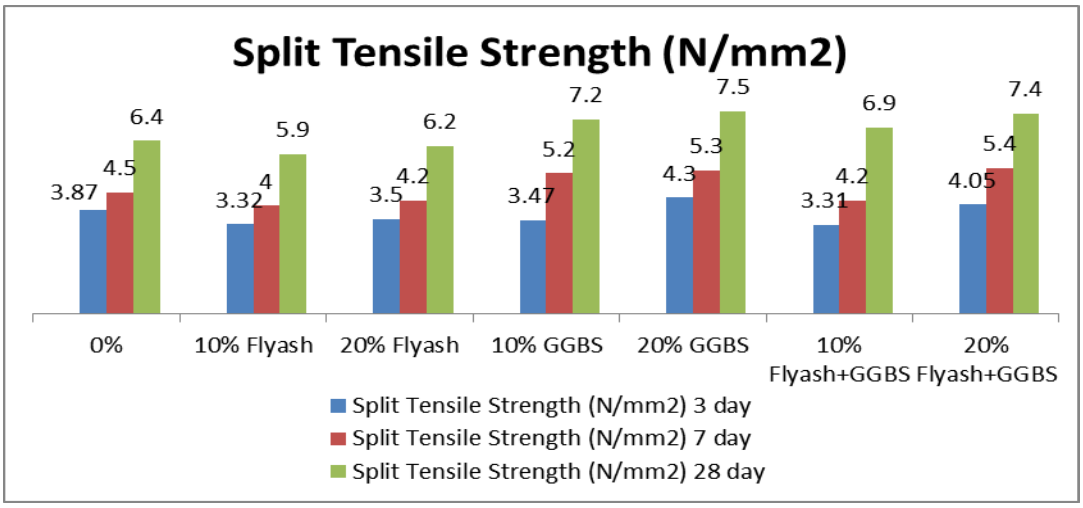

Figure 2

Split Tensile Strength

Figure 3 shows the flexural strengths (FS) of HSSCC mixtures. These graphs compare the FS of concrete with different percentages of admixtures in the mix. The average FS of concrete cubes with 0% replacement at 3 days is 6.3 N/mm^2, at 7 days is 7.2 N/mm^2 and at 28 days is 8.44 N/mm^2. The average FS of concrete cubes with 10% replacement of fly ash at 3 days is 6.15 N/mm^2, at 7 days is 6.8 N/mm^2 and at 28 days is 8.54 N/mm^2. The average FS of concrete cubes with 10% replacement of GGBS at 3 days is 5.55 N/mm^2, at 7 days is 7.15 N/mm^2 and at 28 days is 8.65 N/mm^2. The average FS of concrete cubes with 10% replacement of fly ash + GGBS at 3 days is 5.85 N/mm^2, at 7 days is 7.3 N/mm^2 and at 28 days is 8.76 N/mm^2. The average FS of concrete cubes with 20% replacement of fly ash + GGBS at 3 days is 6.47 N/mm^2, at 7 days is 7.36 N/mm^2 and at 28 days is 8.94 N/mm^2. First, the strength of admixtures 0 percent replacement is lower than the strength of admixtures 20 percent replacement. However, the strength gained by substituting Fly ash + GGBS for 20% of the original amount is acceptable. After 28 days, the concrete's FS had surpassed that of a mix with 0 percent admixture replacement.

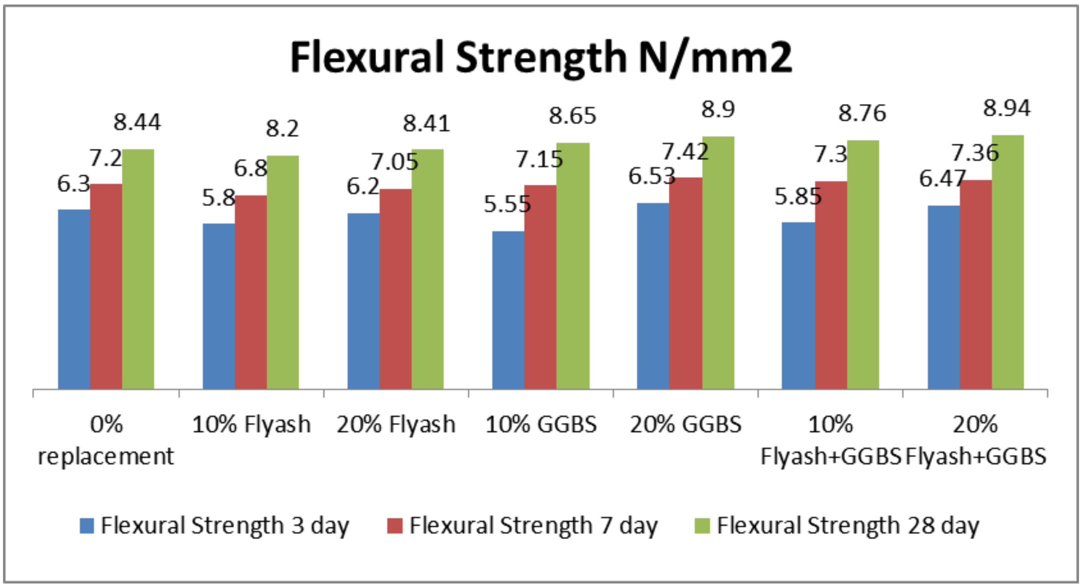

Figure 3

Flxural Strength

Notched prismatic high strength self-compacting concrete (HSSCC) reinforced specimens were subjected to two-point bending tests with different percentages of replacement of admixtures, respectively, and the load–displacement curves are shown. Shows how different admixture content volumes affect HSSCC properties such as the area under the load–displacement curve, maximum displacement and peak load. Fig. 4 shows the Load deflection curve for RC Beams at various percentages of cement replacement with admixtures, as shown in the figure. At 3 days, 7 days, and 28 days, the strength of admixtures 0 percent replacement is slightly greater than the strength of 20 percent replacement of fly ash + GGBS. However, the strength gained by substituting fly ash + GGBS for 20% of the original amount is acceptable. HPSCC strength varies with respect to time due to various factors, and it has been demonstrated that an SCC takes 90 to 180 days to reach its maximum compressive strength.

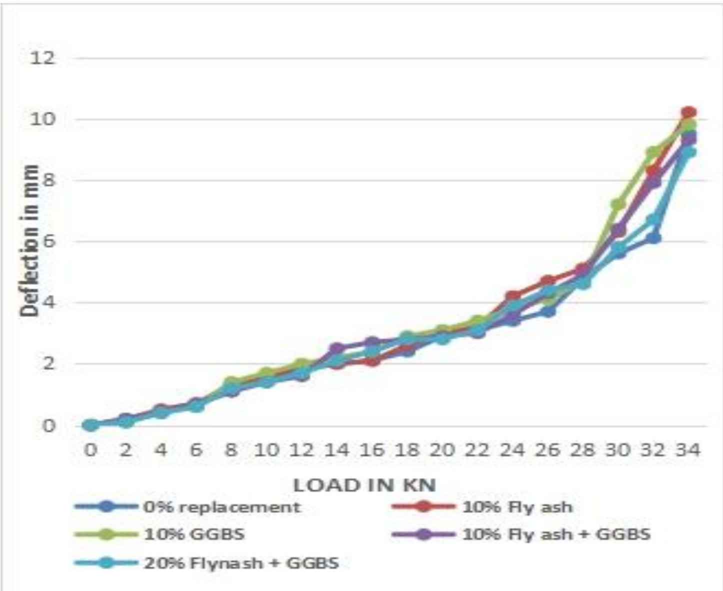

Figure.

4 Load vs Deflection curve for RC Beam

IV. Conclusions:

The industrial byproducts usage such as GGBS as an additive to self-compacting concrete is a new concrete research trend that would benefit from the disposal of industrial waste. This study examined the workability, compressive strength, and flexural strength of SCC made with GGBS and super plasticizers. It's possible, based on the findings, to draw the following conclusions.

- Workability tests on fresh SCC showed that SCC with GGBS added achieved uniformity and self compatibility without any external vibration or compaction under its own weight, as demonstrated by slump flow and L box tests.

- With the addition of VMA and SP, the workability of concrete improves as more cement is replaced with GGBS. Workability and desired results are the primary factors in selecting this mix design.
- In comparison to a 20% GGBS replacement in concrete, the initial strength remains unchanged with no replacement of concrete.
- It was found that concrete cube specimens with 20% of fly ash + GGBS replacement cement had the maximum compressive strength of 67.5 MPA compared to the control cube specimens.
- When fly ash + GGBS was used as a 20% replacement for cement in concrete specimens, the split tensile results were better than the control specimens.
- The flexural strength for the concrete specimens with replacement of cement with 20% fly ash + GGBS was 8.78 higher than that of the control specimens.
- Specimens' results for split tensile strength, compressive strength, and flexural strength are acceptable.

REFERENCE

[1] BS EN 206-9, Concrete, Part 9: Additional rules for self-compacting concrete (SCC), British Standards publication, 2010.

[2] The Concrete Society, BRE. Technical Report No.62 Self-compacting Concrete: A Review, in: R.T.U. Day, I.X. Holton (Ed.), Camberley, UK, Concrete Society, Surrey GU17 9AB, UK, 2005.

[3] K. Ozawa, K. Maekawa, M. Kunishima, H. Okamura, Development of high performance concrete based on the durability design of concrete structures, in: Proceedings of the 2nd East-Asia and Pacifific Conference on Structural Engineering and Construction (EASEC-2), 1, 1989, pp. 445-450

[4] P.J.M. Bartos, D.L. Marrs, Development and testing of self-compacting grout for the production of SIFCON, in: H.W. Reinhardt, A.E. Maaman (Eds.), Proceedings of International Workshop on High Performance Fibre Reinforced Cement Composites, Germany, 1999, pp. 171–180.

[5] K.H. Khayat, Workability, testing, and performance of self-consolidating concrete, ACI Mater. J. 96 (3) (1999) 339–346.

[6] L. Thrane, P. Szabo, M. Geiker, M. Glavind, H. Stang, Simulation of the test method ‘‘L-box” for self-compacting concrete, Ann. Trans. Nordic Rheol. Soc. 12 (2004) 47–54.

[7] J.T. Ding, Z. Li, Effects of metakaolin and silica fume on properties of concrete, ACI Mater. J. 99 (4) (2002) 393–398.

[8] R. Siddique, J. Klaus, Inflfluence of metakaolin on the properties of mortar and concrete: a review, Appl. Clay Sci. 43 (2009) 392–400.

[9] K. Kovler, N. Roussel, Properties of fresh and hardened concrete, Cem. Concr. Res. 41 (2011) 775–792.

[10] A.A. Ramezanianpour, H. Bahrami Jovein, Inflfluence of metakaolin as supplementary cementing material on strength and durability of concretes, Constr. Build. Mater. 30 (2012) 470–479.

[11] J. Bai, B.B. Sabir, S. Wild, J.M. Kinuthia, Strength development in concrete incorporating PFA and Metakaolin, Mag. Concr. Res. 52 (3) (2000) 153–162.

[12] J. Bai, S. Wild, B.B. Sabir, Chloride ingress and strength loss in concrete with different PC–PFA–MK binder compositions exposed to synthetic seawater, Cem. Concr. Res. 33 (3) (2003) 353–362.

[13] J. Bai, S. Wild, B.B. Sabir, Sorptivity and strength of air-cured and water-cured PC–PFA–MK concrete and the inflfluence of binder composition on carbonation depth, Cem. Concr. Res. 32 (11) (2002) 1813–1821.

[14] J. Bai, S. Wild, Investigation of the temperature change and heat evolution of mortar incorporating PFA and metakaolin, Cement Concr. Compos. 24 (2) (2002) 201–209.

[15] R. Lewis, L. Sear, P. Wainwright, R. Ryle, in: J. Newman, B.S. Choo (Eds.), Advanced concrete technology- constituent materials, Cementitious Additions, Elsevier Ltd, Oxford, 2003, pp. 96–159.

[16] P.L. Domone, J.M. Illston, Construction Materials: Their Nature and Behaviour, fourth ed., Taylor and Francis Publication, 2010, ISBN 041546515X. pp. 590.

[17] M. Uysal, M. Sumer, Performance of self-compacting concrete containing different mineral admixtures, Constr. Build. Mater. 25 (11) (2011) 4112–4120.

[18] P. Dinakar, K.P. Sethy, U.C. Sahoo, Design of self-compacting concrete with ground granulated blast furnace slag, Mater. Des., 0261-3069 43 (2013) 161– 169, http://dx.doi.org/10.1016/j.matdes.2012.06.049.

[19] W.B. Russel, High performance concrete-from buildings to bridges, Concr. Int. 19 (8) (1997) 62–63.

[20] A. Oner, S. Akyuz, An experimental study on optimum usage of GGBS for the compressive strength of concrete, Cement Concr. Compos. 29 (6) (2007) 505– 514.

[21] E.P. Koehler, D.W. Fowler, E.H. Foley, G.J. Rogers, S. Watanachet, M.J. Jung. Self-Consolidating Concrete for Precast Structural Applications: Mixture Proportions, Workability, and Early-Age Hardened Properties, Aggregates Foundation for Technology: Research and Education, University of Texas, Austin, CTR Technical Report: 0–5134-1, 2007, pp. 348.

[22] J.K. Kim, S.H. Han, Y.D. Park, J.H. Noh, C.L. Park, Y.H. Kwon, S.G. Lee, Experimental research on the material properties of super flflowing concrete, in: P.J.M. Bartos, D.L. Marrs, D.J. Cleland (Eds.), Production Methods and Workability of Concrete, E&FN Spon, 1996, pp. 271–284.

[23] K.H.H.R.H. Obla, M. Thomas, S.G. Shashiprakash, O. Perebatova, Properties of concrete containing ultra-fifine flfly ash, ACI Mater. J. 100 (5) (2003) 426–433.

[24] R. Shadle, S. Somerville. The benefifits of utilizing fly ash in producing self-compacting concrete. in: 1st North American Conference on the Design and Use of Self-Consolidating Concrete, Chicago,2002, pp. 217–222.