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Feasibility Studies on Granulated Blast Furnace Slag as Cement and Sand Replacement

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Abstract: In India, the conventional concrete is produced using natural sand from river beds as fine aggregate. Decreasing natural resources poses the environmental problem and hence government restriction on sand quarrying resulted in scarcity and significant increase in its cost. The huge quantity of concrete is consumed by construction industry all over the world. Thus, it is becoming inevitable to use alternative materials for aggregates in concrete which include recycled aggregates, fly ash, manufactured sand, crushed rock powder etc. The use of such materials not only results in conservation of natural resources but also helps in maintaining good environmental conditions. The objective of this study is to investigate the rheological and hardened properties of concretes under two cases: (i) with Ground Granulated Blast Furnace Slag (GGBS) as partial replacements for Portland cement and (ii) with Granulated Blast Furnace Slag (GBS) as partial replacement of sand aggregates, in both cases varying combinations are tested and compared the results to conventional concrete. The ordinary portland cement was partially replaced with GGBS by 10%, 20 %, 30%, 40%, 50%, 60% and 70% and natural sand was replaced with GBS by proportions 10%, 20 %, 30%, 40%, 50%, 60% and 70%.This paper presents the optimization of partial replacement of GGBS for Portland cement and partial replacement of GBS by natural sand in Concrete. Partially replaced Concrete mixes were evaluated for compressive strength and split tensile strength and the findings are reported. This paper puts forward the applications of Granulated Blast Furnace Slag as an attempt towards sustainable development in India. It will help to find viable solution to the declining availability of natural sand to make eco-balance.

Keywords: Ground Granulated Blast Furnace Slag (GGBS), Granulated Blast Furnace Slag (GBS), Pozzolanic reaction, Admixtures.

1. INTRODUCTION

Production of Portland cement is very pollutant process which accounts for 5% of the world's annual CO_2 emissions similarly quarrying for fine aggregates is very damaging for environment. But if you forecast demand for concrete, it is set to increase so economically and environmentally sustainable solution is required to eliminate the above shortcomings.

Sand is the one of primary ingredient of concrete making which occupies about 35% of volume of concrete used in construction industry. Natural sand is mainly excavated from river beds and always contain high percentage of in organic materials, chlorides, sulphates, silt and clay that adversely affect the strength, durability of concrete and reinforcing steel there by reducing the life of structure, Sand having fine particles below 600 μ must be at least 30 % to 50% for making good concrete which may not be the case in river sand. Digging sand, from river bed in excess quantity is hazardous to environment. The deep pits dug in the river bed, affects the ground water level. In order to fulfill the requirement of fine aggregate, some alternative material must be found. Therefore, it is necessary to replace natural sand in concrete by an alternate material either partially or completely without compromising the quality of concrete. In this study authors tried the cheapest and the easiest way of getting substitute for natural sand by replacing the percentage of sand by GBS of desired size.

For producing concretes of high performance, Industrial wastes, such as silica fume, blast furnace slag, and fly ash are being used as supplementary cement replacement materials and are also being used as pozzolanic materials in concrete. When pozzolanic materials are incorporated to concrete, the silica present in these materials react with the calcium hydroxide released during the hydration of cement and forms additional calcium silicate hydrate (C – S – H), which improve durability and the mechanical properties of concrete. In our study we used GGBS as both cement and sand replacements to study the durability and the mechanical properties of concrete. GGBS is a by product of iron manufacturing process (slag) which is rapidly cooled and grounded or made into well graded aggregate. In comparison to Portland cement it releases 93% less CO_2 per tonne produced and has greater long term strength, increases consistency, reduces Alkali Silica Reaction expansion, reduces bleeding due to pozzolanic activity and also cheaper. The partial replacement of cement with GGBS reduces the content of cement used in the construction industry, which protects the ecosystem with a small percentage in the reduction of green house gases. The optimum GGBS replacement percentage for obtaining maximum 28- days strength of concrete ranged from 40 to 50 %. GGBS in High Performance concrete will develop strength sufficient for construction purposes. Its use will lead to a reduction in cement quantity required for construction purposes and hence sustainability in the construction industry as well as aid economic construction. The following table presents the environmental impact of OPC and GGBS production.

Environmental Impact of Portland Cement and GGBS production			
Environmental Issues	Measured against	Influence of One tonne of GGBS Production	Influence of One tonne of OPC Production
Climate Change	CO_2	0.07 tonnes	0.95 tonnes
Energy Consumed	Natural Resources	1300 MJ	5000 MJ
Mineral Extraction	Quarrying	0	1.5 tonnes
Waste Disposal	Recycling	1 tonne saved	0.02 tonnes only saved

Cement replacement up to 50% with GGBS leads to increase in compressive strength for high strength grade of concrete (M60) and about 40% replacement with GGBS is possible in Ordinary (M20) and Standard grades (M40) of concretes. GGBS is known to improve both the mechanical characteristics and durability of concrete. The principle physical effect of silica fume is fineness that can fill the space between particles of coarse aggregates and cement grains and improves strength. The super plasticizer Gelinium B233 was used as chemical admixture. Gelinium B233 is based on PCE (Polycarboxylic ether) for concrete and it is a brown liquid instantly dispersible in water. It has been specially formulated to give high water reductions up to 25% without loss of workability and produce high quality concrete to enhance strength and durability with low binder ratio 0.26 to 0.4. Increasing dosage of super plasticizer by weight of binder (Cement and GGBS) improved the performance of concrete and contribute more to improvement of its workability properties as well as mechanical properties with reduced W/B ratio.

The present investigation was carried out to study the optimization of partial replacement of GBS for natural sand and partial replacement of GGBS for Cement in terms of compressive strength and split tensile strengths for Ordinary (M20), Standard (M40) and High strength (M60) grades of concrete. Further, the study helps to identify a suitable material for natural sand and to minimize the usage of cement content in the concrete by alternate material to some proportion.

2. RESEARCH SIGNIFICANCE

Normal concrete lacks required strength and durability which are more often required for large concrete structures such as high rise buildings, bridges and structures under severe exposure condition. Due to booming construction activities natural sand is becoming scarce due to excessive non scientific methods of mining from the river beds. For these reasons it is necessary to produce a concrete with improved strength and performance, with suitable materials. This research shows the effective utilization of by product GGBS in Concrete as replacement for cement and sand.

3. EXPERIMENTAL PROGRAMME

Materials Used

Cement: Ordinary Portland cement of 53 Grade conforming to IS 12269 1987**,** and the specific gravity of cement was found to be 3.15.

Coarse Aggregate: Crushed angular aggregate with maximum grain size of 10mm and other properties are shown below in table 1.

Fine Aggregate: Locally available River sand having properties as per IS 383-1970 shown below is used as fine aggregate in cement replaced GGBS concrete. Granulated Blast Furnace Slag (GBS) conforming to Zone –II (It was collected from Visakhapatnam steel plant) is used as fine aggregate in sand replaced GBS concrete. The percentage of particles passing through various sieve were compared with natural sand and it was found to be similar as shown in table 2.

Table 1: Properties of fine and coarse aggregate

Property	Fine Aggregate (River Sand)	Coarse Aggregate
Specific Gravity	2.512	2.574
Bulk Density (kg/m^3)		
Loose	1513.4	1401.98
Compacted	1666.31	1503.04
Fineness Modulus	2.625	6.64

Super plasticizer: In order to improve the workability of high-performance concrete, superplasticizer Gelinium B233 was used as chemical admixture. Gelinium B233 is based on PCE (Polycarboxylic ether) for concrete.It is a brown liquid instantly dispensable in water.

Water: Fresh potable water, which is free from acid and organic substance, was used for mixing the concrete.

Ground Granulated Blast Furnace Slag (GGBS) for Cement replacement

a) Typical Chemical Composition of GGBS

Calcium oxide 40%
Silica 35%
Alumina 13%
Magnesia 8%

b) Typical Physical Properties of GGBS

Colour	off-white
Specific gravity	2.9
Bulk density	1200 kg/m^3
Fineness	>350m^2/kg

Granulated Blast Furnace Slag (GBS) as sand replacement

It is having high Silica content. It has a higher proportion of the strength enhancing Calcium Silicate Hydrates (CSH).

Table 2: Sieve Analysis for GBS (Zone – II)

S. No.	IS Sieve No.	Weight Retained in gm	% weight retained	Cumulative % weight retained	% Passing
1	40 mm	-	-	-	-
2	20 mm	-	-	-	-
3	10 mm	-	-	-	-
4	4.75 mm	0	0	0	100
5	2.36 mm	6	0.6	0.6	99.4
6	1.18 mm	115	11.5	12.1	87.9
7	600 μm	450	45.0	57.1	42.9
8	300 μ	300	30.0	87.1	12.9
9	150 μ	129	12.9	100.0	0
Total Cumulative % weight retained				256.9	

Mix Proportion

The Table 3 shows the mix proportions of Ordinary (M20), Standard (M40) and High strength (M60) grades of concrete. Concrete mix design in this investigation was designed as per the guidelines specified in IS Code and for High strength (M60) grades of concrete Erntroy and Shacklock's empirical method is used.

M20	M40	M60
1:2.27:3.4:0.55	1:1.73:2.60:0.43	1:1.17:2.07:0.33

4. TEST PROCEDURE

The specimen of standard cube of (100mm x 100mm x 100mm) and standard cylinders (150mm x 300mm) were used to determine the compressive strength and split tensile strength of concrete. To obtain compressive strength of concrete the cubes were tested using Compression Testing Machine (CTM) of capacity 3000KN and the test was carried out conforming to IS 516-1959.Specimens were prepared with each proportion of Ordinary (M20), Standard (M40) and High strength (M60) grades of concrete with optimum cement replacement with GGBS and optimum sand replacement with GBS and were tested at 7, 28, 90 and 180 days for its compressive and split tensile strength as per Indian Standards.

Fig 1(a)

Fig 1(b)

Fig 1 (a): GGBS (For cement replacement)

Fig 1 (b) GBS (For Sand replacement)

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5. TEST RESULTS

Table 3: Cement Replacement with GGBS in M20 Grade Concrete

Mix No	% of GGBS Replacement	Compressive Strength(MPa)		
		28 days	90 days	180 days
A-1	0%	26.45	34.12	36.22
A-2	10%	28.21	38.23	39.25
A-3	20%	32.12	42.12	46.12
A-4	30%	36.00	51.22	58.20
A-5	40%	45.30	54.12	68.50
A-6	50%	44.20	53.40	67.20
A-7	60%	39.60	52.20	62.30
A-8	70%	34.00	50.91	53.52

Table 4: Cement Replacement with GGBS in M40 Grade Concrete

Mix No	% of GGBS Replacement	Compressive Strength(MPa)		
		28 days	90 days	180 days
B-1	0%	42.21	48.21	52.55
B-2	10%	46.32	54.12	56.12
B-3	20%	47.12	56.34	58.32
B-4	30%	48.22	58.66	63.20
B-5	40%	49.51	60.12	74.20
B-6	50%	48.41	59.40	72.60
B-7	60%	47.20	58.41	71.40
B-8	70%	44.12	53.61	63.10

Table 5: Cement Replacement with GGBS in M60 Grade Concrete

Mix No	% of GGBS Replacement	Compressive Strength(MPa)		
		28 days	90 days	180 days
C-1	0%	65.12	70.21	74.55
C-2	10%	68.21	72.35	76.42
C-3	20%	70.50	74.21	78.12
C-4	30%	72.42	76.12	82.21
C-5	40%	77.41	79.91	86.35
C-6	50%	78.16	83.45	89.20
C-7	60%	66.41	74.23	83.20
C-8	70%	60.92	69.30	78.10

Table 6: Sand Replacement with GBS in M20 Grade Concrete

Mix No.	% of GBS Replacement	Compressive Strength (MPa)			
		7 days	28 days	90 days	180 days
A-1	0%	28.22	26.45	34.12	36.12
A-2	10%	30.12	40.31	42.20	44.20
A-3	20%	36.42	43.42	46.12	48.22
A-4	30%	38.90	50.23	52.35	54.21
A-5	40%	39.20	58.61	60.22	62.12
A-6	50%	42.51	64.11	66.31	67.20
A-7	60%	30.94	53.97	56.21	58.12
A-8	70%	30.50	50.11	51.10	54.20

Table 7: Sand Replacement with GBS in M40 Grade Concrete

Mix No.	% of GBS Replacement	Compressive Strength (MPa)			
		7 days	28 days	90 days	180 days
B-1	0%	43.6	48.44	50.12	53.22
B-2	10%	51.86	63.71	64.12	66.21
B-3	20%	55.44	67.44	68.31	69.12
B-4	30%	56.12	69.93	78.12	81.2
B-5	40%	54.86	63.66	76.21	79.22
B-6	50%	51.73	56.67	70.12	74.12
B-7	60%	49.56	54.33	66.21	68.2
B-8	70%	47.69	52.37	60.42	64.12

Table 8: Sand Replacement with GBS in M60 Grade Concrete

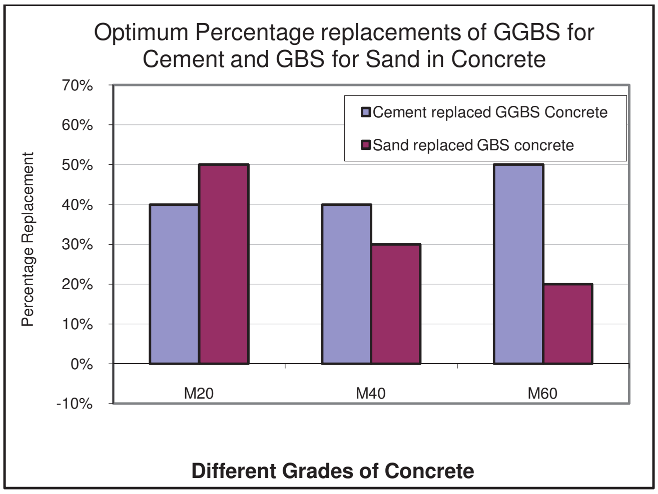
Mix No.	% of GBS Replacement	Compressive Strength (MPa)			
		7 days	28 days	90 days	180 days
C-1	0%	62.21	68.1	71.22	79.12
C-2	10%	68.23	77.89	78.12	82.11
C-3	20%	63.04	90.95	94.02	96.12
C-4	30%	71.84	84.38	92.07	94.46
C-5	40%	68.02	83.74	89.16	90.12
C-6	50%	80.2	82.21	83.24	86.22
C-7	60%	58.04	71.02	80.12	84.12
C-8	70%	56.21	68.11	79.22	81.12

Table 9: Cement Replacement with Optimum percentage of GGBS

Grade of Concrete	Optimum percentage of GGBS Replacement	Split Tensile Strength (MPa) at 28 days
M20	40%	2.71
M40	40%	3.29
M60	50%	3.89

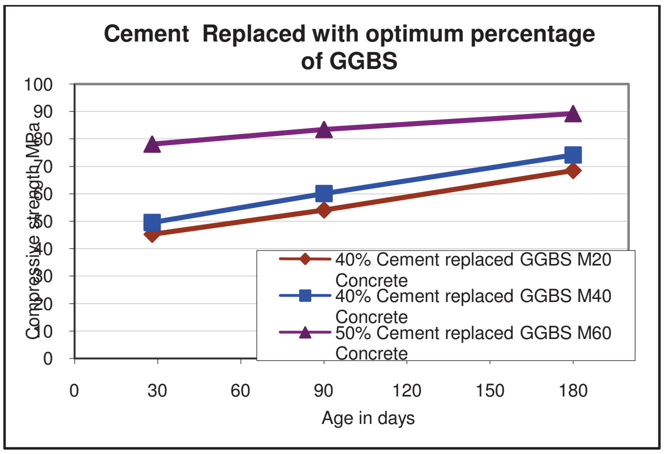
Table 10: Sand Replacement with Optimum percentage of GBS

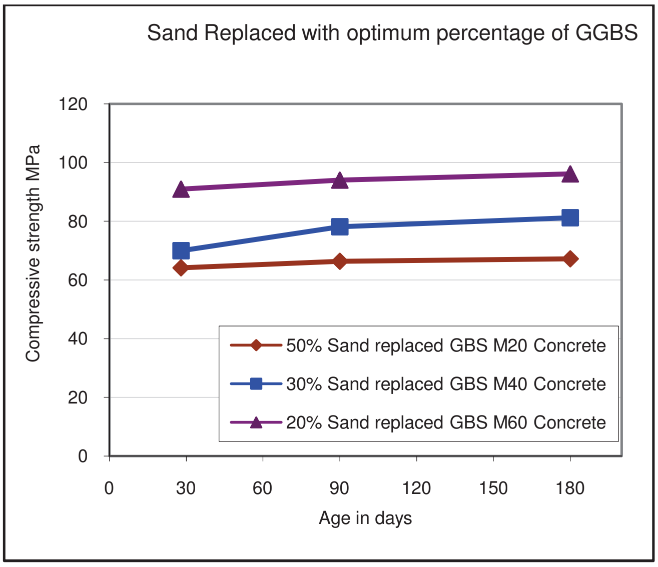
Grade of Concrete	Optimum percentage of GBS Replacement	Split Tensile Strength (MPa) at 28 days
M20	50%	3.71
M40	30%	3.11
M60	20%	3.32



6. DISCUSSION

From the investigation carried out based on strength at various ages of concrete, the optimum cement replacement percentages are 40%, 40% and 50% in Ordinary (M20), Standard (M40) and High strength (M60) grades of concrete respectively. The results indicated that there is an increase in the compressive strength of cement replaced GGBS concrete by nearly 70% to 90% for ordinary M20 grade concrete, 20% to 40% for standard M40 grade concrete and about 20% for high strength M60 grade concrete between 28 days to 180 days age.





The results also revealed that there is an increase in split tensile strength of Concrete in Ordinary (M20), Standard (M40) and High strength (M60) grades.

In case of sand replaced GBS concrete, an increase in the compressive strength of cement is observed to be 86% for 50% replacement of sand by GBS in Ordinary (M20) grade concrete, 53% for 30% replacement of sand by GBS in Standard (M40) grade concrete and 21 % for 20% replacement of sand by GBS in High strength (M60) grades of concrete, at 180 days of age.

7. CONCLUSIONS

The conclusions drawn from this report are:

There is a significant improvement in the compressive strength of Cement replaced GGBS concrete because of the high pozzolanic nature of the GGBS and its void filling ability.

It is observed that there is consistent increase in the strength of concrete when partial replacement of natural sand by GBS. The sharp edges of the particles in GBS provide better bond with cement than rounded particles of natural sand resulting in higher strength up to optimum replacement.

Finally in this study, it is observed that the compressive strength and split tensile strength of all grades of concrete can be improved by partial replacement of GGBS for cement and GBS for fine aggregate.

The dwindling sources of natural sand and its high cost could encourage the adoption of GBS by 40 to 50% replacement of natural sand. Therefore it is feasible to use GBS as sand

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replacement as long as designer is aware of the effects of the different combinations on the hardened and rheological properties.

GBS has a potential to provide alternative to natural sand and helps in maintaining the environment as well as economical balance. Non-availability of natural sand at reasonable cost, forces to search for alternative material. GBS qualifies itself as suitable substitute for river sand at reasonable cost. The GBS found to have good gradation, which was lacking in natural sand. This had been resulted in good cohesive concrete. This sand replacement material is considered as an ideal for concrete.

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