

# Cementitious Composites Using Ground Granulated Blast Furnace Slag

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**ABSTRACT:** With rapid increases in Industrialization the need for efficient disposal of industrial effluents has also surged. One of the biggest industries is the construction industry, a large amount of waste products are released during production of certain construction materials such as paints, cement, metals etc. In this paper we focus on the use GGBFS (ground granulated blast furnace slag, a by-product of steel and iron production) as an admixture in cement in order to reduce cement production and effective disposal of industrial waste.

The waste that have to be disposed can be kept to use in some manner, among the industrial waste possessing cementations nature can be replaced as binder matter in concrete to apart . A large volume of production of cement leads to emission of many harm full gases like greenhouse gases in atmosphere, which are tends for global warming. Hence, the researchers are currently focused on waste material having cementing properties, which can be done by partial replacement of cement which would further lead to reduction in cement production and therefore lesser emission of greenhouse gases, to sustain-able management of the industrial waste, Some of the Pozzolan materials like flay ash, Silica fume, Rice Husk ash, Metakoline, Ground Granulated Blast Furnaces Slag (GGBS) are used as cementations materials. Among them the Ground Granulated Blast Furnaces Slag,(GGBS) which is the waste from, of iron manufacturing industry, which may be used as substitute of cement in concrete due to its inherent cementing properties.

To better understand the influences of Ground granulated blast furnace slag (GGBFS) on the properties of concrete, the compressive strength development with the addition of GGBFS of 45 $\mu$  m were investigated. GGBFS is obtained by quenching molten iron slag (a by-product of steel and iron-production) from a blast furnace in steam or water to produce a glassy, granular product that is then dried and ground into a fine powder. This material has cementitious properties and therefore it can be used as a partial replacement of the cement otherwise it would have been a disposal. Recycling of slag will inevitably become an important measure for the environment protection and therefore will be of great significance. The present paper focuses on investigating characteristics of M25 concrete with partial replacement of cement with GGBFS. The detailed experimental investigation was done to study the effect of using GGBFS (Micro- GGBFS) in various proportions starting from 5% to 20% cement concrete. The compressive strength test on hardened cement concrete cube of size 150mm x 150mm x 150mm at 28 days of curing were carried out. The work presented in this report reveals the effect on the strength of cementitious composites at different proportions of GGBFS. From this study it is found that by the partial replacement of cement with GGBFS helped in improving the strength of the concrete substantially compared to normal mix concrete.

This usage of GGBS serves as replacement to already depleting conventional building materials and the recent years and also as being a by-product it serves as an Eco Friendly way of utilizing the product without dumping it on ground.

However the above research was limited to the use of GGBFS in M25 concrete. The scope of the research is further broadened by understanding the effects and feasibility of using GGBFS as partial replacement material in higher grade, M40 concrete. Efficient disposal of a waste product can only be justified if it is universally viable therefore, if GGBFS can be used flexibly in construction along with varying concrete mixes only then we can achieve its purposeful use in Civil Engineering. Prestressed structures are made with high grade concrete such as M40 concrete therefore, Experimental studies are conducted on M40 grade concrete prepared with 53

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Grade ordinary Portland and special cement and replacement cement with Ground Granulated Blast Furnaces Slag (GGBS). The investigation on compressive strength of the concrete at different ages such as 7 days, 14 days, 28 days, 56 days and 90 days are observed when the Ground Granulated Blast Furnaces Slag (GGBS) is replaced 0%, 10%, 20%, 30%, and 40%, in the place of both OPC 53 cement. The results showed that the optimum dosage of GGBS when it is replaced at 30 % at 28days compressive strength of concrete. The GGBS is obtained from a steel plant in Ahmadabad, Gujarat.

**KEYWORDS:** Ground Granulated Blast Furnace Slag, Eco Friendly Concrete, Sustainable Development.

## I. INTRODUCTION

### 1.1 Ground Granulated Blast Furnace Slag

The ground granulated blast furnace slag (GGBFS) is a by-product of iron manufacturing which when added to concrete improves its properties such as workability, strength and durability. This material is obtained by the heating of iron ore, limestone and coke at a temperature about 1500 degree Celsius. The process is carried out in a blast furnace. The formation of GGBFS is not direct. The by-product of iron manufacturing is a molten slag and molten iron. The molten slag consists of alumina and silica, also with the certain amount of oxides. This slag is later granulated by cooling it. For this, it is allowed to pass through a high-pressure water jet. This results in quenching of the particles which results in granules of size lesser than 5mm in diameter. The main constituents of blast furnace slag are CaO, SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub> and MgO. These are the minerals that are found in most of the cementitious substances. The particles are further dried and ground in a rotating ball mill to form a fine powder, known as ground granulated blast furnace slag cement. Now different methods can be employed to perform the main process called as the quenching. Based on what method is employed, it can be known as pelletized slag, foamed or expanded slag, GGBFS or air-cooled blast furnace slag (ACBFS).

#### 1.1.1 Composition of Ground Granulated Blast Furnace Slag (GGBFS)

The difference in mineralogical composition in GGBFS compared to Portland cement is shown in Table 1. below.

Mineral	GBFS	Portland Cement
CaO	30-50%	55-66%
SiO <sub>2</sub>	28-40%	20-24%
Al <sub>2</sub> O <sub>3</sub>	8-24%	0-8%
MgO	1-18%	5%

Table 1. Composition of GGBFS

#### 1.1.2 Physical Properties of Ground Granulated Blast Furnace Slag (GGBFS)

Ground granulated blast furnace slag has a colour nearly white in appearance. The use of GGBFS in concrete manufacture would give a light and brighter colour to concrete unlike the dark grey colour of ordinary cement concrete structures. This is an added advantage of GGBFS in terms of aesthetics.

Property	Value
Physical Form	Off White Powder
Bulk Density (kg/m <sup>3</sup> )	1200
Specific Gravity	2.9
Specific Surface (m <sup>2</sup> /kg)	425-470

Table 2. Physical Properties of GGBFS

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## 1.1.3 Advantages of Ground Granulated Blast Furnace Slag (GGBFS)

The incorporation of ground granulated blast furnace slag in concrete manufacture gains many advantages which are mentioned below:

1. GGBFS in concrete increases the strength and durability of the concrete structure.
2. It reduces voids in concrete hence reducing permeability.
3. GGBFS gives a workable mix.
4. It possesses good pumpable and compaction characteristics.
5. The structure made of GGBFS constituents help in increasing sulphate attack resistance.
6. The penetration of chloride can be decreased.
7. The heat of hydration is less compared to conventional mix hydration.
8. The alkali-silica reaction is resisted highly.
9. This makes the concrete more chemically stable.
10. Gives good surface finish and improves aesthetics.
11. The colour is more even and light.
12. Lower chances of efflorescence.
13. The maintenance and repair cost of structures are reduced thus increasing the life cycle of concrete structures.
14. Unlike cement, GGBFS does not produce carbon dioxide, sulphur dioxide or nitrogen oxides.
15. It is found that working with GGBFS is easy as it has greater mobility characteristics. This is due to its fineness and the particle shape of the GGBFS particles. These also possess a lower relative density.
16. The GGBFS particles have a very glassy texture that makes them increase the workability. This can help in reduction of water as well as Superplasticizers to get adequate workability in common situations.
17. They also have fewer chances to get segregated during handling as well as pumping of the material. Pumping is facilitated by the lower relative density and flowing ability of the mix, that is owned by GGBFS.
18. The usage of GGBFS in concrete provides a certain unique feature that differs from the ordinary Portland cement concrete. The concrete made from GGBFS sets slowly when compared to ordinary Portland cement mix.

More the GGBFS amount more will be the time taken for its setting. But the strength is gained with time. This slow setting would help in the formation of cold joints. But the situations where faster setting time is required, cannot go for this replacement. The GGBFS composition stays plastic for a longer period that would help in making a smoother finish for the contractor.

The sustainability factor of GGBFS is proved from the above-mentioned advantages. The product itself is a by-product that is used for a greater recognition. The reduction of carbon dioxide in the structure makes them more sustainable. The GGBFS as a replacement has lesser water demand because of their glassy texture. The glassy surface of GGBFS particles does not absorb water onto its surface. GGBFS is facing certain hindrances in its implementation widely due to the low rate of strength gain. It is also highly sensitive to conditions of curing. So, a better quality of curing process ensures the happening of full advantage of GGBFS.

## 1.2 Past Study of GGBFS in Cement

Initial research was carried out to understand the impact of cement replacement by GGBFS in M25 concrete made with OPC43 cement in order to determine the purposefulness of GGBFS use in concrete of lower grades, if proved feasible, and then it could be used in production of higher grade concrete.

Subjective to this motive initial studies and experiments were carried out by replacing 5%, 10% and 20% of cement with GGBFS in production of M25 concrete. The ultimate focus of this work is to ascertain the performance of concrete mix blast furnace slag powder in micro form and to compare it with the plain concrete mix. Properties to be checked are consistency and compressive strength.

The results obtained on conducting the above tests on the prepared cubes were found to be satisfactory. It was seen that on addition of 5% and 10% of GGBFS by weight of cement compressive strength was increased significantly while on addition of 20% GGBFS it was reduced although it is impossible to say but one can relate it somehow with the filling of concrete voids in the first two conditions which lead to the enhancement of strength and replacement of cement by GGBFS as the % by weight of it was increased finally leading to decrease in strength as GGBFS does not have that much cementitious properties.

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As initial test of cement replacement with GGBFS in production of M25 concrete made with OPC43 cement, have further enhanced the strength, durability and workability of concrete without impacting its other properties further research can now be carried out to determine its feasibility when used in production of higher grade M40 concrete. If proved viable then it can be used in construction of prestressed structures.

## II. LITERATURE REVIEW

Throughout the long history of iron and steel industries various steps have been taken to make effective use of iron scrap. Slag previously being used as a landfill material now has drawn a greater attention due to its properties. Due to development in technology 99% of ferrous slag is now useful material. Although history of recycling ferrous slag is long onenow days more efforts are put to bring out the best of its properties.

Some of the characteristics of blast furnace slag are summarized below–

1. Recycling of steel slag will inevitably become an important measure for the environment protection and therefore will be of great significance.
2. Mineral additives are available in large quantities that can be used to replace Portland cement in concrete.
3. Few studies have been performed to determine thermal properties, mechanical properties and the influence of mineral additions on the durability of blended concrete.
4. When compound mineral admixtures with steel slag powder and blast furnace slag powder are mixed into concrete and performance of concrete can be improved further due to synergistic effect and activation.
5. The high performance concrete can be produced using mineral admixtures with steel slag powder and blast furnace slag.
6. The early age strength development of mixtures containing GGBFS is highly dependent on temperature. Under standard curing conditions GGBFS mortar gain strength more slowly than Portland cement mortar.
7. Partial replacement of Portland cement with GGBFS slag is found to improve the sulphate resistance of concrete.
8. GGBFS has no effect on the corrosion of steel on the other hand it helps in the reduction of corrosion by reducing concrete permeability, thus reducing the penetration of chlorides and CO<sub>2</sub> which promote corrosion of steel.
9. Grinding slag for cement replacement requires about 25% of energy needed to manufacture Portland cement.

Arivalagan et al. research paper basically emphasized on the development of green concrete by using ground granulated blast furnace slag (GGBFS), an industrial waste material, which is produced in the production of steel. In this paper M-35 mix design is used for the study of the effect of replacement of GGBFS in cement based composites. GGBFS was replaced up to level of 40% cement replacement. However the maximum compressive strength of concrete cube of Indian standard size (i.e. 150\*150\*150mm) obtained was at 20% cement replacement by GGBFS at the age of 28 days. Other tests like split and tensile test have also been discussed at replacement level 40% and mechanical properties are compared with normal plain concrete.

R. Narde. et al. (2014) in his research paper suggested the effect of addition of waste materials like quarry dust and GGBFS in the cement based composites.

In this paper for M-40 mix design, the mechanical properties have been compared by adding quarry dust and GGBFS. It has been observed that compressive strength of cement based composites increases with the percentage increase of quarry sand for certain limit. By replacing the cement with GGBFS the strength decreases and the workability increases. They concluded that the maximum flexure strength is obtained at the 30% replacement of GGBFS with cement. They also concluded that the maximum split tensile strength is obtained at the 20% replacement level of GGBFS with cement.

Nagendra. et al. suggested the use of GGBFS blended cement concrete for M-20 mix design. Properties like compressive strength and flexure strength are determined for M-20 mix design concrete cubes with the addition of 20, 30 and 50% of GGBFS with OPC 53 grade cement and are compared with the plain concrete cubes prepared by ordinary cement and natural sand. The maximum compressive strength achieved is 32.59 Mpa at 30% of GGBFS

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replacement and 31.11 Mpa, 30.7 Mpa and 27.74 Mpa is achieved for 20, 40, and 50% of GGBFS replacement respectively as compared to 29.11 Mpa of strength of plain cement concrete for 28 days. The flexural strength achieved are 3.17 Mpa, 3.62 Mpa, 3.87 Mpa, 3.55 Mpa and 3.41 Mpa at 0%, 20%, 30%, 40% and 50% for GGBFS concrete respectively for M20 grade concrete of OPC cement and natural sand. This report shows that tensile strength also give good performance for 20%, 30%, and 40% replacement which is more than normal plain concrete.

### III. EXPERIMENTAL PROGRAM

#### 3.1. Selection of materials

Coarse aggregate (20mm, 10mm), sand, ordinary Portland cement (grade-43), GGBFS, normal tap water and superplasticizer were selected to produce the required high strength cementitious composites.

##### 3.1.1. Coarse aggregates

Locally available coarse aggregate in the form of a blend of crushed and round aggregates was used in the work.

##### 3.1.2. Fine aggregate (Sand)

Locally available sand in the form of Badarpur sand is used as fine aggregate (F.A).

##### 3.1.3. Ordinary Portland cement

Normal Portland cement manufactured by J.K. cement was used as the main cementing material. It complied with the requirements of IS 12269. The cement was tested for standard consistency, setting time, and compressive strength (of mortar and cement-concrete).

##### 3.1.4. Ground Granulated Blast Furnace Slag

GGBFS was used as a supplementary cementing material (SCM). It was produced in very fine powder form with off white colour.

##### 3.1.5. Water

The water used for mixing and curing was clean and free from injurious amount of oils, acids, alkalis, salts, sugar, organic materials or other substances. Normal tap water was used as the mixing water for preparing the concrete and mortar specimens.

##### 3.1.6. Superplasticizer

A poly-carboxylate-based HRWR, commercially known as AT-CARPOL 401, was used to assist production concrete of the required strength and flowability. The HRWR was available in the form of a brown liquid, and is manufactured by Ado additives Technologies Private Limited.

#### 3.2. Cement Consistency test

The standard consistency of a cement paste is defined as that consistency which will permit the Vicat plunger having 10mm diameter and 50mm length to penetrate to a point 5 to 7mm from the bottom of the Vicat mould when the cement paste is tested.

##### 3.2.1. Apparatus:

Name	Capacity/size	Accuracy/Least count
Vicat apparatus	Should be made as per IS:5513	-
Balance	1000 g	1 g
Measuring cylinder	100 ml	1 ml

Table 3. Apparatus Specifications

##### 3.2.2. Test results:

S.No.	Cement property	Reading obtained
1	Normal consistency	35%
2	Initial setting time	45 minutes
3	Final setting time	660 minutes

Table 4. Consistency and setting time results

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### 3.3. Compressive strength test on concrete cubes

The acceptance criterion of quality of concrete is laid down in IS: 456-2000. The criterion is mandatory and various provisions of the code have to be complied before the quality of concrete is accepted. In all the cases, the 28-days compressive strength shall alone be the criterion for acceptance or rejection of the concrete. In order to get a relatively quicker idea of the quality of concrete, optional test for 3, 7 and 14 days compressive strength of concrete be carried out. The compressive strength of concrete cubes is shown in Table 6.

The cube moulds of required size (150 mm for nominal size of aggregate not exceeding 38 mm) shall be made in such a manner as to facilitate their separation into two parts. Cube moulds shall be provided with a base plate and they shall be as per IS: 10086-1982. The dimensions, tolerance and materials of cube moulds shall be as given in Table 5.

S.No.	Description	Requirements
1	Distance between opposite faces, mm	150 ± 0.2
2	Height of mould, mm	150 ± 0.2
3	Thickness of wall plate, mm	8
4	Angle between adjacent interior faces and between interior faces and top and bottom plates of mould.	90 ± 0.5°
5	Length of base plate, mm	280
6	Width of base plate, mm	215
7	Thickness of base plate, mm	8
8	Permissible variation in the planeness of interior faces: for new moulds, mm for moulds in use, mm	0.03 0.05
9	Permissible variation in the planeness of base plate, mm	0.03
10	Materials a) Side plate b) Base plate	Cast iron Cast iron

Table 5. Dimensions, material and tolerance of moulds

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Fig 1. A universal testing machine (Earthquake Lab, Civil Dept. DTU)



Fig. 2. UTM digital output device

Table 6. Compressive strength of concrete cubes

Specimen specification	3 Days Compressive Strength)	7 Days Compressive Strength	14 Days Compressive Strength	28 Days Compressive Strength
G0	27.75	34.20	40.50	41.00
G10	30.00	35.50	41.65	44.75
G20	28.25	38.30	44.20	47.70
G30	25.50	39.20	45.60	52.20
G40	24.00	28.25	38.55	44.00

(Note: G0 means themixwith 0 % replacement ofGGBSwith OPC 53,G10represents themix with 10% replacement of GGBSwith OPC 53 in the samewayin G20, G30, G40.)

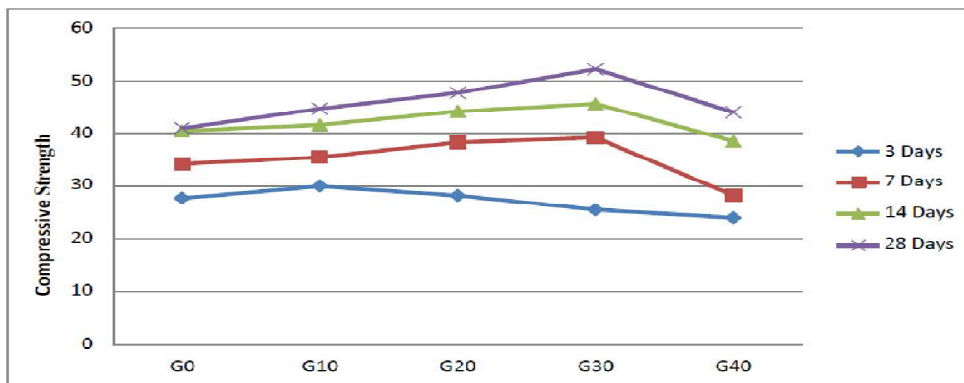


Fig. 3. Graphical comparison of Compressive Strength of concrete cubes

### 3.5. Test for flexural strength of concrete beams

Beam moulds of size 100 x 100 x 500 mm are used in the project. The specimen is placed in the machine in such a manner that the load shall be applied to the uppermost surface as cast in the mould, along two lines placed 14cm apart. The maximum load applied to the specimen during the test is recorded. The flexure test results are given in table and figure. The flexural strength of the specimen is expressed as the modulus of rupture  $f_b$  which, if 'a' equals the distance between the line of fracture and the nearer support, measured on the centre line of the tensile side of the specimen, in cm,

$$f_b = 3pa/bd^2$$

Where, a = 14cm

b = measured width in cm of the specimen

d = measured depth in cm of the specimen at the point of failure

p = maximum load in kg applied to the specimen

**Point bend Test:** This is a compression test where you support a length of material by spanning it across two supports on each end. There is nothing supporting the middle portion underneath of it. Then you press down from above directly in the middle of the span of material until the supported material breaks or reaches a specific distance. This test measures how strong the material in flexure (flexural strength).



Fig. 4. 3 point load test using UTM



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Specimen specification	28 day flexure strength
G0	12.02
G10	12.85
G20	13.85
G30	14.28
G40	11.50

Table 7. 28 day Flexural strength of concrete beams

## IV. DISCUSSION ON TEST RESULTS

### 4.1. Discussion on compressive strength of concrete

The detailed results for compressive strength are given in table IV. The addition of GGBFS in proportion of 10, 20 and 30% of cement resulted in higher compressive strength of concrete as compared to control for 3,7,14 and days of curing. At 28 days the compressive strength of concrete having 30% GGBFS is 52.20 MPa as compared to 25.50 MPa of control specimen. For all curing durations the GGBFS content of 30% shows the maximum gain in compressive strength. It shows that the concrete with GGBFS takes more time to gain strength as compared to plain concrete. The addition of GGBFS has been found to increase compressive strength due to the pozzolanic effect.

### 4.2. Discussion on flexural strength of concrete

The results of flexure test on beams of 0, 10, 20, 30 and 40% of GGBFS are shown in table V. The beam was tested after 28 days of curing and the flexural strength of beam having GGBFS was marginally positive. The maximum flexural strength obtained is 14.28 MPa as shown in the table and the flexural strength decreases as the GGBFS content increases to 40 %. This shows that the development of strength due to GGBFS requires sufficient duration of curing. GGBFS being a pozzolanic material is expected to gain strength after 56 days and 90 days, due to which in 28 days testing the result of flexural strength test is marginally positive.

## V. CONCLUSION

- Early strength development of GGBS blended cement concrete was observed to be lesser as compared to the early strength of normal concrete after carrying out the compressive test at 3 days.
- The degree of workability was reduced but very marginally.
- An increase of compressive strength at 28 days was around 27.3% for the 30% replacement of cement by GGBS.
- The compressive strength result at 28 days suggested that the maximum compressive strength at 28 days was for 30% replacement of cement by GGBS.
- The flexure test for beams shows that there is a marginal gain in strength by addition of GGBFS in any proportion for the curing duration of 28 days.

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