Utilization of Granulated Blast Furnace Slag in the Manufacturing of Solid Concrete Blocks

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***Abstract*— In the present scenario manufacturing of solid concrete blocks become intricate from quality and economic point of view, because of non-availability of natural resources and skilled labors. This scarcity of natural sand because of environmental issues leads to usage of manufactured sand (M-Sand) and crusher dust. In the present study, granulated blast furnace slag (GBS) which is a by-product of steel manufacturing plant is used by replacing partially and completely for manufactured sand (about 0%, 25%, 50%, 75%, and 100%). Characterizations of all materials were carried out to know the properties and behavior in solid concrete blocks during its fresh and hardened state. Dimensionality, Compressive strength, Water absorption and Block density tests were carried on hardened concrete blocks as per IS 2185(Part1):2005.**

Tests reveals that increase in percentage of GBS in the manufacturing of concrete blocks as a replacement to M-sand beyond 50% leads to gradual decrease in compressive strength and block density . Meanwhile, increase in the percentage of GBS results in increase in water absorption.

***Keywords* — Manufactured sand, Natural sand, Granulated Blast Furnace Slag (GBS), Solid Concrete Block**

I. INTRODUCTION

A. General

As we know aggregates normally occupy 65% to 80% of concrete by volume and have a significant influence on both rheological and mechanical properties of mortar, concrete and concrete blocks. The Construction Industry is very large consumer of naturally derived aggregates like natural sand, manufactured sand, crushed rock etc. In south India, Natural River sand, manufactured sand and quarry dust are commonly used fine aggregates in the manufacturing of concrete blocks. Sources of high-quality aggregate near major developed cities or urbanised areas that are suitable for use in concrete are becoming increasingly more difficult to obtain as existing pits and quarries become exhausted. Environmental concerns have been raised against uncontrolled extraction of natural materials particularly river sand considering to protect riverbeds against erosion and the importance of having natural sand as a filter for ground water process, therefore mining of river sand is banned by state Governments in most areas of country. However, growing environmental restrictions to the exploitation of sand from riverbeds have resulted in a search for alternative material to natural sand and Manufactured-sand (M-Sand). This has brought for looking to the quantum of requirements, quality and properties of Granulated blast furnace slag (GBS); this has been taken as a suitable material for replacing natural sand, M-Sand and crushed fine aggregates by its availability and properties.

In this study, GBS is used as fine aggregate and replaced partially / completely for M-sand which is used in present concrete block manufacturing practice. Characterization of materials, physical properties and chemical composition of various ingredients are studied along GBS. Compatible behaviour of GBS with other ingredients of concrete block was studied both at fresh and Hardened state at in-situ condition. Tests were carried on hardened concrete blocks as per Indian Standards 2185(Part-1): 2005.

Most of developed countries are already practicing and implementing the granulated blast furnace slag as fine aggregate in building concrete works, precast elements and Road works to replace natural aggregate and it is well established.

B. Background to GBS

Granulated Blast Furnace Slag is a main by-product generated during iron and steel production in the steel industry. Blast Furnace Slag are generated at two different stages of steel production i.e., Iron making and Steel making, known as Blast Furnace slag and Steel Slag respectively. While in the production, blast furnaces are fed with controlled mixture of iron-ore, coke and limestone and operated at a temperature of about 1500°C. When iron-ore, coke and limestone melt in blast furnace, two products are produced – molten iron and molten slag. As the molten slag is lighter it floats on the top of the molten iron inside blast furnace. The molten slag mostly consists of silicates and alumina from the original iron ore, combined with some oxides from the limestone. This molten slag is solidified in air after dumping into the existing pit and granulated by striking through very high pressure water jets. This high pressure water jet rapidly quenches the slag and forms granular particles of size not more than 5mm. The rapid cooling prevents the formation of larger crystals and results in granular material. Over the past decades, the steel production has increased worldwide and they are consequently producing higher volume of by-products and residues, which have driven to the reuse of these waste materials in an increasingly efficient way. The slag amount very much depends upon charging material, for example, the grade of iron ore. It varies from about 200 to 600 kg for producing one ton of hot metal. On average, it contains about 0.5–0.8 % FeO, 35–42% CaO, 35–40% SiO_2, 8–9% MgO, 8–15% Al_2O_3, 0.3–1.0% MnO and 0.7–1.5% in weight.

The chemical compositions of the slag is very much similar to that of the cement, so the fast-cooled Ground Granulated Blast Furnace slag can be used as a high-value Partial replacement to conventional Portland cement. Most of the modern steel plants now completely granulate the BF slag and use in cement making. However this granulated BF slag (GBS) is very similar to natural sand and can be used directly as fine aggregate in construction works. In the present study, GBS is investigated and tested for its compatibility with M-sand in the manufacturing of solid concrete blocks.

Figure 1: Granulated Blast Furnace Slag

C. Objective of Project Work

The main objective of work is to utilize the industrial waste as an alternative material for natural river sand and M-Sand, so that the scarcity of natural raw materials can be reduced to some extent.

- To evaluate the properties of GBS in the manufacturing of concrete blocks.
- To evaluate the GBS based concrete blocks for its mechanical properties as per IS 2185-2005.
- To characterize GBS for its physical and chemical properties.

D. Scope of Project Work

In the present work, GBS is utilized as a partial or complete replacement to M-sand in the manufacturing of concrete blocks for mix proportion 1:4:5 i.e., 1 part of cement, 4 part of Fine aggregate, 5 part of coarse aggregate of 6mm downsize. Concrete blocks of size 400x150x200mm were casted and tested as per IS 2185 (Part 1) : 2005 for its Dimensionality, Compressive strength, Water absorption and Block density to know the behavior of GBS in Solid concrete blocks.

II. METHODOLOGY

A. Characterization of Materials

In this study, material classification and characterization were done to find its suitability in the manufacturing of solid concrete blocks. Physical properties and chemical composition tests were carried for all ingredients of block and each will be explained in detail.

1. Cement

Ordinary Portland Cement (OPC) of grade 53 is used to manufacture concrete blocks and its Procured from local vendor. Tests on Physical properties and chemical composition of cement were carried as per IS: 4031-1988 and it meets the requirements of IS: 12269 – 1987. Results are tabulated in Table 1 and 2

Table 1: Chemical composition of Cement

Sl. No.	Characteristics	Requirements as per IS:12269-1987	Test result
1	Lime Saturation Factor (%)	0.8 min. 1.02 max.	0.90 %
2	Alumina Iron Ratio (%)	0.66 % min.	1.10 %
3	Insoluble Residue (%)	2 % max.	1%
4	Magnesia (%)	6 % max.	2.5 %
5	Loss on Ignition (%)	4 % max.	3 %

Table 2: Physical Properties of Cement

Sl. No	Characteristics	Obtained Values	Requirements as per IS:12269-1987
1	**Standard Consistency**	34%	No standard value
2	**Specific surface**	303 m^2/kg	Should not be less than 225 m^2/kg
3	**Soundness**		
	a) By Le Chatelier method	0.5 mm	Should not exceed 10 mm
	b) By Autoclave method	0.09%	Should not exceed 0.8%
4	**Setting time**		
	a) Initial Setting	105 min	Not < 30 min
	b) Final Setting	325 min	Not > 600 min
5	**Compressive strength**		
	a) 3 days	31 Mpa	Should not be less than 27Mpa
	b) 7 days	44 Mpa	Should not be less than 37Mpa
	c) 28 days	59 Mpa	Should not be less than 53Mpa
6	**Specific Gravity**	3.09	3.15 – 3.25

2. Manufacture Sand

Manufactured Sand is available at nearby source. It is procured and tests were carried for its physical properties as per IS 383:1970 and results are tabulated in Table 3.

Table 3: Physical Properties of Manufacturing Sand

Sl. No.	Characteristics	Obtained values
1	Zoning	Zone III
2	Specific Gravity	2.52
3	Water Absorption	2.67%
4	Loose Bulk Density Roded Bulk Density	1.5 kg/lt 1.76 kg/lt

3. Granulated Blast Furnace Slag

Granulated Blast Furnace Slag (GBS) is procured from JSW Steel Plant at Bellary district, Karnataka to block manufacturing site and material is tested for its following physical properties and chemical composition and results are tabulated in Table 4 and Table 5.

Table 4: Physical Properties of GBS as per IS 383:1970

Sl. No.	Characteristics	Obtained Values
1	Zoning	Zone II
2	Specific Gravity	2.31
3	Water Absorption	4.17%
4	Loose Bulk Density Roded Bulk Density	1.202 kg/lt 1.309 kg/lt

Table5: Chemical Compositions of GBS as follows:

Sl. No.	Characteristics	Requirement as per IS: 12089	Test result
1	SiO_2 (%)	-	33.11
2	Al_2O_3	-	21.95
3	Fe_2O_3	-	1.28
4	CaO	-	34.68
5	MgO	17.0 Max	8.85
6	Loss on Ignition	-	0.08
7	IR	5.0 Max	0.43
8	Manganese content	5.5 Max	0.07
9	Sulphide Sulphur	2.0 Max	0.52
10	Glass content	85 Min	90.0
11	Moisture content	-	10.80
12	Particle Size Passing 50.0 mm	95%	100%
13	Chemical Moduli $(CaO+MgO+Al_2O_3)/SiO_2$	Greater than or equal to 1.0	1.97

4. **Coarse Aggregate**

Coarse aggregate of 6mm downsize is procured from nearby source and tested for its physical properties as per IS 383:1970 and the results are tabulated in Table 6.

Table 6: Physical Properties of Coarse Aggregate

Sl. No.	Characteristics	Obtained Values
1	Specific Gravity	2.65
2	Water Absorption	0.8%
3	Loose Bulk Density Roded Bulk Density	1.412 kg/lt 1.532kg/lt

5. **Water**

The water used is clean and free from organic impurities and salts. It is available in block manufacturing unit and meets the requirements of IS 456:2000.

B. Mix Proportion of Solid Concrete Block

Partially and complete replacement of GBS is done for the Mix proportion 1:4:5 concrete i.e., 1 part of Cement, 4 part of Manufacture sand and 5 part of Coarse aggregate as shown in Table 7

Table 7: Mix proportion of Solid Concrete Blocks

Sources	Percentage Replacement of GBS	Mix proportion for Concrete blocks
A	0% of GBS	1:4:0:5
B	25% of GBS	1:3:1:5
C	50% of GBS	1:2:2:5
D	75% of GBS	1:1:3:5
E	100% of GBS	1:0:4:5

C. Batching

After procurement of desired materials for concrete blocks, batching of all materials is done before mixing. Weigh batching is done for GBS and Cement and volume batching is done for coarse aggregate and manufactured sand.

D. Mixing

V - Type concrete mixer of capacity 0.3 m^3 with fixed inner blades which is able to rotate at 12 rpm is used. For this electrically operated mixer, dry materials were added and allow it to mix for a period of 3- 4 minutes to get uniform, homogenous and cohesive mix.

E. Casting

Semi – mechanized egg laying machine of impact type is used to cast solid concrete blocks of size 400mm x 150mm x 200mm. Machine consists of single vibrator and 3 - 4 impact blows is given to compact the concrete mix into desired block shape as shown in Figure 2. In one punch it's able to produce five solid concrete blocks.

Figure 2: Solid Concrete Blocks

F. Stacking

After casting of concrete blocks, it is left on platform for a period of 24 hours to get hardened to handle them. Then the blocks are lifted from the casting yard and stacked on a nearby level ground to ensure a full surface contact to concrete blocks. Concrete blocks are stacked in such a way that, the height of the stack should not be more than 1.2 m. Length of the stack should not be more than 3 m and width of the stack should not be more than 2 to 3 blocks.

G. Curing

The stacked blocks were then cured for 12 days by frequent sprinkling of water by covering the blocks with damp gunny bags upon it.

H. Drying

After 12 days of curing the blocks are allow to air drying by leaving blocks exposed to ambient temperature for about 4 weeks. It shall be ensured that the blocks have been thoroughly dried and allowed to complete their initial drying shrinkage before take for testing.

I. Testing of Concrete Blocks

As per IS 2185 (Part 1): 2005, 20 blocks were taken from each source A, B, C, D & E. All 20 blocks of each source were tested for dimensionality and out of which 8 blocks were tested for compressive strength, 3 blocks were tested for water absorption and 3 blocks were tested for block density.

1. **Dimensionality Test**

All twenty full sized blocks is measured for its length, breadth and height with a scale graduation of 1mm Length division. Blocks is measured in such a way that length shall be measured on the longitudinal centre line of each face, width across the top and bottom bearing surfaces at midlength, and height on both faces at midlength. As per IS 2185(part 1):2005, the maximum variation in the length of the blocks shall not be more than ± 5 mm and width and height of the block shall not be more than ±3mm.

2. **Block Density**

Three blocks are taken from each source of twenty blocks and it is kept for oven drying at temperature 100°C for 24 hours. After 24 hours the blocks is cooled to room temperature and overall dimensions of blocks are measured and weight of the block is taken. The block density is calculated by the formula given below:

$$\text{Density} = \frac{Mass\ of\ block, in\ kg}{volume\ of\ specimen, in\ cm^3} \times 10^6$$

3. **Water Absorption**

Three blocks are selected from each source and it is completely immersed in water for a period of 24 hours. Further, blocks are removed from water and allowed it to drain for a minute. Visible surface water is cleaned from damp cloth and immediately weighed and then the blocks are kept to oven dry for 24 hours at temperature 100°C. Samples taken from oven were cooled to room temperature and dry weight and measurements are taken.

The water absorption is calculated from below formula:

$$\text{Water absorption, percent} = \frac{A-B}{B} \times 100$$

4. **Compressive Strength**

Eight blocks were selected out of twenty to carry compressive strength test prior to that Gypsum plaster capping is done on both bearing surface of the block to ensure uniform bearing surface. After minimum 2 hours gap of capping the blocks are placed in compressive testing machine between two steel plates of thickness 12mm.

Blocks are placed in such a way that steel plates, block and machine base are vertical and centrally aligned. Later, blocks are subjected to compressive load at the rate of 2 N/mm^2 per minute. The compressive strength is calculated by using the below equation.

$$\frac{Loads\ in\ KN}{Gross\ area\ of\ unit\ perpendicular\ to\ direction\ of\ load},\ {}^{N}\!/_{mm^2}$$

III. Results and discussions

In order to find out the behavior of GBS in concrete blocks, twenty blocks were casted for each percentage replacement for manufactured sand that is (0%, 25%, 50%, 75% & 100%). From each twenty concrete blocks, all blocks were tested for dimensionality, 3 blocks out of twenty were taken for block density, and water absorption. Eight blocks were selected for compressive strength test. Behavior and results of GBS at various replacements in Solid Concrete Blocks were studied and the results are compared to conventional mix of concrete blocks.

A. Dimensionality Test

Table 8: Dimensionality Test of concrete blocks

Percentage replacement of GBS	Average length in mm	Average width in mm	Average height in mm
A – 0% GBS	397.6	150.4	198.6
B – 25% GBS	397.55	150.95	197.8
C - 50% GBS	397.6	150.3	198.6
D - 75% GBS	397.6	150.4	201.6
E – 100% GBS	398.2	149.65	199.4

For Dimensionality test of concrete blocks, the maximum variation in the length of the blocks shall not be more than ± 5 mm and width and height of the blocks shall not be more than ±3 mm with respect to nominal dimensions of the blocks. From the above Table 8, the average length, width and height of all blocks are well within the limits to the nominal dimensions of blocks.

B. Block Density

According to Indian Standards 2185(part 1): 2005 clause 5.2, the density of the solid concrete blocks should not be less than 1800kg/m^3. From the Figure 3, it is cleared that, source A, B, C & D shown block density more than 1800kg/m^3. But source E (100% replacement of GBS) shown 1783 kg/m^3 which is less than desired block density of 1800kg/m^3. This may due to lower loose and roded bulk density of GBS compared to loose and roded bulk density of M-sand.

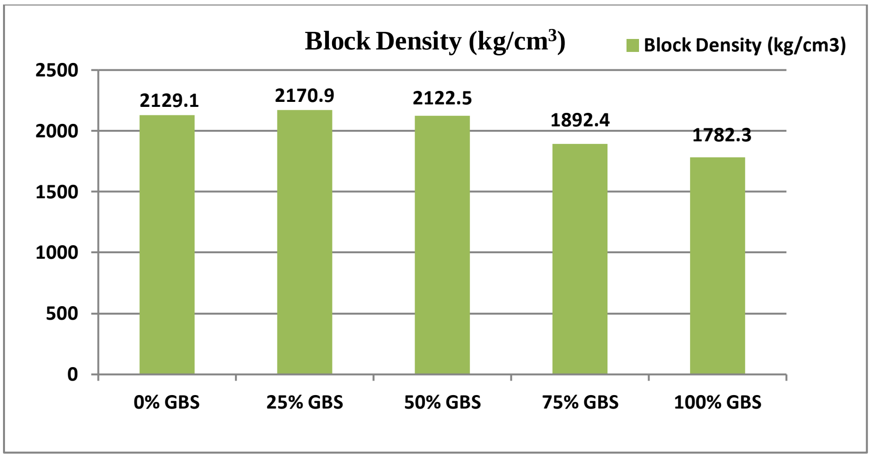

Figure 3: Bar chart of Block density Solid Concrete Blocks

C. *Water Absorption*

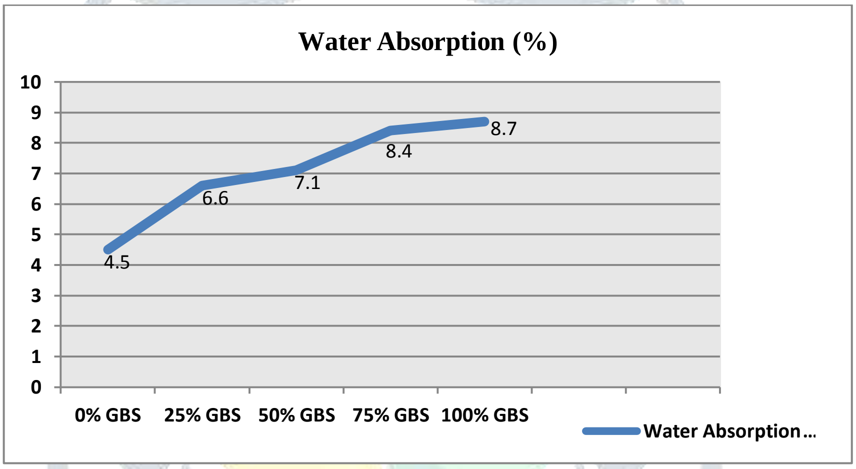

Figure 4: Graph showing Water Absorption Solid Concrete Blocks

From the above graph, it can be clearly conclude that increase in percentage of GBS in concrete blocks as a replacement for M-sand results in increase in water absorption. But at 100% replacement of GBS, water absorption is around 8.7% which is less than maximum water absorption limit of 10% by mass as specified in IS 2185 (Part 1): 2005 clause 9.5.

D. Compressive strength

From Table 9, we can observe that source B (25% replacement of GBS to M-sand) shown higher compressive strength of range 10.5 Mpa to 13 Mpa compared to source A (0% replacement of GBS to M-sand) which is in the range 10.1 Mpa to 13 Mpa. We can conclude that increase in the percentage of GBS from 0% to 100% results in decrease in the compressive strength. This may due to lower density of GBS and also may due to excess vibration and compaction during casting of concrete blocks.

It is noticeable that the compressive strength of concrete blocks at 100% replacement of GBS to M-sand shows around 7.5 Mpa to 8.4 Mpa which is greater than 3.5 Mpa as per IS 2185 (Part 1): 2005.

Table 9: Compressive Strength Test of Solid Concrete blocks

Source	**Compressive Strength of Concrete Blocks (Mpa)**								**Average Compressive strength (Mpa)**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	
A (0%)	10.12	13.1	11.18	10.9	10.41	10.2	10.31	10.5	10.84
B (25%)	10.98	13.01	12.51	10.7	11.45	10.5	11.33	10.8	11.41
C (50%)	9.16	10.5	10.22	9.5	10.26	10.86	10.42	10.12	10.13
D (75%)	10.94	9.5	10.15	9.11	9.63	10.54	9.73	10.11	9.96
E (100%)	8.12	8.38	7.56	8.25	8.04	7.86	8.36	7.96	8.1

IV. CONCLUSION AND SCOPE OF THE FUTURE WORK

A. Conclusions

A comprehensive study on Granulated Blast Furnace Slag (GBS) based concrete blocks was conducted to find out whether the GBS based concrete blocks possess desirable engineering properties and also meet the codal standards. This has led to the following important conclusions.

- As we increase the percentage of GBS in concrete blocks from 0% to 100% resulted in increase in water absorption.
- For 25% replacement of GBS, the block density will be similar to that of conventional mix blocks (source A). But after 25% replacement, the block density of blocks decreases gradually.
- Up to 75% of replacement the block density will be more than the required block density of 1800 kg/m^3 and for 100% replacement there will be decrease of block density than the required limit.
- As percentage of GBS increase in concrete block the compressive strength decreases gradually. But all source of blocks i.e.,[A, B, C, D & E] has achieved more than the required limit of compressive strength.
- Test results show us the industrial waste material GBS can be used efficiently as a partial replacement to M-Sand in manufacturing of concrete blocks.
- Depending on type of machine used to manufacture concrete blocks, quality of ingredients, Curing and Drying period, Lifting period and type of chemical admixtures, we can say that, up to 50 - 70% of GBS can be replaced to natural fine aggregates.
- As we increase the percentage of GBS more than 70% in concrete blocks there will be loss in cohesiveness followed by increase in water absorption which inturn leads to decrease in block density.
- By utilizing this type of steel industry waste product we can reduce the consumption of natural sand followed by decrease in embodied energy, carbon foot print and other environmental issues.

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B. *Scope of the Future Work*

Further work is need to have industry-institution and end user programmes, to address the need of utilization of GBS in the manufacturing of pre-cast products such as Paver blocks, Kerb stones, Drainage slab and many more products and the implication of the same on safety aspects of construction.

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