International Journal of Civil and Structural Engineering– IJCSE
Volume 2 : Issue 1 [ISSN : 2372-3971]
Publication Date: 30 April, 2015

Sustainable Concrete Structures with GBFS as Suitable Replacement of Fine Aggregate : A Study on Mechanical Behavior

[Amiya K. Samanta[1], Ashok K. Sahani[2], and D. K. Singha Roy[1]]

***Abstract*— With the rapid industrial growth globally, steel industries, in particular, are producing huge quantity of slag as by-product in different forms obtained through various cooling processes. These by-products are environmentally hazardous, create problems of storage, thereby reducing effective land-use affecting economy of the country. That is why, proper utilization of such waste materials and its management has become one of the most complex and challenging tasks over a period of time. Present study basically aims at investigating the scope of use of such a by-product Granulated Blast Furnace Slag (GBFS) as fine aggregate replacing natural sand partially or fully in concrete structures, in order to reduce environmental problems and waste disposal, also in terms of preserving natural resources. In this experimental investigation, design mix of various grades are prepared with various percentages of replacement of natural sand by GBFS. Based on the test results and detail investigation of cubes, cylinders and prisms, it is observed that GBFS can be utilized partially up-to 70% as alternative construction material replacing natural sand in concrete structures. Of course, the reduction in workability in such cases has to be enhanced to the desired level by adding suitable percentage of super plasticizer for higher percentages of replacements.**

***Keywords*—Granulated Blast Furnace slag, Compressive strength, Workability, Sustainable, Concrete**

I. Introduction

In India, natural sand (NS) is traditionally used in concrete and mortars. River sand, which is one of the constituents used in the production of conventional concrete, has become highly expensive and also becoming costly as well as scarce. Natural sand excavated from river bed impacts on environment in many ways also. Due to digging of the sand from river bed reduces the water head, so less percolation of rain water in ground, which result in lower ground water level. There is erosion of nearby land due to excess sand lifting which, in turn, destroys the flora and fauna in surrounding areas.

1. Amiya K. Samanta & D. K. Singha Roy
National Institute of Technology Durgapur
India – 713 209

2. Ashok K. Sahani
Durgapur Steel Plant, SAIL
India – 713 203

Local authorities sometime imposed laws to stop this unabated destruction of natural river bed causing limited supply of natural sand with enhanced cost and inconsistent supply of natural sand. Thus there is large demand for alternate construction materials from industrial waste. Thus manufactured fine aggregates (industrial waste like GBFS) appear as a salient alternative to natural fine aggregates for cement mortars and concrete. The consumption of slag, which is a waste generated by steel industry, in concrete not only helps in reducing green-house gases but also helps in making environmentally friendly material for green house building.

GBFS is totally different from natural river sand in their chemical constituents. A number of features of blast furnace slag fine aggregate for concrete have been noted such as it has got a) reliable quality manufactured under suitable, quality-controlled conditions, b) it does not contain materials that may affect the strength and durability of concrete, such as chlorides, organic impurities, clay and shells, c) compressive strength is similar to that of natural sand is achieved at a material age of 7 days and 28 days. Additionally, increased strength is seen as the material ages. d) also it does not participate in alkali-aggregate reactions. A number of studies have dealt with the influence of both grading and particle shape of the fine aggregate in mortars and concrete. It has been found that concrete made with GBFS achieved compressive strength equal to or higher than concrete made with natural sand, reducing the void content of the aggregate, thereby lubricating the aggregate system without increasing the water requirement of the mixture.

K Ganesh Babu et al. (2000) has given an effort to quantify the overall strength efficiency of ground granulated blast furnace slag (GBFS) in concrete at the various replacement levels. The overall strength efficiency was found to be a combination of general efficiency factor, depending on the age and a percentage efficiency factor, depending upon the percentage of replacement as was the case with a few other cementitious materials like fly ash and silica fume. It has defined Slag Activity Index (SAI) plot, indicating ranges of strength of slag.

Yüksel et al. (2006) reported the results of some experimental studies on the use of non-ground-granulated blast-furnace slag as fine aggregate in concrete. Two groups of concrete samples were produced. The first group (C1) contains only 0-7 mm sand as fine aggregate and the second group (C2) contains two sub-types of fine aggregates that are 0-3 mm as well as 0-7 mm sands. GBFS replaces 0-7 mm sand in both groups. Strength and durability characteristics of concrete were compared with respect to control samples. According to the results, the concrete is porous and has relatively low compressive strength for C1 type whereas, concrete strength and durability characteristics were better for C2 type. It was concluded that the non-ground-granulated blast-furnace slag can be used as fine aggregate under some conditions. Isa Yüksel et al. (2007) investigated on the usage of bottom ash (BA), granulated blast furnace slag (GBFS), and combination of both of these materials as fine aggregate in concrete and its durability. Finally, it concludes that concrete industry may develop concrete technologies that have technical, economical and ecological advantages for a sustainable development like normal strength, durability and environmental friendliness using such replacements of natural fine aggregates.

H. Binici et al. (2012) has studied, the effects of blast furnace slag, ground basaltic pumice and blast furnace slag + ground basaltic pumice at 5%, 10% and 15% replacement level by weight, in place of fine aggregate on the durability of concrete pipes. It was observed that the ultimate load of specimens depends on the type and percentage of admixtures. The maximum ultimate load was obtained in concrete specimens containing 5% blast furnace slag and 5% ground basaltic pumice, which was 20% larger than that of the reference concrete specimens. According to the results, granulated basaltic pumice and blast furnace slag can be used in place of fine aggregate in the production of concrete pipes for wastewater and sewage systems

Wakchaure et al. (2012) studied on 'Effect of Fine Aggregate on mechanical properties of Cement Concrete' and concluded that the C-S-H gel micro-fibers penetrate in micro-pores of aggregate. Further it was added that such gel penetrated easily in crushed sand having rough surface than river sand particles which resulted in more strength. Nadeem, D. Pophale (2013) studied on Granular Slag as a potential sustainable alternative to Fine Aggregate in Construction Applications. It concluded that in mortar, replacement was favorable to increase the flow properties and compressive strength for various mix proportions. However 100 % replacement level is not feasible since it reduces the flow. In general, granular slag replacement level of 50 to 75 % had increased the packing density of mortar which resulted in reduced w/c ratio, increased strength properties of all mortar mixes. The rough spherical particles of granular slag had also improved the bond and adhesion strength. Hence it could be recommended that the granular slag could be effectively utilize as fine aggregate in masonry construction and plastering work economically in place of conventional cement mortar mixes with natural sand as fine aggregate. Nataraja et al. (2013), examined the possibility of utilizing Granulated Blast Furnace Slag (GBFS) as a sand substitute in cement mortar, in order to reduce environmental problems related to aggregate mining and waste disposal.

Based on the brief review of the existing literature, the objectives of the present study are to examine the mechanical properties of hardened concrete in details with or without the replacement of NS by GBFS as fine aggregate in Indian context and to study the influence of GBFS on the grades of concrete in the perspective of compressive strength.

II. Experimental Study

A. *Material Properties*

Ordinary Portland Cement 53 grade (OPC 53) was used throughout the investigation. The cement used has been tested for various properties as per IS: 4031 (1988) and found to be conforming to various specifications of IS: 8112 (1989). The fine aggregates used for this work were natural river sand and GBFS. Natural sand (NS) confirms to grading zone II and GBFS confirms to grading zone III as per IS: 383 (1970). The physical properties of sand such as sieve analysis, specific gravity, bulk density, etc., were determined as per IS: 2386 (1963).

Table 1: Properties of Fine Aggregates

Fine Aggregate	Natural Sand (NS)	GBFS
Specific Gravity	2.62	2.32
Bulk density (kg/m^3) (Compact)	1.69	1.95
Bulk density (kg/m^3) (Loose)	1.56	1.78
Water absorption (%)	0.28	4.06
Fineness Modulus	3.46	3.37

In the present investigation Conplast SP 430 super plasticizing admixture, complies with IS:9103:1979, is used to maintain the same workability of two designed concrete mixes. Conplast SP 430 is based on sulphonated naphthalene polymers and is supplied as a brown liquid instantly dispersible in water. It has been specially formulated to give high water reduction up to 25% without loss of workability. Its specific gravity is 1.145 (at 30 °C) and chloride content is Nil. Air entrainment is approximately 1%.

B. *Casting and Test Method*

Concrete mixes have been designed for M25 and M30 based on IS10262: 2009. M25 grade of concrete was cast for a target strength of 31.6MPa having water-cement ratio 0.43 for a design mix proportion 0.43:1.0:1.50:2.74. M30 grade of concrete was cast for a target strength of 36.6MPa having water-cement ratio 0.40 for a design mix proportion 0.40:1.0:1.40:2.75. Design mix of for all the grades of concrete have been used in the present study both with and without the replacement of natural sand (NS) by GBFS. For each concrete mix, cubes of size 150 x 150 x 150 mm, cylinder of size 150mm (dia) x300mm (length) and prism of size 100mm x 100mm x 500mm (length) have been cast as per IS: 4031 (2000). After 24 hours, the samples were demoulded and cured for the period of 7, 28, 60 and 90 days. At the end of each curing period, a total of 3 cube specimens, 6 cylindrical specimens (3 for compressive strength and 3 for split tensile strength) and 3 prisms have been tested for determining the compressive strength, split tensile strength and flexural strength as per IS: 516 (1959). For each grade of concrete 12 nos cube, 12 nos cylinders and 9 nos. prisms were cast for each category.

III. Discussion on test results

The test results for M25 grade of concrete for cube compressive strength and cylinder compressive strength have been listed in Table 2 for all ages (7, 28, 60 and 90 days) and in Figure 1 and 2. It may be noted that the cube compressive strength increases up to 30% replacement of NS by GBFS. Thereafter marginal decrease in compressive strength is observed up to 50% replacement level, showing close proximity of the compressive strength of respective control mixes. Beyond 50% replacement of NS by GBFS for all ages, considerable decrement of compressive strength has been observed.

TABLE 2 STRENGTH VS REPLACEMENT LEVELS OF NS BY GBFS FOR M25 GRADE OF CONCRETE

Replace - ment (%)	7-days	28-days	60-days	90-days	Remarks
0	25.32	39.97	47	49.76	Cube Compressive strength
10	26.28	41.91	47.67	49.89	
30	26.33	40.78	48.05	51.1	
50	27.53	39.69	46.27	47.36	
70	23.01	37.85	41.78	42.38	
100	14.56	29.19	36.27	32.71	
0	14.23	24.52	26.72	27.92	Cylinder Compressive Strength
10	15.89	24.91	26.8	28.2	
30	16.85	24.31	27.06	28.34	
50	15.49	22.65	25.4	28.08	
70	14.46	23.76	22.2	24	
100	9.12	14.59	17	17.56	

It may further be noted that the compressive strength of concrete with natural sand has increased by 5.93% at 7-days, 5.98% at 28-days, 3.25% at 60-days, and 2.10% at 90-days on 30% replacement of NS by GBFS.

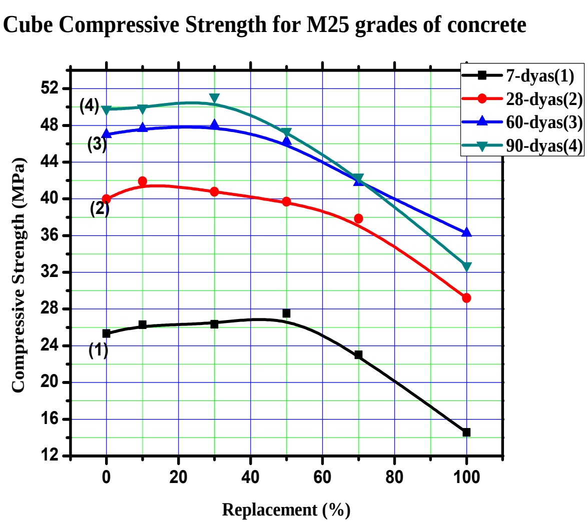

Figure 1. Variation of Cube Compressive Strength (M25)

The cylindrical compressive strength increases up to 10% and for last 2 ages (60 and 90 days) the compressive strength increases up to 50% replacement of NS by GBFS for M25 grade of concrete. Also the same with natural sand has increased by 0.4% at 7-days, for 10% replacement, 1.08% at 28-days for 10% replacement, 3.8% at 60-days, for 30% replacement and 3.22% at 90-days on 50% replacement of NS by GBFS.

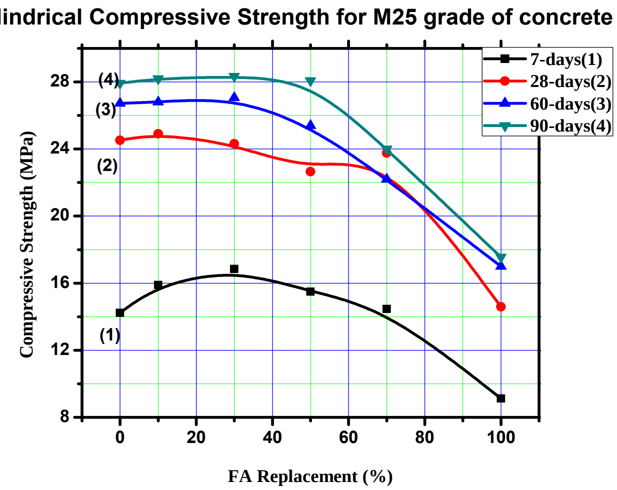

Figure 2. Variation of Cylindrical Compressive Strength (M25)

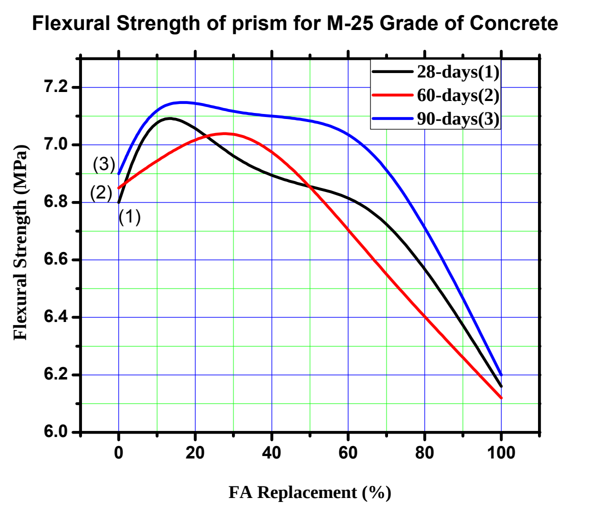

Figure 3. Variation of Flexural Strength (M25)

It is evident from Figure 2 that for 28-days the flexural strength increases up to 70%, for 60-days the flexural strength increases up to 50% and for 90-days the flexural strength increases up to 70% replacement of NS by GBFS for M25 grade of concrete. Thereafter marginal decrease in compressive strength is observed up to 50% replacement level, showing close proximity of the compressive strength of respective control mixes. Beyond 70% replacement of NS by GBFS for all ages, considerable decrement of compressive strength has been observed.

TABLE 3 STRENGTH VS REPLACEMENT LEVELS OF NS BY GBFS FOR M30 GRADE OF CONCRETE

Replace - ment (%)	7-days (Cylinder)	28-days (Cylinder)	7-days (Cube)	28-days (Cube)
0	20.16	25.71	30.77	38.42
10	21.71	26.1	31.24	42.33
30	22.16	24.84	32.74	42.85
50	19.11	23.12	28.4	39.76
70	16.48	21.2	22.17	37.6
100	10.32	16.8	14.34	31.4

The test results for M30 grade of concrete for cube compressive strength and cylinder compressive strength have been listed in Table 3 for 7 and 28days respectively and in Figure 4. It is observed that the compressive strength increases up to 30% replacement of NS by GBFS for M30 grade of concrete followed by a decrease in compressive strength is observed up to 50% replacement level, showing close proximity of the compressive strength of respective control mixes. Also, the compressive strength of concrete with natural sand has increased by 9.02% at 7-days, 10.33% at 28-days for 30% replacement of NS by GBFS for M30 grade concrete.

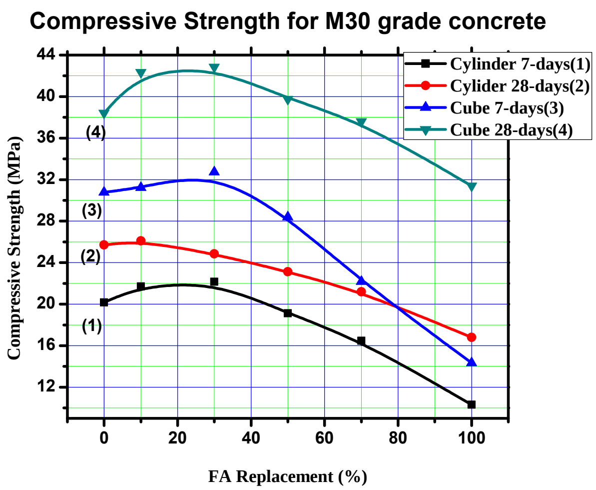

Figure 4. Variation of Cube & Cylinder Compressive Strength (M30)

IV. Conclusion

Based on the analysis and discussion of the test results for two different grades of concrete containing various percentage replacements of FA by GBFS, it is observed that the compressive strength of concrete increases as the replacement level of GBFS increases. This increase is not substantial. However for 100% Replacement the strength decreases marginally compared to 100% natural sand. It is may be due to the presence of flaky particle in GBFS or improper bond between cement paste and aggregate. This trend is true for all ages of testing. It is obvious that GBFS sand can be used as an alternative to natural sand from strength point of view, but upto 50% replacement level and thereafter decreases considerably till 70% replacement level but maintaining the closer proximity of the strength with that of control concrete without GBFS. Of course, with the increase in GBFS content in concrete, the workability of material decreases and the same can be controlled with the addition of 0.5% to 1% of super plasticizer to achieve desired workability.

In general, GBFS can be used as a partial substitute of Natural sand. Also GBFS being industrial byproduct, its long term performance from the point of view of durability needs to be studied along with its shape characterization. Future scope is also open to check its suitability and utilization in producing higher performance concrete.

References

[1] K Ganesh Babu, V Sree Rama Kumar, "Efficiency of GBFS in concrete," Cement and Concrete Research, vol.30(7), pp 1031-1036 , July 2000

[2] S.C Pal, A Mukherjee, S.R Pathak, "Investigation of hydraulic activity of ground granulated liast furnace slag in concrete," Cement and Concrete Research, vol. 33(9), pp. 1481-1486, September 2003.

[3] Yüksel, Ö. Özkan, T. Bilir, "Use of granulated blast-furnace slag in concrete as fine aggregate," ACI Materials Journal, vol. 103 (3), pp. 203–208, 2006.

[4] Isa Yüksel, Turhan Bilir, Ömer Özkan, "Durability of concrete incorporating non-ground blast furnace slag and bottom ash as fine aggregate," Building and Environment, vol. 42, pp. 2651–2659, 2007.

[5] H. Binici, M.Y. Durgun, T. Rızaoğlu, M. Koluçolak, "Investigation of durability properties of concrete pipes incorporating blast furnace slag and ground basaltic pumice as fine aggregates," Scientia Iranica, vol. 19(3), pp. 366-372, June 2012,

[6] Wakchaure M. R., Shaikh A.P., Gite B.E, "Effect of Types of Fine Aggregate on Mechanical Properties of Cement Concrete," Intl. Journal of Modern Engineering Research, Vol.2(5), pp. 3723-3726, 2012.

[7] Md. Nadeem, A. D. Pophale, "Granular Slag - Potential Sustainable Material alternative to Fine Aggregate in Construction Applications," Gazi University Journal of Science, vol. 26(2), pp. 269-278, 2013.

[8] M C Nataraja, P G Dileep Kumar, A S Manu and M C Sanjay, "Use of Granulated Blast Furnace Slag as fine aggregate in cement mortar," International journal of structural and civil engineering research, Vol. 2(2), pp. 59-68, 2013.

[9] IS 383-1970 "Specifications for coarse and fine aggregates from natural sources for concrete", Bureau of Indian Standards.New Delhi, 1970.

[10] IS 10262-2009 "Recommended guidelines for concrete mix design", Bureau of Indian Standards.New Delhi, 1982.

[11] IS 456-2000 "Code of practice for plain and Indian Standards".Bureau of Indian Standards New Delhi, 2000.

About Author (s):

This experimental investigation highlights effective utilization of industrial slag such as GBFS as fine aggregate replacing natural sand partially or fully in concrete structures and thereby preserving natural resources. It is observed that GBFS can be utilized partially up-to 50% as alternative construction material replacing natural sand in concrete structures