

Evaluation of Blast Furnace Slag as Alternative of Natural Sand in Cement Concrete and Cement Mortar

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ABSTRACT: Desperate need for infrastructure development in developing nation has increased the pressure on construction industry. Cement Concrete and cement mortar are indispensable part of construction works. For making cement concrete and cement natural sand is invariably used. As the demand of concrete construction works is augmented the scare of good quality natural sand also increases. It is also create the heavy thrust on the environment. In contrast to that solid waste produced by different industries involve heavy cost of disposal of solid waste and also threat for environment. So one idea is that as demand of natural sand is increasing day by day suitable alternatives from the solid waste of the different industries shall be used in place of natural sand to protect and preserve the environment. In this study we have evaluated suitability of Blast Furnace slag which is solid waste produced by quenching of iron ores in blast furnace, to replacement of natural sand for making cement concrete and cement mortar. In the present study an attempt has been made with mortar cubes of 1:4 and 1:6, with alternative i.e. Blast Furnace Slag (BSF) (20, 40, 60, 80 and 100% replacement of sand) were prepared and determined their compressive strength for 3 and 7 days. Also, M-20 and M-30 concrete mixes were prepared using alternative (20, 40, 60, 80 and 100% replacement of sand). Compressive strength of standard concrete cubes (7 days and 28 days) was determined. Thus this suggest that the use of Blast-Furnace Slag (BFS) as fine aggregate in cement concrete and cement mortar provides economic as well as environmental benefits.

KEYWORDS: Blast Furnace Slag (BFS), natural sand, construction industry, solid waste, cement concrete, compressive strength.

I. INTRODUCTION

Concrete is an artificial conglomerate stone made essentially of Portland cement, water, fine and coarse aggregates. The mixture of the materials results in a chemical reaction called hydration and a change in the mixture from plastic to a solid state occurs over a period of time. The cost of concrete can be reduced by reducing cost of constituent materials. Cost reduction can also be achieved by using locally available alternative materials, instead of conventional materials. Although concrete technology across the industry continues to rise to the demands of a changing market place. The construction industry recognizes that considerable improvements are essential in productivity, product performance, energy efficiency and environmental performance [1]. Properties of aggregate affect the durability and performance of concrete, so fine aggregate is an essential component of cement concrete and cement mortar.

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The most commonly used fine aggregate is natural river or pit sand. Fine and coarse aggregate constitute about 75% of total volume. It is therefore, important to obtain right type and good quality aggregate at site, because the aggregate forms the main matrix of cement concrete or cement mortar. Some alternative materials have already been used as a part of natural sand e.g. Fly-ash, granulated blast furnace slag, limestone and siliceous stone powder are used in concrete mixtures as a partial replacement of natural sand. However, scarcity in required quality is the major limitation in some of the above materials. Now a days sustainable infrastructural growth demands the alternative material that should satisfy technical requisites of fine aggregate as well as it should be available abundantly [2]. Thus, this study presents the evaluation of Blast furnace slag (BFS) as an alternative of natural sand in cement concrete and cement mortar works. These evaluations were carried out by testing of cement concrete and cement mortar cubes by replacement natural sand to Blast furnace slag in laboratory.

II. BACKGROUND OF THIS STUDY

Granulated slag is produced by quenching the molten slag by means of high-pressure water jets. Quenching prevents crystallisation, thus resulting in granular, glassy aggregates. This slag is crushed, pulverised and screened for use in various applications, particularly in cement production because of its pozzolanic characteristics. The use of Granulated Blast-Furnace Slag (GBFS) as an aggregate in cement mortar and concrete provides environmental as well as economic benefits. Many steel industries in India are supplying GBFS as an alternative to sand (Mohammed and Pofale, 2012)[3]. GBFS may be used as general purposes construction sand in civil engineering applications. This could be an ideal select fill behind reinforced earth wall construction. Within a relatively short time, the pozzolanic properties of granulate cause it to set up and form a solid block. GBFS is used in glass manufacture as a source of alumina and silica.

Nataraja et al. [4] investigated 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. In this investigation, cement mortar mix 1:3 and GBFS at 0, 25, 50, 75 and 100% replacement to natural sand for constant w/c ratio of 0.5 is considered. The work is extended to 100% replacements of natural sand with GBFS for w/c ratios of 0.4 and 0.6. The flow characteristics of the various mixes and their compressive strengths at various ages are studied. From this study it is observed that GBFS could be utilized partially as alternative construction material for natural sand in mortar applications.

Rao and Bhandare [5] presented a case study of Granulated Blast Furnace Slag (GBFS/GBS) sand application as a partial substitute of Crushed Stone Sand (CSS) in cement concrete. Laboratory Studies were conducted for different grades of concrete viz. M30 to M70 using blend of crushed stone sand and granulated slag sand in the ratio of 50:50 of total fine aggregate in concrete. From this study it is observed that GBS sand and CSS blend could be used as alternative construction material for natural sand in cement concrete applications.

The Ordinary Portland Cement (OPC) is one of the main ingredients used for the production of concrete. Unfortunately, production of cement involves emission of large amounts of carbon-dioxide gas into the atmosphere, a major contributor for greenhouse effect and the global warming, hence it is inevitable either to search for another material or partially replace it by some other material. The search for any such material, which can be used as an alternative or as a supplementary for cement should lead to global sustainable development and lowest possible environmental impact. Concrete property can be maintained with advanced mineral admixtures such as blast furnace slag powder as partial replacement of cement 5 to 30%. Compressive strength of blast furnace slag concrete with different dosage of slag was studied as a partial replacement of cement. From the experimental investigations, it has been observed that, the optimum replacement of Ground Granulated Blast Furnace Slag Powder to cement without changing much the compressive strength is 15% [6].

Siddique and Kaur [7] assessed the mechanical properties of concrete made with ground granulated blast furnace slag (GGBFS) subjected to temperatures up to 350°C. For this purpose, normal concrete having compressive strength of 34 MPa was designed using GGBFS as partial replacement of cement. Cylindrical specimens (150 x30 mm) were made

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and subjected to temperatures of 100, 200 and 350°C. Measurements were taken for mass loss, compressive strength, splitting tensile strength and modulus of elasticity. This investigation developed some important data on the properties of concrete exposed to elevated temperatures up to 350°C.

The findings from the background of the different studies explained above are as follows

- BFS could be used as constituent of cement due to its pozzolonic characteristic and it is also used in the glass industry.
- The disposal of BFS solid waste produced from the steel industry is a huge problem as it requires manpower, machinery and a lot of funds.
- Very few studies only show that BFS could be utilized partially as an alternative construction material for natural sand in cement mortar and cement concrete applications so we need to more specifically evaluate the suitability of BFS as an alternative of natural sand for natural sand in cement mortar.

The background of the mentioned studies suggests that BFS can be used as an alternative of natural sand as fine aggregate for cement mortar and cement concrete, so the basic need is to evaluate the suitability and respective percentage of BFS replacement of natural sand in cement concrete and cement works.

III. EXPERIMENTAL WORK FOR PROPOSED STUDY

This study evaluates the suitability and respective percentage of BFS replacement of natural sand in cement concrete and cement works. The cement, sand, aggregate, water and blast furnace slag are used for the preparation of cement concrete and cement mortar. Firstly, the characteristics of different materials used in this study are evaluated, then testing was done by making cement mortar cubes and cement concrete cubes.

Characterization of Cement

Cement (43 grade OPC, Bangur-buland) used for making concrete and cement mortar was characterized for its suitability as per IS: 8112-1989 [8]. Results of the tests are shown in Table 1.

Table 1 Properties of ordinary Portland cement

S. No.	Descriptions	Test Values	IS: 8112-1989
1.	Fineness, Blain's Value, m ² /kg	250	More than 225
2.	Setting time (min) Initial setting time Final setting time	80 240	Not less than 30 Not more than 600
3.	Soundness, Le-Chatelier method (mm)	1	10

Table 1 clearly shows that the cement proposed to be used in this study is having all the properties of cement as per IS: 8112-1989, within the permissible limit. Hence for this study, the same brand of cement (43 grade OPC, Bangur-buland) was used. Care was taken to procure cement of the same batch and stored under standard conditions till completion of the study.

Characterization of Coarse Aggregate

Crushed stone with maximum 12.5 mm graded aggregates (nominal size) was tested for its suitability for this study. Properties of coarse aggregate are shown in Table 2.

Table 2 Physical properties of coarse aggregate

S. No.	Properties	Observed values	Range as per code IS: 383-1970
1.	Aggregate Abrasion Value	18.30 %	Not more than 50%
2.	Aggregate Impact Value	13.42 %	Not more than 45%
3.	Aggregate Crushing Value	16.35 %	Not more than 45%

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4.	Fineness Modulus	06.35	5.50-8.00
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It can explicitly observe that the sieve analysis the coarse aggregate fulfil the IS: 383-1970[9] requirement, as shown in Table 3.

Table 3 Sieve analysis of coarse aggregate

IS Sieve Size	Percentage passing	IS: 383-1970 Requirement
80mm	100	----
40mm	100	----
20mm	100	----
12.5mm	95.20	90-100
10mm	63.10	40-85
4.75mm	03.90	0-10
Pan	00	----

Physiochemical Evaluation of Natural Sand and Blast Furnace Slag

Locally available Narmada Sand (NS) and its alternative i.e. Blast Furnace Slag (BFS) were tested for its suitability as fine aggregate. Blast furnace slag was collected from Bhilai Steel Plant, Chhattisgarh (India). This was produced by quenching molten iron slag (a by-product of iron and steel-making) from a blast furnace in water or steam, to produce a glassy, granular product that is then dried and ground into a fine powder. The physical properties of natural sand and Blast Furnace Slag as fine aggregates shown in Table 4.

Table 4 Physical properties of natural sand and alternative

S. No.	Properties	Natural Sand	Blast Furnace Slag	IS: 383-1970 Requirement
1.	Bulk density(kg/m ³)	1533	1340	1280-1920
2.	Specific gravity	02.73	02.55	2.30-2.90
3.	Fineness Modulus	02.11	02.30	2.10-3.20
4.	Water absorption (%)	06.22	03.21	0-8

After evaluating the physical properties of natural sand and alternative Blast Furnace slag the sieve analysis of was performed, result are shown in Table 5.

Table 5 Sieve analysis of natural sand and alternative Blast Furnace Slag

I.S. Sieve Size	Percentage Passing		IS: 383-1970 Requirement for Zone II
	Natural Sand	Blast Furnace Slag	
4.75 mm	100	100	90-100
2.36 mm	99.20	99.60	75-100
1.18 mm	97.00	91.70	55-90
0.600 mm	88.90	59.20	35-59
0.300 mm	02.60	14.20	8-30
0.150 mm	00.90	04.50	0-10

The physical evaluation of Natural sand and Blast Furnace Slag indicate that bulk density ,specific gravity , fineness modulus are similar range presented in Table 4, only water absorption of BFS is lesser as compare to NS but it is range in Indian standard. The sieve analysis of NS and alternative material BFS confirms the zone II requirement of fine

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aggregate as per Indian standards explicitly presented in Table 5. Hence, it can be suggested that physical properties of NS and BFS are similar and confirms the Indian standard requirement.

Chemical composition evaluation of Natural Sand and Blast Furnace Slag

For evaluation of surface morphology, SEM analysis was done. JEOL, Japan made SEM model JSM 5600 / LINK ISIS 300 was used. Its resolution was 3.5 nm/138 eV and magnification limit was 0.1 million times. SEM images of sand and blast furnace slag are shown in Fig. 1.

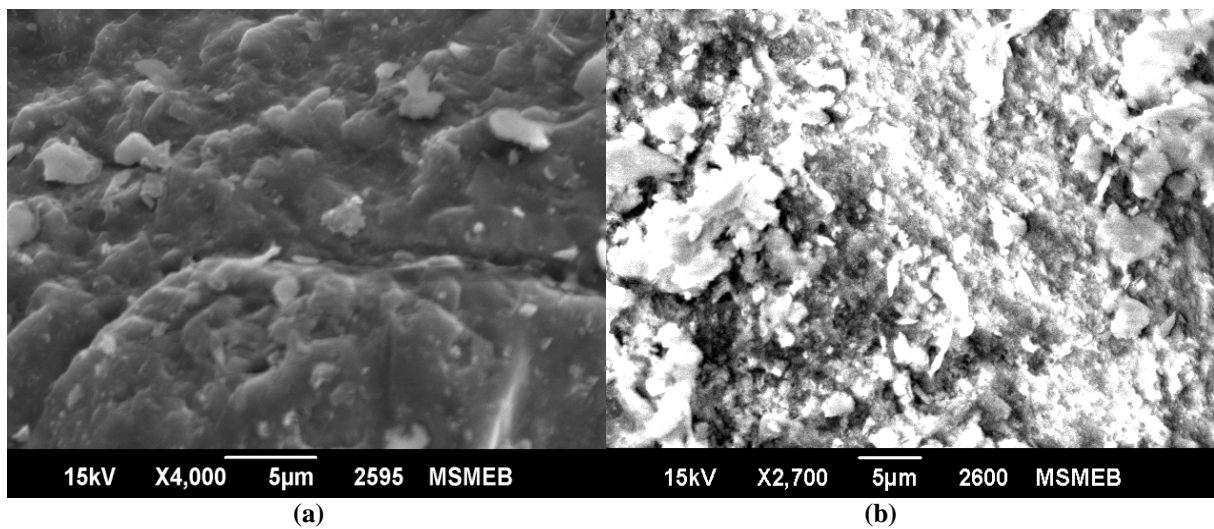


Fig. 1. SEM analysis (i) SEM image of Natural Sand (b) SEM image of Blast Furnace Slag

EDX analysis was done for the study elemental composition of sand and its alternative. Elemental composition of alternatives and that of sand is presented in Table 6.

Table 6 Elemental composition of Natural Sand and Blast furnace slag

S. No.	Elements	N-SAND	Blast Furnace Slag
1.	Si	32.21	30.19
2.	Al	02.93	17.51
3.	O	30.01	42.71
4.	Ti	--	04.45
5.	Fe	13.99	--
6.	Na	01.51	--
7.	V	--	02.71

Fig. 1 shows that the morphology of NS and BFS seems similar and Table 6 shows explicitly that composition with respect to Silica, Aluminium, and Oxygen are nearest to NS in BFS. Hence, it could be suggested physio-chemically that BFS can be alternative material for replacement of NS as fine aggregate for cement concrete and cement mortar. However, presence of Titanium and Vanadium in Blast furnace slag and may be harmful in the long run.

IV. EXPERIMENTAL RESULTS OF PROPOSED STUDY

The proposed study evaluated the suitability of Blast Furnace Slag as alternative fine aggregate material in cement concrete and cement mortar production in place of Natural Sand. The M-20 and M-30 cubes were prepared respective concrete mixes using alternatives material BFS to 20, 40, 60, 80 and 100% replacement of NS. Similarly, standard

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mortar cubes were prepared using alternative material BFS to 20, 40, 60, 80 and 100% replacement of NS. Firstly, the results of compressive strength tests of cement mortar cubes present as follows

Compressive Strength of Cement Mortar

Standard mortar cubes of 7.07 cm size with cement –sand proportion of 1:4 and 1:6, with alternative material to 20, 40, 60, 80 and 100% replacement of NS were prepared and determined their compressive strength for 3 and 7 days, shown in Table 7.

Table 7 Comparison of mortar strength of alternative

S. No.	Combination	C/S Proportion	Compressive Strength, (MPa)	
			3 Days	7 Days
1.	100% NS	1:4	2.20	3.81
		1:6	1.73	2.92
2.	20% BFS + 80% NS	1:4	5.2	5.83
		1:6	2.7	3.95
3.	40% BFS + 60% NS	1:4	4.8	5.21
		1:6	2.19	3.27
4.	60% BFS + 40% NS	1:4	3.93	4.51
		1:6	1.71	2.66
5..	80% BFS + 20% NS	1:4	3.16	3.94
		1:6	1.43	2.19
6.	100% BFS	1:4	3.16	3.3
		1:6	1.15	1.98

Table 7 presented the comparative results of compressive strength of mortar cube with variation of NS to BFS. With 20 percent replacement NS to BFS shows that higher values of compressive strength then it reaches highest value of compressive strength at 40 percent replacement of NS to BFS after that further increase in percentage of BFS to NS the compressive strength of cement mortar cubes get reduce. Hence, it can be assumed that replacement of NS to BFS between 40 to 50 percentages for mortar works could be suitable for mortar works.

Setting of Mortar

Mortar as prepared above was observed for its setting behaviour also mortar mixes were filled in 4 inch diameter glass petri plates and observed for its setting trend. Mortar was also placed on brick masonry under actual environmental conditions and setting was observed. For assessing setting behavior of mortar prepared with proposed alternatives, mortar was applied on brick wall. Its setting was observed under actual environmental conditions for the prolonged period of two months. Fig.2 shows the setting of mortar on wall surfaces.



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Fig.2. Setting of mortar on wall surfaces (a) mortar prepared with NS (b) mortar prepared with 40 percent replacement of NS to BFS

Fig. 2 (a) shows the surface with the mortar prepared with natural sand only and Fig.2 surface with the mortar prepared with 40 percent replacement of natural sand to BF. Although cracks were not there at the surfaces prepared with blast furnace slag shown in Fig.2 (b) but in this case workability decreased drastically beyond 40 and 20% respectively and it was not possible to apply this mortar on the wall. Hence, it can be suggest that mortar prepared with 40 percent replacement of NS to BFS is not suitable plastering of walls.

Compressive strength of cement concrete

M-20 and M-30 concrete mixes were prepared using alternatives (20, 40, 60, 80 and 100% replacement of sand). Compressive strength of standard concrete cubes (7 days and 28 days) was determined and compared with that of the cubes prepared with using only natural sand (IS 456 : 2000[10]) shown in Table 8.

Table 8 Compressive strength of cement concrete with Blast Furnace Slag

Material	W/C ratio	Replacement of NS with BFS (%)	Compressive strength of M-20 concrete cube		Compressive strength of M-30 concrete cube	
			7 Day	28 Day	7 Day	28 Day
Blast Furnace Slag	0.5	20	27.40	41.90	32.70	46.60
	0.5	40	30.90	44.50	34.10	48.90
	0.5	60	25.80	40.30	32.30	44.40
	0.5	80	22.90	35.10	29.90	40.50
	0.5	100	20.40	29.60	26.20	38.60

The results of compressive strength presented in Table 8 clearly shows that compressive strength of concrete cubes (28 days) was comparable with that of the cubes prepared with natural sand up to 40 -50% replacement. Beyond this, compressive strength decreases with increase in the replacement. Almost similar trend in the compressive strength of 7 days is noticed. Hence, It could be suggested that rational percentage replacement of Blast Furnace Slag to Natural Sand is 40 to 50 percent, this percent could be maximum compressive strength as Blast Furnace Slag as alternative of natural sand in cement concrete and cement mortar

V. CONCLUSIONS

The important conclusions of this study may be summarized as follows:

- The physiochemical evaluation shows that particles of natural sand and blast furnace slag particles are well distributed.
- The compressive strength of mortar cubes prepared with natural sand is compared with the cubes prepared with BFS, strength of 1:4 mortar cubes prepared with BFS is higher than the mortar cube prepared by natural sand. Although mortar prepared with 40 replacement of BFS is not suitable for plastering work of walls because it reduces the workability.
- The evaluation of compressive strength of cement concrete cube prepared with natural sand and percentage replacement of natural sand with Blast Furnace Slag (BFS) as fine aggregate has been carried out. The compressive strength of concrete cube at 40 percent – 50 percent of BFS replacement to natural sand gives higher strength.

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- The Utilization of blast furnace slag such as substitution of fine aggregates in cement concrete and cement mortar works resolves the solid waste management issue related to BFS disposal and also reduce detrimental impact of BFS on the environment.

Thus, this study justifies that Blast Furnace Slag can be used as substitute of Natural sand in cement concrete and cement mortar works and it is also recommended that up to 40%-50% of BFS can be used as a replacement for fine aggregates in order to obtain a concrete with good strength and durability requirements in developing nation like India.

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