ASIAN JOURNAL OF CIVIL ENGINEERING (BUILDING AND HOUSING) VOL. 9, NO. 1 (2008)
PAGES 61-74

STRENGTH DEVELOPMENT OF CEMENT MORTAR AND CONCRETE INCORPORATING GGBFS

M. Shariq*, J. Prasad and A.K. Ahuja
Department of Civil Engineering, IIT Roorkee, India

Abstract

In the present study, the effect of curing procedure on the compressive strength development of cement mortar and concrete incorporating ground granulated blast furnace slag is studied. The compressive strength development of cement mortar incorporating 20, 40 and 60 percent replacement of GGBFS for different types of sand and strength development of concrete with 20, 40 and 60 percent replacement of GGBFS on two grades of concrete is investigated. The compressive strength of cement mortar and concrete obtained at the ages of 3, 7, 28, 56, 90, 150 and 180 days. Tests results show that the incorporating 20% and 40% GGBFS is highly significant to increase the compressive strength of mortar after 28 days and 150 days respectively. The magnitude of compressive strength of mortar for standard sand is higher than the magnitude of river sand. Incorporating 60% BFS replacement is showing lower strength at all ages and water-cement ratio for both types of sand. The compressive strength of OPC concrete shows higher strength as compare to the GGBFS based concrete for all percent replacement and at all ages. Incorporating 40% GGBFS is highly significant to increase the compressive strength of concrete after 56 days than the 20 and 60% replacement. Among GGBFS based concrete 40% replacement is found to be optimum.

Keywords: Blast furnace slag; compressive strength; cement mortar; concrete; curing; time

1. Introduction

The reuse of industrial by products is gaining popularity since last few decades due to its long-term performance characteristics. Concrete is known for its compressive strength which is an important property in the design and the construction of the concrete structures. Although, concrete is very strong in compression, but, due to the development of various types of admixtures, it is necessary to investigate the effect of mineral admixtures on the compressive strength of cement mortar and concrete. Literature shows that very little data is available on the strength development of mortar and concrete containing ground granulated blast furnace slag (GGBFS) [1-8]. For this purpose, experimental investigation is carried out to

*E-mail address of the corresponding author: mshariqdce@gmail.com

develop the data on the compressive strength development of mortar and concrete with time and with different percent replacement of GGBFS. The objectives of the present study are:

- To select the GGBFS mix proportion for cement mortar and OPC concrete.
- To investigate the effect of fine aggregates on compressive strength development of cement mortar with GGBFS replacement.
- To perform the experiments on the time-dependent compressive strength of cement mortar and concrete containing GGBFS. The strengths were measured at the age of 3, 7, 28, 56, 90, 150 and 180 days.

2. Experimental Program

2.1 Materials properties

Two strength of concrete is obtained on the basis of trial in the present study, i.e. 46.50 MPa and 37.09 MPa concrete and designated as Mix-I and Mix-II. The test specimen were cast using cement, fine aggregate, coarse aggregate, water and GGBFS. The materials, confirmed to the specification laid down in the relevant Indian Standard codes. The following section describes the physical properties of the material used in the study.

Table 1. Physical properties of ordinary portland cement (OPC)

Characteristics	Experimental values
Blaine's fineness (m^2/kg)	301
Specific gravity	3.15
Soundness (mm)	3.5
Normal consistency (%)	
OPC	27
OPC + 20% BFS	28.5
OPC + 40% BFS	29.5
OPC + 60% BFS	31
Setting time (minutes)	
(i) Initial	105
(ii) Final	180
Compressive strength (MPa)	
(i) 3-days	24
(ii) 7-days	34
(iii) 28-days	45

2.2 Cement and GGBFS

Ordinary Portland Cement 43 grade (OPC 43) was used throughout the investigation. The physical properties of cement are given in Table 1. All the tests were carried out as per the recommendation of IS 4031-1988 [9]. The cement was stored in airtight silos to prevent from the moisture. The GGBFS used in the present investigation was from the Indorama cement industry. The physical properties are given in Table 2. It was stored in the airtight silos to prevent from the ambient conditions. As per clause, No. 43 IS: 456-2000 [10] the water to be used for both mixing and curing should be free from injurious amount of deleterious materials. Generally Potable water is fit for this purpose. In the present investigation potable tap water was used.

2.3 Fine aggregate, coarse aggregate, standard sand and water

Two types of fine aggregate or sand was used, one is standard sand as per IS specification and other is locally available river sand. The river sand passed through IS: 480 sieve (aperture 4.75 mm square) and was almost all retained on IS:15 sieve (150 micron size). The particle size distribution and physical properties are given in Table 3. The locally available crushed stone aggregate of maximum nominal size of 16 mm was used as coarse aggregate. The sieve analysis and physical properties are given in Table 4 Coarse aggregate was sieve through the 4.75 mm to remove the small sizes. Washed aggregate was used in the study [11].

Table 2. Physical properties of ground granulated blast furnace slag

Characteristics	**GGBFS values**
Fineness (m^2/kg)	340
Specific gravity	2.86
Soundness (mm)	1.5
Initial setting time (minutes)	150

Table 3. Sieve analysis and physical properties of fine aggregate

IS Sieve designation	**Weight retained (gm)**	**percent weight retained**	**percent weight passing**	**Cumulative percent weight retained**
4.75 mm	3	0.6	99.4	0.6
2.36 mm	38	76	91.8	8.2
1.18 mm	108	21.6	70.2	29.8
600 micron	83	16.6	53.6	46.4
300 micron	115	23	30.6	69.4
150 micron	105	21	9.6	90.4
Residue	48	9.6	-	-

Physical properties:
Grading = Zone II (IS: 383-1970)
Fineness modulus = 2.45
Specific gravity = 2.61
Density (loose) = 15.4 kN/m^3

Table 4. Sieve analysis and physical properties of coarse aggregate

IS Sieve designation	Weight retained (gm)	Percent weight retained	percent weight passing	Cumulative percent weight retained
80 mm	0	-	100	-
40 mm	0	-	100	-
20 mm	40	0.4	99.6	0.4
10 mm	8150	81.5	18.1	81.9
4.75 micron	1550	15.5	2.6	97.4
Residue	260	2.6	-	-

Physical properties:
Fineness modulus = 6.8
Specific gravity = 2.63
Density (loose) = 14.3 kN/m^3

3. Mixture Proportions

3.1 Cement mortar mix

In the present study, total of 14 mixes in 1:3 (one part of cement & slag and 3 parts of sand) fractions is prepared. In the first series of mixes the water is taken as per cement consistency only with different percentage of slag and sand. In the second series of mixes the water is taken as per the combination of cement and slag consistency with varying percentage of slag and with different sand. All mixes are prepared at room temperature. 0%, 20%, 40% and 60% blast furnace was used in replacement of OPC. The details of the mix proportions are given in the Table 5.

3.2 OPC and GGBFS concrete mixes

The mix proportions were decided on the basis of method of trial keeping in view of IS mix design guidelines [12]. The ratio of fine aggregate to coarse aggregate was fixed at 0.6 from the consideration of the maximum density of combined aggregate. Initially, coarse aggregate and fine aggregate were mixed thoroughly for about one minute. Then, cement was added to this dry mix and turned over twice or thrice in the dry state itself in a tilting type rotary drum mixer for about one minute so as to get the uniform mix in dry condition. Ten numbers of cubes for each mix were prepared and 15 cm size cubes for all the mixes. The concrete was poured in cube moulds in three layers. After one day the cubes were demoulded and kept under water for the period of 7 and 28 days. After 7^{th} and 28^{th} day the cubes were tested under compression. The details of the designed mixes are given in Table 6.

Table 5. Mix design details

Mix	Cement (%)	GGBFS (%)	Water	Sand
1	100	0	Cement consistency (78 ml)	Standard sand
2	80	20		
3	60	40		
4	40	60		
5	80	20	cement blending consistency (81 ml) (80% Cement+20% BFS)	
6	60	40	cement blending consistency (83 ml) (60% Cement+40% BFS)	
7	40	60	cement blending consistency (86 ml) (40% Cement+60% BFS)	
8	100	0	Cement consistency (78 ml)	River sand
9	80	20		
10	60	40		
11	40	60		
12	80	20	cement blending consistency (81 ml) (80% Cement+20% BFS)	
13	60	40	cement blending consistency (83 ml) (60% Cement+40% BFS)	
14	40	60	cement blending consistency (86 ml) (40% Cement+60% BFS)	

Table 6. OPC concrete mix proportion

Mix	Cement (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	Water-cement ratio
Mix-I	400	665	1107	0.45
Mix-II	350	680	1132	0.50

Ground granulated blast furnace slag concrete mixes were prepared after re-proportioning the OPC concrete mixes. The cement in OPC concrete mixes was direct replaced by the equal weight of blast furnace slag with cement replacement of 20, 40 and 60 percent respectively. The ratio of fine aggregate and coarse aggregate was kept constant for the entire investigation. The amount of fine aggregate and coarse aggregate was kept constant. The water for a particular mix was also kept constant. The details of granulated blast furnace slag are given in the Table 7.

Table 7. GGBFS based concrete mix proportion

Mix	Direct percent replacement of GGBFS (%)	Cement (kg/m^3)	GGBFS (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	w/c ratio
	20	320	80			
Mix-I	40	240	160	665	1107	0.45
	60	160	240			
	20	280	70			
Mix-II	40	210	140	680	1132	0.50
	60	140	210			

3.3 Testing Procedure

For each mix 35 samples of 70.6 x 70.6 x 70.6 mm cube for compressive strength was prepared. After 24 hr the sample was demoulded and cured for the period of 3, 7 and 28 days. 15 samples of cube were tested at the age of 3, 7 and 28 days curing. After 28 days curing, the remaining sample was kept at room temperature (27±3 ^{0}C) until the time of testing for 56, 90, 150 and 180 days results.

Similarly, for concrete mixes, compression tests were carried out in accordance with IS: 516-1959 [13] at a loading rate of 14 N/mm^2 per minute on 150 x 150 x 150 mm cubes and 150 x 300 mm cylinders on 200 tons Amsler's compression testing machine. After 24 hr the sample was demoulded and cured for the period of 3, 7 and 28 days. 15 samples of cube were tested at the age of 3, 7 and 28 days curing. After 28 days curing, the remaining sample was kept at room temperature (27±3 ^{0}C) until the time of testing for 56, 90, 150 and 180 days results. The bearing surfaces of the machine were properly cleaned before testing and the test specimen was placed between the bearing surfaces such that the load was applied on the face other than the casting faces of the specimen. 20 cubes and cylinders were tested each time for each mix at the ages of 3, 7, 28, 56, 90, 150 and 180 days. The compressive strength was calculated by dividing the ultimate load to the cross sectional area of the cube and cylinder specimens. The compressive strength was recorded on the basis of average of five cubes and cylinders.

4. Results and Discussion

4.1 Compressive strength development of cement mortar

The compressive strength development of cement mortar containing different percent replacement of blast furnace slag and for different types of sand is shown in Figure 1 to 4.

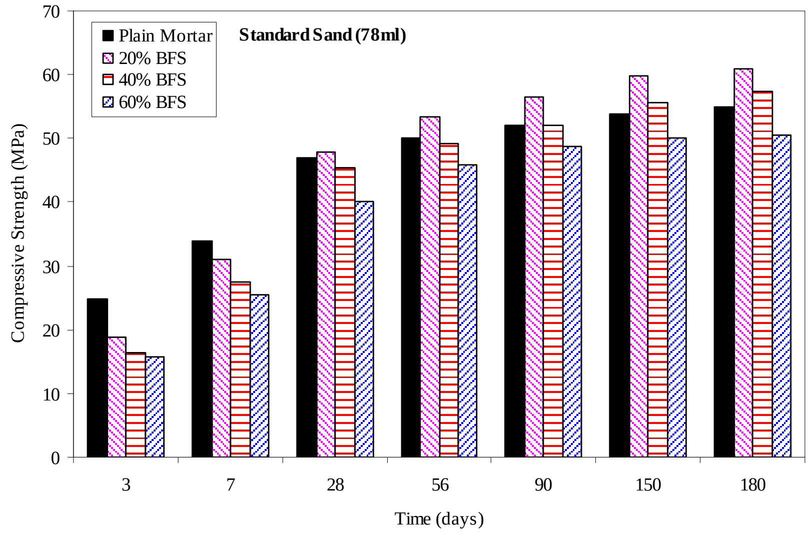

Figure 1. Relationship between compressive strength of cement mortar containing GGBFS with time for standard sand for water = cement consistency

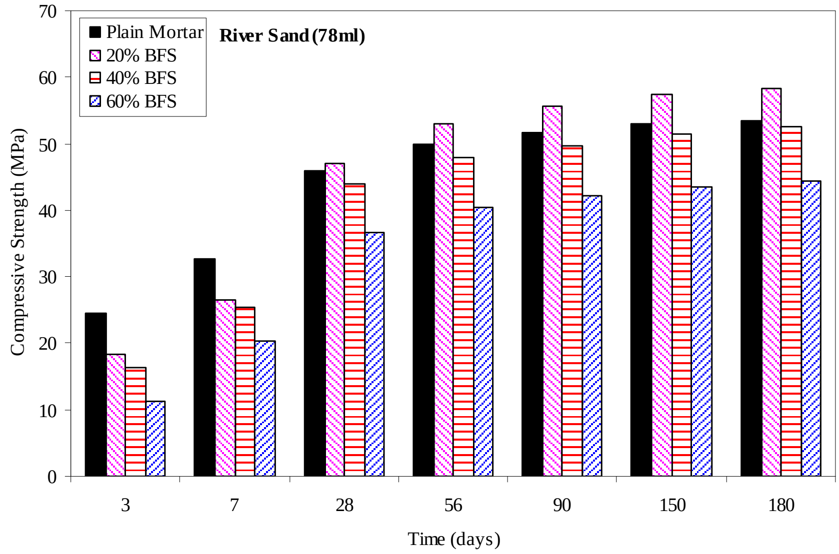

Figure 2. Relationship between compressive strength of cement mortar containing GGBFS with

time for river sand for water = cement consistency

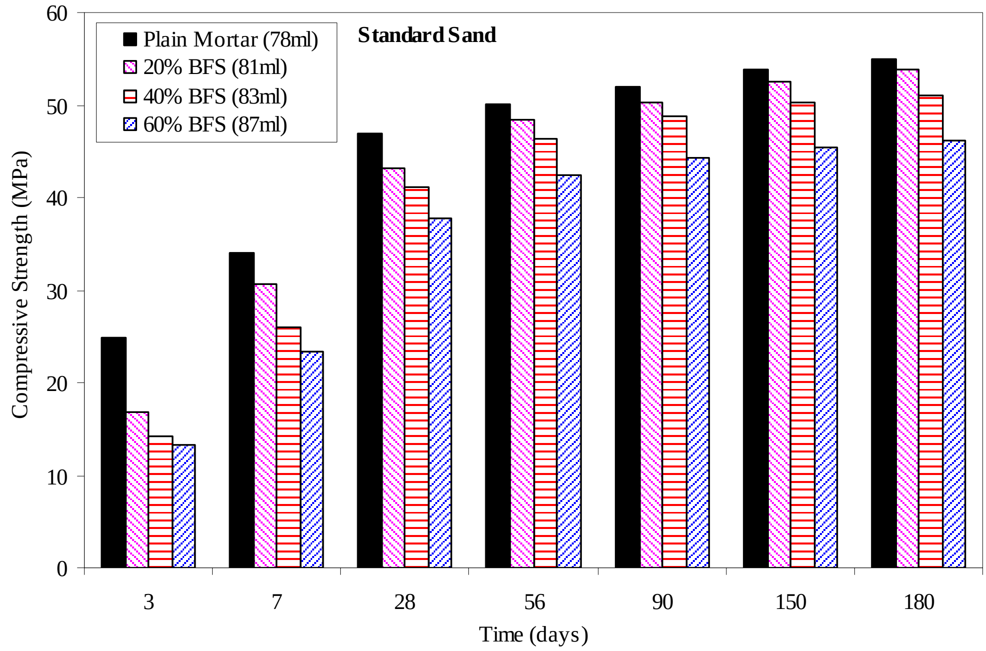

Figure 3. Relationship between compressive strength of cement mortar containing GGBFS with time for standard sand for water = cement blending consistency

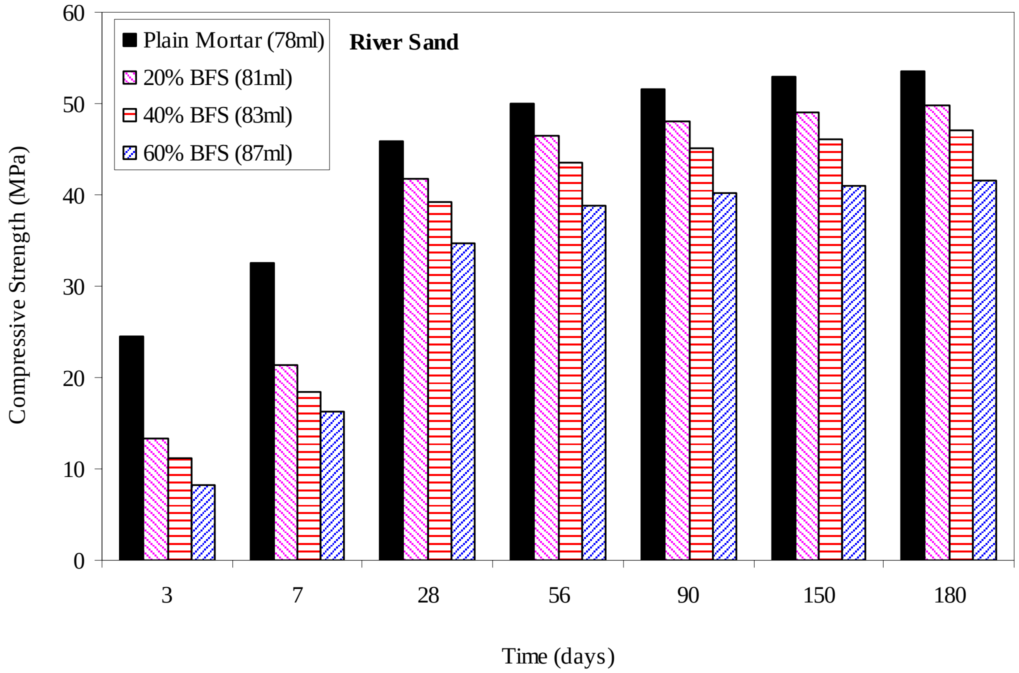

Figure 4. Relationship between compressive strength of cement mortar containing GGBFS with time for standard sand for water = cement blending consistency

Figure 4 shows that, the compressive strength of cement mortar is increasing consistently with time and the magnitude of strength is close with each other. It can be seen that the early strength of BFS mortar strength is lower than the cement mortar strength for all percent replacement upto 7 days. In case of standard sand the compressive strength of mortar containing 20% BFS is higher than the cement mortar strength after 28 days. The strength development is quit slowly in case of 40% BFS replacement and observed higher than the cement mortar after 150 days. Incorporating the 60% BFS decreases compressive strength at all ages. The reason of the above observation is that the rate of hydration is slow at early ages for the mortar incorporating BFS. In the present study, the curing age is fixed for all the mixes i.e. 28 days. Therefore, rate of gain of strength is slow in all the percent replacement of BFS. Figure 2 shows the compressive strength development of cement mortar containing different percent replacement of BFS with time for river sand and for water-cement ratio equal to normal cement consistency. It can be seen that the early strength is lower than the OPC strength for all percent replacement of BFS. After 28 days the compressive strength is higher than the OPC mortar for 20% replacement of BFS. But, in case of 40% and 60% replacement the strength is lower than the OPC strength at all ages. In this case also the rate of hydration is slow in BFS mortar mix as compare to OPC mortar and due to the bond failure between coarser particles of sand and cement mortar. The strength of cement mortar containing 60 percent GGBFS attain the 28 days strength of plain cement mortar between age of 56 to 90 days for standard sand and 90 to 150 days for river sand.

Another possible reason for the above strength development of GGBFS mortar observed by Olorunsogo and Wainwright [8] may be due to the liberation of alkalies leading to a more rapid hydration.

Figure 3 also shows that the compressive strength of mortar is increasing consistently with time and not much variation in magnitude of strength is observed with GGBFS. This Figure shows the importance of cement and cement blending consistency which gets very much emphasized. Higher the consistency results in lowering of mortar strength at all ages. As the percentage of BFS replacement is increases the consistency of blended cement is also increases as shown in Table 1. Therefore, the compressive strength of BFS replacement mortar is found lower than the OPC mortar due to increase in water content in the blended cement mortar mix. Figure 4 shows the compressive strength development for OPC and BFS replacement mortar with time and for water-cement ratio equal to blending of cement with BFS consistency and for river sand. Same pattern is obtained as in case of standard sand but the magnitude of strength is lower as compare with the standard sand. The strength of percent replacement of BFS mortar is lower than the OPC mortar at all ages because of increase water content in the mix. The 28 days strength of cement mortar mix for standard sand is observed to be attained by the GGBFS mortar mix with cement replacement of 20, 40 and 60 percent within 28 to 56 days and 56 to 90 days period 20 and 40% replacement and for 60 percent replacement it beyond 180 days period.

For river sand this value is obtained within 28 to 56 days period for 20 percent replacement, 90 to 150 days period for 40 percent replacement and for 60 percent replacement this beyond the 180 days period.

The magnitude of compressive strength of OPC and BFS replacement mortar is higher in case of standard sand as compare to the river sand at all ages. The reason of higher strength in standard sand is due the coarser particles in river sand and due to the non uniform grading of river sand. Most of the failure occurs due to the early bond failure between the paste and coarser particle of the river sand.

4.2 Compressive strength development of concrete

The variation of cube and cylinder compressive strength of ordinary concrete and concrete containing GGBFS with time is shown in Figure 5 to 8 for Mix-I and Mix-II. Figure shows that the compressive strength increases with the time at a decreasing rate. The pattern of strength development is same in all the mix.

At the age of 28 days the cube compressive strength of GGBFS concrete mixes with cement replacement of 20, 40 and 60 percent was observed to be 83, 75 and 65 of the plain concrete for Mix-I respectively. For Mix-II this percentage was observed as 89, 84 and 73 percent of the plain concrete. Similarly, the cylinder compressive strength of GGBFS concrete mixes with cement replacement of 20, 40 and 60 percent was observed as 83, 77 and 66 percent for Mix-I and 87, 81 and 71 percent for Mix-II respectively. However, at the age of 180 days this variation of cube compressive strength development of GGBFS concrete with the cement replacement of 20, 40 and 60 percent is increased as 93, 97 and 74 percent for Mix-I and 93, 97 and 80 percent for Mix-II respectively with the Plain concrete strength.

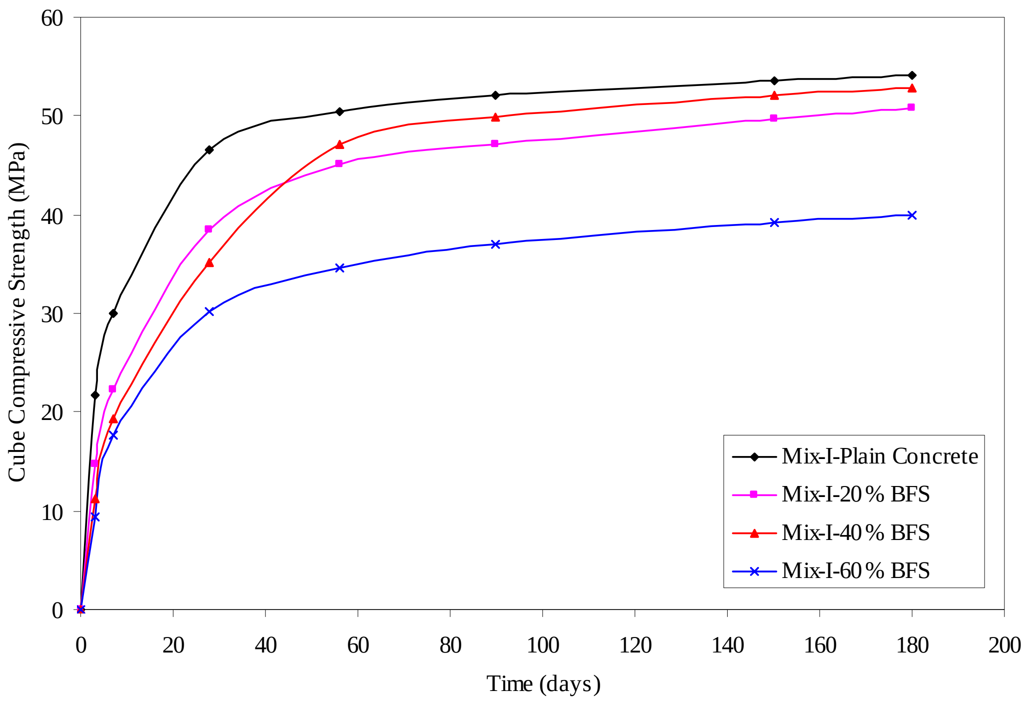

Figure 5. Cube compressive strength development with time for plain and GGBFS concrete for Mix-I

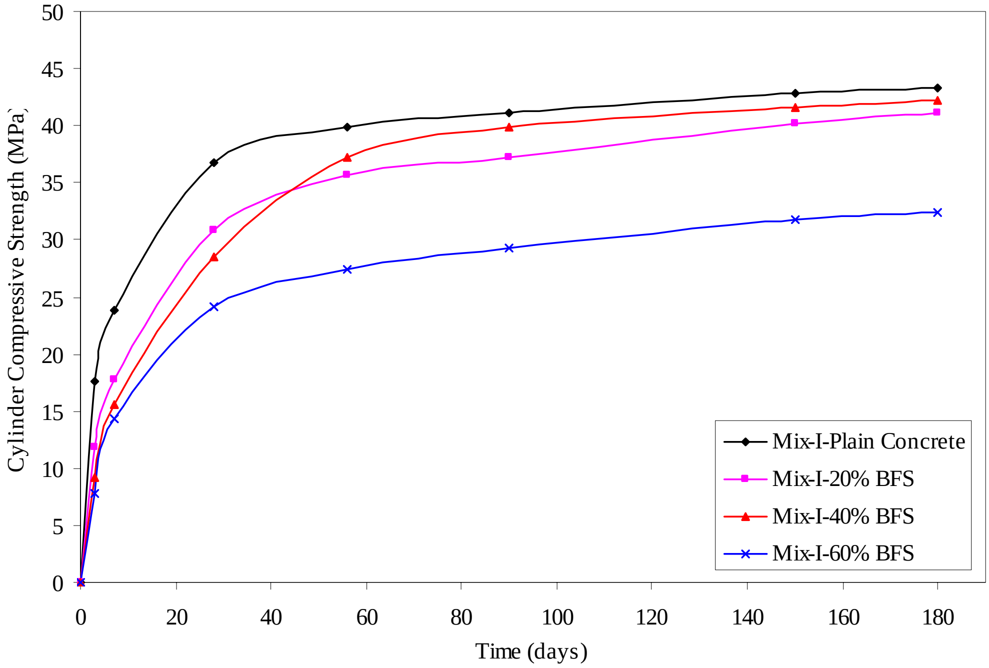

Figure 6. Cylinder compressive strength development with time for plain and GGBFS concrete for Mix-I

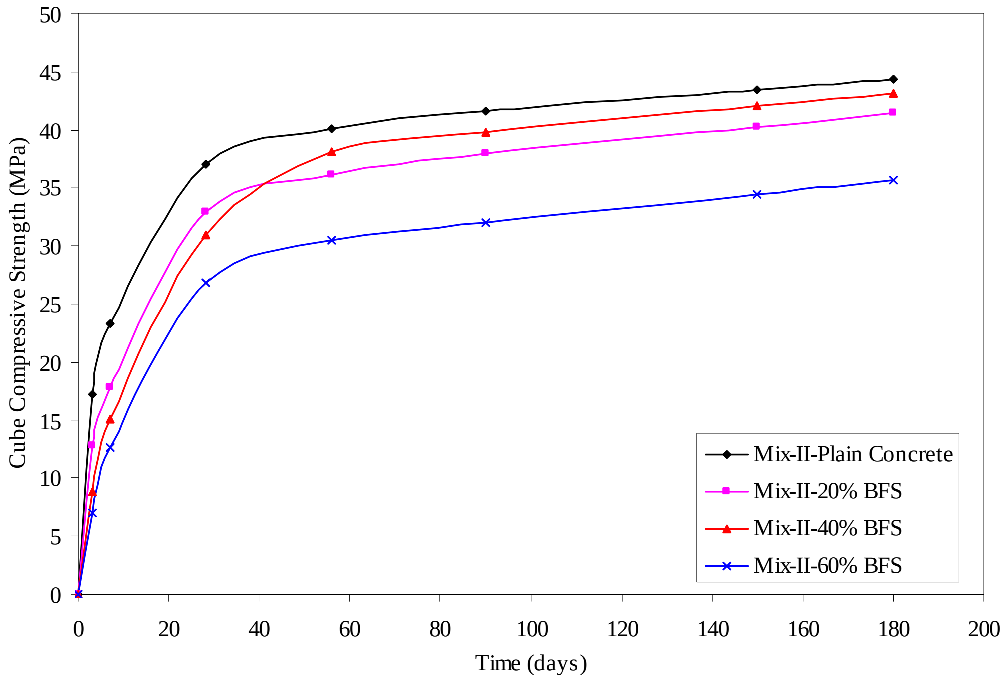

Figure 7. Cube compressive strength development with time for plain and GGBFS concrete for Mix-II

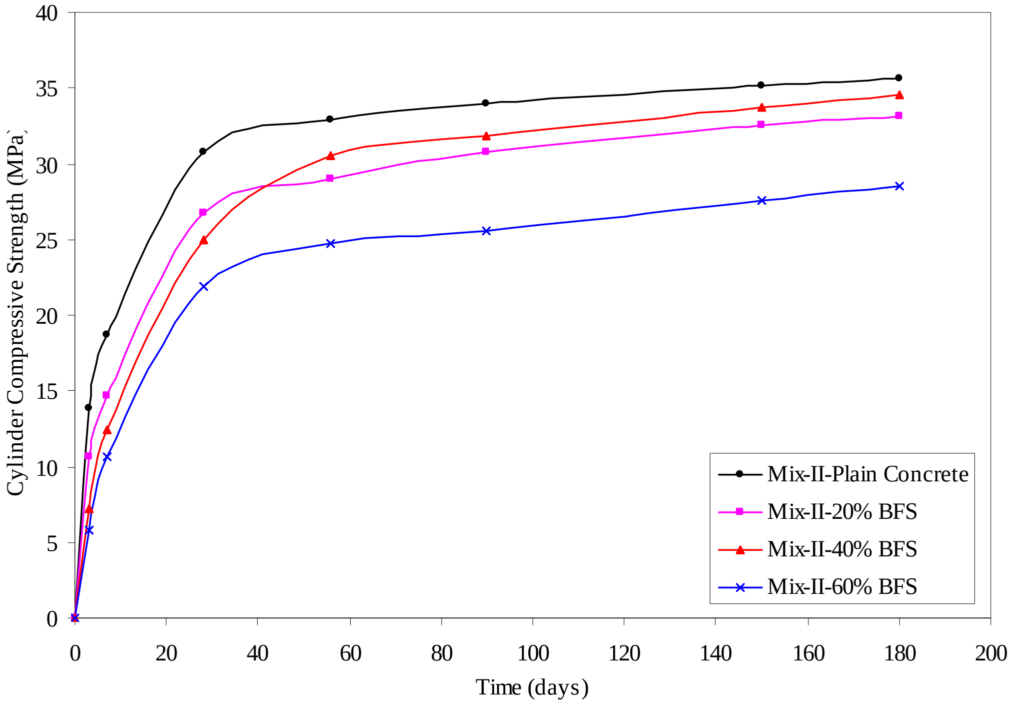

Figure 8. Cylinder compressive strength development with time for plain and GGBFS concrete for Mix-II

Likewise, for cylinder compressive strength the variation in strength development after 180 days was observed as 95, 97 and 75 percent for Mix-I and 93, 97 and 80 percent for Mix-II respectively with the concrete strength without GGBFS.

The increase in cube compressive strength of plain concrete from 28 to 180 days is observed 16 percent whereas the increase in cube compressive strength of 20, 40 and 60 percent cement replacement with GGBFS is observed 32, 50 and 32 percent respectively for Mix-I. Similarly, for Mix-II the increase in compressive strength of plain concrete is observed as 20 percent and compressive strength of 20, 40 and 60 percent replacement is 26, 39 and 33 percent respectively for Mix-II. The increase in cylinder compressive strength from 28 to 180 days is almost same for Mix-I but lower for Mix-II than the cube compressive strength. For plain concrete mix it is observed 18, and 16 for Mix-I and Mix-II respectively and for cement replacement of 20, 40 and 60 percent with GGBFS 34, 48 and 34 percent for Mix-I, and for Mix-II it is 24, 38 and 30 percent . This type of strength development of GGBFS concrete is observed by Malhotra [1987] for Canadian pelletized slag concrete.

The strength of concrete at a given age and the rate of strength development are depends upon the type and characteristics mix proportion of the slag in concrete. This shows that the pozzolanic reactivity of GGBFS contributes to the rate of gain of strength at later ages.

In all the two mixes, plain concrete strength is found higher than the GGBFS replacement with cement. The reason for this is due the method of mix proportioning and curing conditions. In the present study the curing period was 28 days, after that the remaining samples was kept at ambient temperature room till the time of testing i.e. 56, 90, 150 and 180 days.

Based on this curing method, for plain concrete mixes 28 days is sufficient for hydration of cement. But, in case of GGBFS replacement rate of hydration is slow so that strength development is also slow. Literature also shows that the early age strength is lower than the OPC concrete due to the slow rate of hydration. So, this slow rate of hydration is influencing the strength development of GGBFS concrete after 28 days.

Among GGBFS concrete, the strength in 40 percent replacement is found higher than the 20 percent replacement after 56 days. The cement replacement of 60 percent is showing lower strength as compare with the 20 and 40 percent replacement at all ages. Therefore, 40 percent replacement seems to be the optimum replacement in the present investigation. This strength development of GGBFS concrete can be explained by the hydration process according to Regourd [14] and Roy and Idorn [15]. The predominant reaction is due to the alkali hydroxide but, at later ages dominant reaction is due to the calcium hydroxide. At higher cement replacement the amount of cement for hydration and liberation of calcium hydroxide is smaller. The cement replacement of 40 percent with GGBFS yields the hydration products due to the pozzolanic reaction and fills the pores results in increase in strength of concrete among GGBFS based concrete. The concrete containing 60 percent GGBFS shows decrease strength at all ages. The decrease in strength is due the presence of excessive fines which will cause greater mobility of the unhydrated GGBFS particle. The failure takes place due to the early crushing of paste and Hence strength is found lower than the 20 and 40 percent replacement of GGBFS at all ages.

5. Conclusions

Based on the above study the following conclusions are drawn.

5.1 Cement mortar compressive strength

1. Test results show that the incorporating 20% and 40% GGBFS is highly significant to increase the compressive strength of mortar after 28 days and 150 days respectively.
2. The magnitude of compressive strength of mortar for standard sand is higher than the magnitude of river sand.
3. Incorporating 60% BFS replacement is showing lower strength at all ages and water-cement ratio for both types of sand.

5.2 Concrete compressive strength

1. The compressive strength of OPC concrete shows higher strength than the GGBFS based concrete for all replacement (in percent) and at all ages.
2. Incorporating 40% GGBFS is highly significant to increase the compressive strength of concrete after 56 days than the 20 and 60% replacement.
3. Among GGBFS based concrete 40% replacement is found to be optimum.

References

1. Brooks JJ, Al-Kaisi AF. Early strength development of portland and slag cement concretes cured at elevated temperatures, *ACI Materials Journal*, **87**(1990) 503-7.
2. Haque MN, Chulilung T. Strength development of slag and ternary blend concrete, *Cement and Concrete Research*, **20**(1990) 120-30.
3. Swamy RN, Bouikni A. Some engineering properties of slag concrete as influenced by mix proportioning and curing, *ACI Materials Journal*, **87**(1990) 210-220.
4. Jianyong L, Pei T. Effect of slag and silica fume on mechanical properties of high strength concrete, *Cement and Concrete Research*, **27**(1997) 833-7.
5. Tan K, Pu X. Strengthening effects of finely ground fly ash, granulated blast furnace slag, and their combination, *Cement and Concrete Research*, **28**(1998) 1819-25.
6. Miura T, Iwaki I. Strength development of concrete incorporating high levels of ground granulated blast-furnace slag at low temperatures, *ACI Materials Journal*, **97**(2000) 66-70.
7. Douglas E, Pouskouleli G. Prediction of compressive strength of mortars made with Portland cement - blast furnace slag – fly ash blends, *Cement and Concrete Research*, **21**(1991) 523-34.
8. Olorunsogo FT and Wainwright PJ. Effect of GGBFS particle-size distribution on mortar compressive strength, *ASCE Journal of Materials in Civil Engineering*, **10**(1998) 180-7.
9. IS: 4031, Methods of physical tests for hydraulic cement (part 1-6), Bureau of Indian Standards, New Delhi, 1988.
10. IS: 456, Plain and reinforced concrete-code of practice, Bureau of Indian Standards, New Delhi, 2000.
11. IS: 383, Indian standards specification for coarse and fine aggregates from natural sources for concrete, Bureau of Indian Standards, New Delhi, 1970.
12. IS: 10262, Recommended guidelines for concrete mix design, Bureau of Indian Standards, New Delhi, 1999.
13. IS: 516, Methods of tests for strength of concrete, Bureau of Indian Standards, New Delhi, 1959.
14. Regourd M. Microanalytical studies (X-Ray photo electron spectrometry) of surface hydration reactions of cement compound, *Philosophical Transactions* (London), Series A, **310**(1980) 85-91.
15. Roy DM, Idorn GM. Hydration, structure, and properties of blast furnace slag cements, mortars, and concrete, *ACI Journal Proceedings*, **79**(1982) 444-57.