A study on partial and full replacement of fine aggregate in high-performance concrete with granulated blast furnace slag

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Abstract. The influence of the partial / full replacement of fine aggregates with granulated blast furnace slag (GBS) and its effect on mechanical strength and durability properties (acid attack) of high-performance concrete of grade (M60) had been studied in the present work. The high-performance concrete mix had been designed in such a way that one group with natural sand and another with manufactured sand (Quarry dust). Each group of concrete mix with natural and manufactured sand consisted of five sub-groups, having 0%, 30%, 50%, 80% and 100% of GBS content. Other pozzolanic materials such as fly ash and silica fume were also employed to replace ordinary Portland cement (OPC) at 20% and 8% respectively, with a constant w/c ratio of 0.32 for the desired slump of 100 mm. According to the results, all the replacement levels of fine aggregate by GBS proved to enhance the mechanical and durability performance of concrete. It is concluded that the high-performance concrete can be produced by utilizing 100% GBS as fine aggregate, with improved mechanical and durability performance.

1. Introduction
Due to the increase in urbanization and infrastructural development all over the world, especially in developing countries like India, it requires a huge amount of natural resources used to make the concrete. One such resource is the fine aggregate (river sand). As the deposits of natural sands have slowly been depleted and posing many serious problems to both environment and humankind, it has resulted in a search for other suitable alternatives in the form of fine aggregate. From the literature [1]–[4], it was observed that the manufactured sand (Msand), granulated blast furnace slag (GBS), waste foundry sand, glass waste, etc. were used as a fine aggregate alternative to natural river sand. Among these, though Msand is a by-product of the stone crushing industry, due to the increased demand and the intentional manufacturing of Msand further causes the depletion of rock sources which takes millions of years to form.

A non-metallic Granulated blast furnace slag is the by-product of steel and iron industries, consisting essentially of non-crystalline calcium-aluminosilicates [5], GBS is produced by rapid quenching of molten slag with water jets, which resulted in a granular glassy aggregate. This granular aggregate with little fines used for fine aggregate replacement in the present study.
High-performance concrete (HPC) has led to a decrease in section size of structural elements due to its high compressive strength, toughness and durability when exposed to severe environmental conditions [6]. But, to produce HPC it requires higher paste content. If we use OPC alone to produce HPC, it will lead to increased cost, the heat of hydration and drying shrinkage. Generally, HPC is produced by utilizing other supplementary cementitious materials (SCM’s) such as fly ash (FA), silica fume (SF), rice husk ash, ground granulated blast furnace slag (GGBS) [7]–[9]. HPC demands a lower w/c ratio to give higher strength and low permeable concrete. So, water-reducing admixtures such as naphthalene based or ether-based are employed to increase the workability. Utilization of SCM’s further led to reduced cost of concrete and at the same time made it more sustainable. Although some studies have been reported on utilizing the GBS as fine aggregate in normal concrete [2], [10] and self-compacting concrete [1], there has been little research on the influence of GBS as fine aggregate in HPC.

For the present study two different groups of concrete were developed, one with river sand (RS) as fine aggregate and other with manufactured sand (Msand) as fine aggregate. Compressive, split tensile, flexural strength and acid attack tests were conducted to evaluate the performance of concrete containing GBS as fine aggregate, in place of RS and Msand.

2. Experimental details

2.1. Materials

Ordinary Portland cement (OPC) of 53 grade confirming to IS 269: 2015 having the physical properties as given in table 1 was used for making the high-performance concrete (HPC). Pozzolanic materials such as fly ash (FA) having a specific gravity of 2.5 confirming to IS 3812 (Part 1): 2013 and silica fume (SF) having average particle size of 150 nm and specific gravity of 2.2 confirming to IS 15388: 2003 were employed to replace total cementitious material by 20% and 8% respectively, by weight based on the trial mixes.

Locally available coarse aggregate (CA) passing 20 mm and 12.5 mm, manufactured sand (MS), river sand (RS) and granulated blast furnace slag (from JSW Steel Ltd.) confirming to IS 12089: 1987 were used for making the concrete. The standard physical properties of these materials were shown in table 2. To improve the workability of HPC, PCE (poly carboxylic ether) based superplasticizer (SP) (ECMAS HP-904) having a specific gravity of 1.13 and tap water confirming to IS 456:2000 was used.

2.2. Mix design and methodology

Trial mix designs were carried and finalized the material proportions per cubic meter volume as given in table 3 according to IS 10262: 2009 to achieve the predetermined compressive strength and workability.

The methodology of the present study is to compare the mechanical and resistance to acid attack properties of the control sub-groups in each group and concrete in which fine aggregate is replaced with 30, 50, 80, and 100% of GBS at a constant w/c of 0.32.

2.3. Test procedure

- Workability test on fresh concrete was conducted with the slump cone apparatus in accordance with IS 1199: 1991.
- Compressive strength on 150 mm size cubes after 7 and 28 days of curing and flexural strength on simple beam (100 mm × 100 mm × 500 mm) with fourth point loading after 28 days of curing was conducted in accordance with IS 516: 1959.
- Split tensile test was conducted on cylindrical specimens (150 mm dia. and 300 mm height) after 28days of curing in accordance with IS 5816: 1970.
- Acid attack test was conducted in accordance with ASTM C267 - 01 (2012) on 70.6 mm concrete cubes and residual strength was found after exposure to 5% concentrated sulfuric acid solution for 28 days.
Table 1. Properties of cement.

| Property                        | Result |
|--------------------------------|--------|
| Specific gravity               | 3.16   |
| Fineness (m$^2$/kg)            | 311.85 |
| Soundness (mm)                 | 0.6    |
| Initial setting time (min)     | 145    |
| Final setting time (min)       | 215    |
| Compressive strength (MPa)     |        |
| 3 days                         | 42.8   |
| 7 days                         | 48.2   |
| 28 days                        | 62.1   |

Table 2. Properties of aggregate.

| Property                        | RS    | Msand | GBS  | CA   |
|--------------------------------|-------|-------|------|------|
| Specific gravity               | 2.65  | 2.80  | 2.85 | 2.80 |
| Bulk density (kg/m$^3$)         | 1630  | 1850  | 1220 | 1560 |
| Moisture content (%)            | 0.8   | 1.5   | 1.0  | -    |
| Water absorption (%)            | 1.0   | 4.0   | 1.0  | 0.04 |
| Fineness modulus                | 2.63  | 2.67  | 2.86 | 2.86 |
| Impact value (%)                | -     | -     | -    | 9.22 |
| Crushing value (%)              | -     | -     | -    | 0.82 |

Table 3. Mix proportions of concrete specimens (kg/m$^3$).

| Material                 | RS 100% | RS 30% | RS 50% | RS 80% | RS 100% | Msand 100% | Msand 30% | Msand 50% | Msand 80% | Msand 100% |
|--------------------------|---------|--------|--------|--------|---------|------------|-----------|-----------|-----------|------------|
| Cement                   | 333.0   | 333.0  | 333.0  | 333.0  | 333.0   | 333.0      | 333.0    | 333.0    | 333.0    | 333.0    |
| Fly ash                  | 92.5    | 92.5   | 92.5   | 92.5   | 92.5    | 92.5       | 92.5     | 92.5     | 92.5     | 92.5     |
| Silica fume              | 37.0    | 37.0   | 37.0   | 37.0   | 37.0    | 37.0       | 37.0     | 37.0     | 37.0     | 37.0     |
| RS/Msand                | 767.4   | 541.1  | 386.5  | 154.6  | 0       | 806.2      | 569.0    | 403.1    | 162.5    | 0         |
| GBS                      | 0       | 257.2  | 428.6  | 687.8  | 858.0   | 0          | 257.2    | 429.0    | 686.4    | 858.0     |
| CA                       | 1078    | 1078   | 1078   | 1078   | 1078    | 1078       | 1078     | 1078     | 1078     | 1078      |
| Chemical admixture       | 2.08    | 2.08   | 2.08   | 2.08   | 2.08    | 2.08       | 2.08     | 2.08     | 2.08     | 2.08      |
| Water                    | 166.9   | 166.3  | 163.9  | 162.5  | 160.9   | 184.2      | 177.4    | 172.7    | 165.7    | 160.9     |
| w/c ratio                | 0.32    | 0.32   | 0.32   | 0.32   | 0.32    | 0.32       | 0.32     | 0.32     | 0.32     | 0.32      |

3. Results and discussion

3.1. Workability

From table 4 it can be observed that with the increase in GBS content, the super plasticizer requirement increased to achieve the desired slump of 100 mm, irrespective of the concrete series. Due to more angular structure and water absorption, Msand utilized more super plasticizer (SP) than river sand. The ability to reduce the workability of fine aggregate was in the order as RS < Msand < GBS.
Table 4. Variation in dosage of superplasticizer.

| GBS content (%) | Design SP in gm | RS Total added SP in gm | Extra dosage in % | Msand Total added SP in gm | Extra dosage in % |
|-----------------|-----------------|-------------------------|-------------------|-----------------------------|-------------------|
| 0               | 2081            | 2111                    | 1.4               | 2151                        | 3.3               |
| 30              | 2081            | 2143                    | 2.9               | 2175                        | 4.5               |
| 50              | 2081            | 2161                    | 3.8               | 2195                        | 5.4               |
| 80              | 2081            | 2176                    | 4.5               | 2205                        | 5.9               |
| 100             | 2081            | 2193                    | 5.4               | 2193                        | 5.4               |

3.2. Compressive strength

Average compressive strength results at the end of 7 and 28 days of curing of both the groups (RS and Msand) are shown in figure 1. It is observed that the target mean strength i.e., 46.58 MPa for 7 days cured specimens and 68.25 MPa for 28 days cured specimens has been achieved by all mix proportions. Also, compressive strength of mixes having GBS as fine aggregate is higher (26 – 33% at 7 days and 2 – 13% at 28 days) and (25 – 47% at 7 days and 11 – 34% at 28 days) when compared to mix having only Msand and RS as fine aggregate respectively.

![Figure 1. Variation in average compressive strength.](image)

Whereas this increment is lower in case of normal and standard grade concrete [11], [2], this higher increment in compressive strength can be attributed to the inclusion of fly ash and silica fume as supplementary cementitious materials [12]. The maximum compressive strength is achieved at 100% GBS as fine aggregate. It is clear that both Msand and GBS not only helped in achieving the early age strength but also higher strength at later ages.

3.3. Flexural strength

Figure 2 represents variation in the average flexural strength of 28 days cured specimens. It is observed that the flexural strength of concrete mixes is increased with the increase in the incorporation of GBS. The flexural strength value of control mix with only Msand as fine aggregate is 6.89 MPa and this value further increased to 6.93, 6.96, 7.33 and 7.45 MPa which is 0.58%, 1.01%, 6.38% and 8.12%
higher than control mix for 30%, 50%, 80% and 100% replacement with GBS respectively. Similar trend is also observed in case of concrete with RS as fine aggregate and these values are 0.73%, 1.31%, 4.1% and 9.23% higher than control mix having only RS as fine aggregate. Highest flexural strength is observed at 100% replacement levels for both the series. This is due to the lower w/c ratio and pozzolanic action of supplementary cementitious materials and GBS [3].

3.4. Split tensile strength

Variation in the average split tensile strength of 28 days cured specimens of all mixes is graphically represented in figure 3. Msand series mixes have 0.55%, 4.42%, 5.53%, 5.90% and 9.04% higher split tensile strength than target strength of 5.42 MPa at 0%, 30%, 50%, 80% and 100% replacement with GBS respectively. Mix with 100% RS has 2.4% lesser split tensile than what it is designed for. On the other hand, remaining mixes of RS series have 0.73%, 2.58%, 4.24% and 9.04% higher split tensile strength than target mean strength at 30%, 50%, 80% and 100% replacement with RS with GBS. It is clear from the above results that the GBS as a fine aggregate along with lower w/c ratio and pozzolanic materials enhanced the tensile properties of HPC.

3.5. Residual compressive strength after acid attack

The acid attack test was conducted to measure the durability of the concrete. The figure 4 indicates the variation of Residual compressive strength for different percentages of GBFS replacement. The
percentage decrease in compressive strength due to acid attack are 53.88%, 31.73%, 29.64%, 21.48% and 31.97% for 0%, 30%, 50%, 80% and 100% replacement with GBS respectively in case of Msand. Similarly, the percentage decrease in compressive strength due to acid attack in case of River sand are 48.87%, 33%, 31%, 32% for 0%, 30%, 50%, 80% and 100% replacement with GBS respectively. Though the mix with 80% GBS performed well compared to all other mixes in both the series, the mix with 100% replacement with GBS also has better resistance towards acid attack, which is consistent with mechanical properties.

![Figure 4. Variation in average residual compressive strength.](image)

4. Conclusions
From the tests conducted, following conclusions can be drawn:

- Replacement of fine aggregate with GBS resulted in decrease in workability of both RS and Msand based concrete and increases with the increase in GBS content.
- The rate of increase in compressive strength is higher at lower replacement levels, whereas the rate of increase in tensile strength is higher at higher replacement levels.
- Though 80% replacement with GBS shows better performance against acid attack. 100% replacement can be done when compared with the control mix.
- Combination of GBS and Msand performs well compared to that of GBS and RS combination.
- Inclusion of pozzolanic materials to the concrete improves the mechanical and durability performance relatively at higher replacement percentages of fine aggregate with GBS.

5. References
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