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Study of Granulated Blast Furnace Slag as Fine Aggregates in Concrete for Sustainable Infrastructure

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Abstract

Growing environmental restrictions to the exploitation of sand from river beds leads to search for alternatives particularly near the larger metropolitan areas. This has brought in severe strains on the availability of sand forcing the construction industry to look for alternative construction materials without compromising the strength criteria of concrete. Granulated blast furnace slags are one of the promising sustainable solutions as they are obtained as solid wastes generated by industry. Hence it reduces the solid waste disposal problem and other environmental issues. Present experimental work explores the possibility of using GBFS as replacement of natural sand in concrete. In this study an attempt is done to understand the variation in compressive strength of concrete with GBFS content. Along with that cost analysis is also done to suggest the most optimized percentage of GBFS to be used in various conditions.

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Keywords: GBFS, Sustainable infrastructutre

1. Introduction

Concrete is a mixture of cement, aggregates, water, etc. which are economically available. Concrete is made up of granular materials. It looks like coarse aggregates embedded in a matrix bound together with cement or binder which fills the space between the particles and glues them together. Almost three quarter volume of concrete is made of aggregates. To meet the global demand of concrete in the future, it is becoming a more challenging task to

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find sustainable ways of construction. Sustainable construction mainly aims to reduce the negative environmental impacts generated by construction industry. Over a period of time, waste management is becoming one of the most challenging problem in the world. The rapid growth of industrialization is giving birth to various kinds of wastes which are very dangerous to our environment. The consumption of slags in concrete not only helps in reducing green house gases but also helps in making environmentally friendly. During the production of iron and steel, fluxes (limestone and/or dolomite) are charged into blast furnace along with coke as fuel. The coke after combustion produces carbon monoxide, which converts the iron ore into molten iron product. Slag is a non-metallic inert waste consisting of mainly silicates, alumino silicates and calcium-alumina-silicates. Iron cannot be prepared in blast furnace without blast furnace slags. The use of granulated blast furnace slag (GBFS) aggregates in concrete by replacement of natural aggregates is very promising concept because its impact strength is quite more than natural aggregate. Steel slag aggregates are already being used as aggregates in asphalt paving road m due to their mechanical strength, stiffness, porosity, wear resist and water absorption capacity.

2. Literature Review

Many researchers have try to study GBFS in the past years to assess its properties and its behavior. (K.Ganesh Babu, 2000) try to quantify the 28-day cementitious efficiency of ground granulated blast furnace slag(GBFS) in concrete at various replacement levels. The replacement levels vary from 10% to 80% and the strength at the 28days were calculated. Strength efficiency factor varies from 1.29 to 0.70 for replacement of 10% to 80%. (Pazhani.K, 2010) presented that the slump for 100% replacement of fine aggregate with copper slag increases by 60-85 mm. The replacement of 30% cement by GGBS leads to decrease in water absorption up to 4.58%, chloride ion permeability by 29.9% and pH value by 0.39%. The replacement of 100% of fine aggregate by copper slag decreases water absorption by 33.59%, chloride ion permeability up to 77.32% and pH value by 3.04. (Venu Malagavelli, 2010) studied the characteristics of M30 grade concrete with partial replacement of cement by GGBS and sand with ROBO sand (crusher dust). Compressive strength and split tensile strengths of the cubes and cylinders were increased with increase in % of ROBO sand. The percentage increase in compressive strength were 19.64% and 8.03% after 7 and 28 days and increase in split tensile strength was 1.83% after age of 28 days by replacing 30% sand with ROBO sand. Percentage increase in compressive strength of concrete was 11.06% and 17.6% after 7 and 28 days by replacing 50% cement with GGBS and 25% sand with ROBO sand. (Mahesh Patel, 2013) investigated the characteristics of M35 grade concrete with partial replacement of cement with GGBS and sand with crusher sand. Results show that compressive strength and split tensile strength was increased as the percentage of crusher sand increased & 50% of cement can be replaced with GGBS. The increase of compressive strength of concrete is 10.04 % and 16.54% after 7 and 28 days by replacing 40% of cement with GGBS and 20% of sand with crusher sand. (Susanto Teng, 2013) studied ultrafine GGBS (30%), he showed that it possesses large surface area which increases the rate of hydration, pozzolanic reactions and provides a better filling effect. Concrete with UFGGBS has a higher early strength, lower permeability and improved durability even after 3 days of curing. And also, it is possible to obtain a consistent mix as the UFGGBS improves the workability and consistency of fresh concrete. (Oner, 2007) presented a laboratory investigation on optimum level of GGBS on the compressive strength of concrete. Concrete was obtained by adding GGBS in 0%,15%,30%,50%,70%, 90% and 110% of cement content and the specimens were moist cured. The test results proved that the compressive strength of concrete mixtures containing GGBS increases as the amount of GGBS increase. After an optimum point of 55% replacement, the addition of GGBS does not improve the compressive strength. The early strength of GGBS concretes was lower than the control concretes. As the curing period is increased the strength increase was higher for the GGBS concrete. The optimum level of GGBS content for maximizing strength is about 55%-59%.

In this experimental study we have tried to study the variation in compressive strength of concrete subjected to normal and artificial marine environment with various GBFS content. Initially 88 cylinders were casted with GBFS percentage from 0% to 100%. Half of them were subjected to normal curing and half of them were cured in saline solution with accelerated conditions in order to simulate the effect of sea water. The specimens were tested after 28 and 90 days for compressive strength. The goal of this study is to generate a model to explain the behavior of GBFS concrete subjected to normal and marine environment and provide the optimum percentage of GBFS based on economy and strength.

3. Research Significance

The present infrastructure development is creating immense pressure on construction industry. One of the most important materials in construction is concrete. Approximately five billion tonnes of concrete are used around the world each year. The huge requirement of concrete is putting question marks on sustainability of natural sand reserves of all the countries. These environmental issues are forcing engineers to look forward for more sustainable construction materials. As a solution for this, various alternatives such as quarry dust, wastes from demolished concrete, industrial wastes like copper slag, eco sand etc have been used.

This research is a small attempt in the direction of sustainable infrastructure. It explores the possibility of using GBFS (a industrial waste) in construction industry as a substitute of natural sand. It focuses on providing the most optimum and economical percentage of GBFS in concrete for the construction of structures not only on land but also in sea. The research findings will help the researchers to understand the behaviour of GBFS concrete in a better way.

4. Experimental programme

4.1 Materials

4.1.1 Cement

Ordinary portland cement of 53 grade conforming to IS 269-1976 was used throughout the experiment. Different tests and investigations were done to ensure that it conforms the requirement of Indian Standards.

4.1.2 Aggregates

The coarse aggregates used were of size 20 mm and 12.5mm (Down) and were mostly angular in shape. Locally available fine aggregates conforming to Zone –II of IS 383-1970 were used . Sieve analysis result of fine aggregates are in shown in Table 1 and the other test data for materials are given in Table 2.

Table1: Sieve analysis result of fine aggregates

IS Sieve Designations(mm)	%Passing	As PerIS383-Table- no.4	Conformance of Grading Zone IS– 383 -1970
10	100	100	
4.75	100	90-100	Conforming to Grading Zone II of Table 4 of IS:383-1970
2.36	92.83	75-100	
1.18	80.5	55-90	
600 micron	48.5	35-59	
300 micron	9.33	8-30	
150 micron	0.66	0-10	

4.1.3 GBFS

The blast furnace slag was procured from Durgapur Steel Plant a unit of Steel Authority of India Limited. The material was crushed and sieved passing through 20mm sieve and retaining on 4.76mm sieve.

Table 2: Test Data of Materials

Materials Property	Value
Cement Grade	OPC 53
Specific gravity of cement	3.15
Specific gravity	
1)Coarse aggregate(20mm)	2.87
2)Coarse aggregate(12.5 mm)	2.84
3)Fine aggregate	2.58
Water absorption	
1)Coarse aggregate(20mm)	1.28
2)Coarse aggregate(12.5 mm)	2.10
3)Fine aggregate	0
Free (surface) moisture	
1)Coarse aggregate(20mm)	Nil
2)Coarse aggregate(12.5 mm)	Nil
3)Fine aggregate	Nil

4.2 Mix proportion

Table 3: Mix Proportions

Water	Cement	Fine Aggregates	Coarse Aggregates(20mm)	Coarse Aggregates(12.5)
0.435	1	1.95	1.4	0.89

One of the ultimate goal of investigating the properties of materials is to design a proper mix for a particular strength and workability. Based on the properties of materials a concrete mix of M25 grade is designed following the Indian Standard IS-10262. The mix proportions are shown in Table 3.

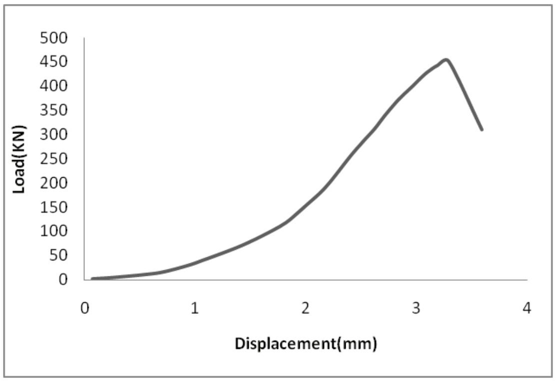
4.3 Specimen Preparation and Curing

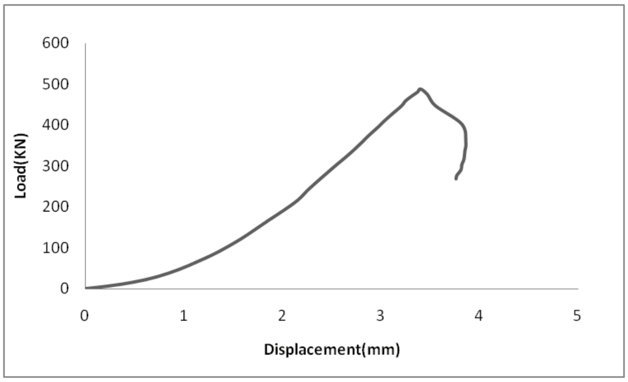
A total of 88 cylinders with 0%, 10%, 50% ,60%, 70%,80%,90% and 100% replacement of sand by GBFS were prepared . Eight of them (with 0% GBFS) were prepared as control specimens. The size of cylindrical specimens was 300x150 as per the Indian Standards. Half of the specimens were cured with tap water under room temperature.

Remaining specimens were cured in artificial marine environment with accelerated aging. The 3% NaCl concentration was used to simulate a marine environment or the use of de-icing salts in northern regions as used by (Kim H-Y, Park Y, 2008) and (Bérubé MA, Dorion JF, 2003).
Along with that they were also subjected to variation in temperature from 50 °C (the mean annual temperature and the marine environment of the Middle East and warm regions) to 10°C (mean average temperature of northern regions). Normally cured specimens were named as G1, G2....G11 and specimens cured in marine environment were named as GM1 , GM2.....GM11 as per the percentage of GBFS.

4.4 Testing of Specimens

The concrete cylinders were tested for the compressive strength under UTM after 28 and 90 days of curing. The load versus displacement curve for G4 and GM4 specimens are shown in fig.1. It is quite clear that after a certain point in load vs deflection curve there is a sudden increase in deflection which conforms the failure of specimen as shown in fig.2. The test results are summerized in Table 4 and Table 5.





(a) (b)

Fig.1 (a) Load vs Displacement curve for G4 specimen (b) Load vs Displacement curve for GM4 specimen

Fig.2 (a) Failure of G4 specimen (b) Failure of GM4 specimen

Table:4 Test results of normally cured specimens

S.No.	Sample No.	GBFS percentage	28 Days Strength(MPa)	90 Days Strength(MPa)	%Increase in strength	Economy Index
1	G1	0	20.79	22.56	8.51370851	0.856226968
2	G2	10	21.12	23.58	11.6477273	0.866369055
3	G3	20	23.65	26.56	12.3044397	0.945669466
4	G4	30	25.32	30.96	22.2748815	1.069252478
5	G5	40	28.63	36.62	27.907789	1.227882836
6	G6	50	35.62	40.63	14.0651319	1.323772846
7	G7	60	32.56	38.23	17.4140049	1.211287376
8	G8	70	28.56	34.26	19.9579832	1.056417955
9	G9	80	26.78	32.26	20.4630321	0.968791147
10	G10	90	24.35	30.6	25.6673511	0.895571782
11	G11	100	23.53	27.45	16.6595835	0.783457488

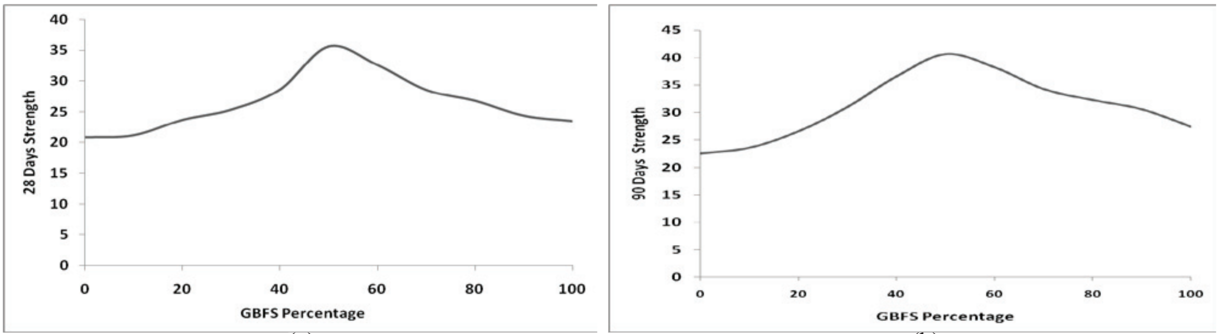
Table 5: Test results of concrete cured in marine environment

S.No.	Sample No.	GBFS percentage	28 Days Strength(MPa)	90 Days Strength(MPa)	%Increase in strength	Economy Index
1	GM1	0	19.78	20.85	5.409505	0.791327
2	GM2	10	20.53	22.59	10.0341	0.829995
3	GM3	20	20.62	24.67	19.64113	0.878376
4	GM4	30	25.73	29.26	13.71939	1.01054
5	GM5	40	28.3	30.59	8.091873	1.025695
6	GM6	50	29.76	32.46	9.072581	1.057585
7	GM7	60	32.63	36.58	12.10542	1.159008
8	GM8	70	30.39	34.29	12.83317	1.057343
9	GM9	80	24.56	28.46	15.87948	0.854674
10	GM10	90	22.23	26.94	21.18758	0.788454
11	GM11	100	22.56	26.65	18.12943	0.760624

5. Results and Discussion

5.1 Normally Cured Specimens

It was observed that the compressive strength of concrete increases with the increase in GBFS content up to a certain percentage after that it decreases. The highest strength was observed with 50 percent of replacement of natural sand which was 35.62 Mpa and 40.63 Mpa after 28days and 90 days respectively. Increase in strength of GBFS concrete from 28 days to 90 days was always more than the control specimens and it was maximum for 40% replacement as shown in fig.5(a).



(a) (b)

Fig.3 Plot of Strength vs GBFS percentage for normally cured specimens after 28 (a) and 90(b) days

Based on the contemporary market rates the cost of materials used to cast a specimen was calculated. In order to consider both the parameters strength and economy of construction an index known as *Economy Index* was defined to provide the most optimum percentage of GBFS.

$$Ecomomy\ Index = \frac{Strength}{Cost} \quad (1)$$

It was observed that the most optimum percentage of GBFS is from 40% to 50% with a economy index greater than 1.2.

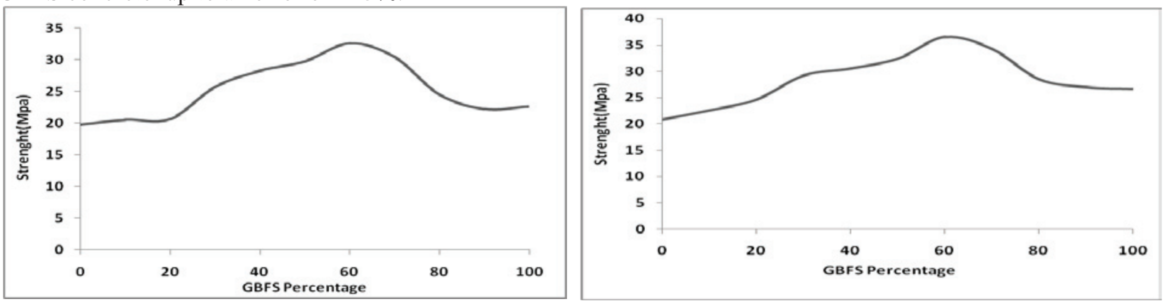
5.2 Specimens Cured Under Marine Conditions

For the specimens cured in saline water with accelerated conditions the observed strength was little less than the normally cured specimens. The highest strength was observed with 60 percent replacement of natural sand which was 32.63 Mpa and 36.58 Mpa after 28 days and 90 days respectively. Under saline environment also increase in strength of GBFS concrete from 28 days to 90 days was always more than the control specimens as shown in fig.5(b). Based on the Economy Index the most optimum percentage of GBFS to be used in saline environment is from 50% to 60% with a economy index greater than 1.05.

5.3 Numerical Model

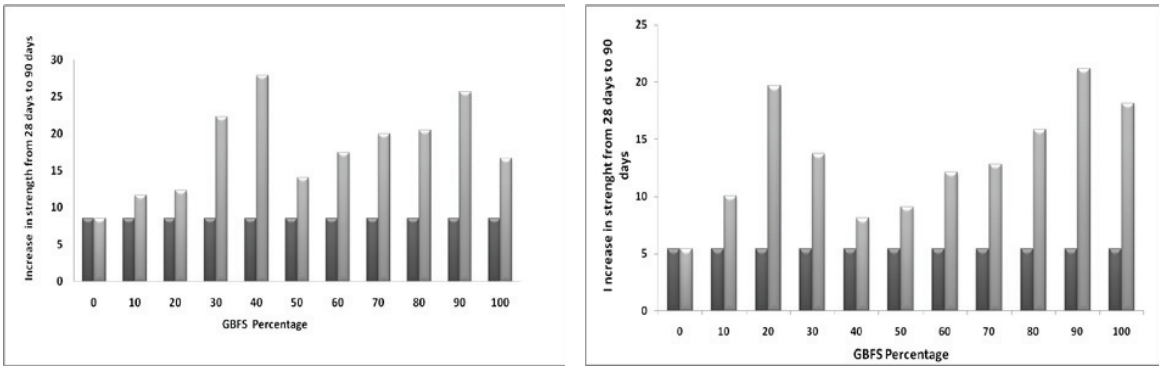
Based on the above observation an attempt is done to develop a theoretical model which can estimate the 90 days strength of concrete for a particular GBFS percentage . The experimentally observed data set is analyzed using

Curve Fitting Tool of Matlab. After several attempts it was observed that the behaviour of GBFS can be modelled as a Gaussian Model. Hence a Gaussian equation is developed which can effectively predict the 90 Days strength of GBFS concrete up to an error of 2-3%.



(a) (b)

Fig.4 Plot of Strength vs GBFS Percentage for specimens cured under marine conditions after 28(a) and 90(a) days



(a) (b)

Fig.5 Plot of Increase in strength of GBFS concrete from 28 days to 90 days for (a) Normally cured specimens (b) Specimens cured under marine conditions

$$f(z) = a_1 e^{-\left(\frac{z-b_1}{c_1}\right)} + a_2 e^{-\left(\frac{z-b_2}{c_2}\right)} \; where \; z = \frac{x-\mu}{\sigma} \quad (2)$$

where z is the normalized value of GBFS percentage and $a_1, b_1, c_1, a_2, b_2, c_2$ are the coefficients whose value depends upon the curing environment. The percentage of GBFS is represented by variable x having mean and standard deviation as μ and σ respectively. The value of the coefficients are tabulated in Table 6.

Table 6: Coefficients of Gaussian Equation

Coefficients	Normal Curing	Marine Curing
a_1	8.69	5.91
b_1	0	0.36
c_1	0.48	0.31
a_2	32.5	31.1
b_2	0.38	0.27
c_2	2.95	2.73

6. Summary and Conclusion

GBFS (Granulated Blast Furnace Slag) is a slag obtained from the manufacture of iron in steel industries. This research aims to investigate the possibility of using GBFS in place of natural sand in concrete. In this study the sand is replaced from 10% to 100% by GBFS and its effect on compressive strength of concrete is studied. Along with that the economic study is also done to suggest the most optimum percentage of GGBS to be used in industry. The following study is also conducted for concrete subjected to artificial marine environment**.** Some of the important findings are

- The compressive strength of concrete increases with increase in GBFS percentage up to a certain percentage and after that it decrease following a Gaussian Model.
- Gaussian Equation based on the observed behaviour is developed to estimate the strength in concrete after for a particular percentage of GBFS subjected to normal and marine conditions.
- The most optimum percentage of GBFS to be used in normal conditions considering both strength and economy factor is from 40% to 50% and for marine conditions its from 50% to 60%.
- The long term strength development of GBFS concrete is almost double of normal concrete in both normal and marine conditions.

Based on these findings it can be stated the GBFS can be used as a replacement to natural sand provided that it is used judicially. It is one of the promising solutions towards sustainable infrastructure without compromising strength and economy.

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