

# High Strength Concrete using Ground Granulated Blast Furnace Slag (GGBS)

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**Abstract** — Concrete is a brittle material when it undergoes heavy loads, cracks will form and to reduce this and improve high strength in concrete certain admixtures are used. To produce high strength concrete these Ground Granulated Blast Furnace Slag is used. It is obtained by quenching molten iron Slag (a by-product of iron and steel making) from blast Furnace in water or steam. GGBS is used to make durable concrete structure in combination with ordinary Portland cement and (or) other pozzolona materials. Concrete containing GGBS cement has a higher ultimate strength than concrete made with Portland cement. It has a higher portion of the strength enhancing calcium silicate hydrates (CSH) than concrete made with Portland cement only and a reduce content of free lime which does not contribute to concrete strength, concrete made with GGBFS continues to gain strength overtime, and has been shown to double its 28-day-strength over periods of 10 to 12 years. Our project is a testing project compared with the compressive strength of PCC and GGBFS, used concrete. Here the amount of cement is reduced and that amount is replaced with GGBS.

**Index Terms**— Ground Granulated Blast Furnace Slag (GGBS), Calcium silicate hydrates, Portland Blast Furnace Cement, Sulfate Resisting Portland cement, Sieve Analysis, Pyconometer, Pozzolona materials.

## 1 INTRODUCTION

Any construction activity requires several materials such as concrete, steel, brick, stone, glass, clay, mud, wood and so on. However, the cement concrete remains the main construction material used in construction industries. For its suitability and adaptability with respect to the changing environment, economize and lead to proper utilization of energy. To achieve this major emphasis must be laid on the use of wastes and byproducts in cement and concrete used for new constructions. The utilization of recycled aggregate is particularly very promising as 75 percent of concrete is made of aggregates. In that case, the aggregates considered are slag, power plant wastes, recycled concrete, mining and quarrying wastes, waste glass, incinerator residue, red mud, burnt clay, sawdust, combustor ash and foundry sand. The enormous quantities of demolished concrete are available at various construction sites, which are now posing a serious problem of disposal in urban areas. This can be easily recycled as aggregate and used in concrete. Research and Development activities have been taken up all over the world for proving its feasibility, economic viability and cost effectiveness. Concrete is basically a mixture of cement, fine and coarse aggregates. High-Performance Concrete (HPC) conforms to a set of standards above those of the most common applications, but not limited to strength.

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Some of the standards are ease of placement, compaction

without segregation, early age strength, permeability etc. The researchers have done considerable work on replacing the cement with fly ash and blast furnace slag without affecting the strength.

GGBS is obtained by quenching molten iron slag from a blast furnace in water or stream, to produce a glassy, granular product that is then dried and ground into a fine powder. GGBS is used to make durable concrete structures in combination with ordinary Portland cement and/or other pozzolanic materials. GGBS has been widely used in Europe, and increasingly in the United States and in Asia for its superiority in concrete durability, extending the life span of buildings from fifty to a hundred years. GGBS reacts like Portland cement when in contact with water.

Bulk GGBS is stored and handled in conditions identical to that of Portland cement. Bulk storage is in watertight silos. Transportation is by bulk tankers, as for Portland cement. GGBS can also be moved by airslides, cement screws and bucket elevators. Dust control is the same as that required for Portland cement. GGBS dust does not present any fire or explosion hazard.

### 1.1 Applications of GGBS

GGBS used in the production of quality-improved slag cement, namely Portland Blast Furnace Cement (PBFC) and High Slag Blast Furnace Cement (HSBFC) with GGBS content ranging typically from 30 to 70% and in the production of ready-mixed or site-batched durable concrete. GGBS reduces the risk of damages caused by alkali-silica reaction (ASR), provides higher resistance to chloride ingress-reducing the risk of reinforcement corrosion and provides higher resistance to attacks by sulfate and other chemicals. GGBS cement is added to concrete in the concrete manufacturer's batching plant, along with Portland cement, aggregates and water. The normal ratios of aggregates and water to cementitious material in the mix remain unchanged. GGBS is used to direct replacement for Portland cement, on a one-to-one basis by weight.

Replacement levels for GGBS vary from 30 to 85%. Typically 40 to 50% is used in most instances.

## 1.2 Advantages of GGBS

- Durability
- Appearance
- Strength
- Sustainability
- Better workability

The disadvantage of the higher replacement level is that early-age strength development is somewhat slower. GGBS is also used in other forms of concrete, including site-batched and precast. Unfortunately, it is not available for smaller scale concrete production because it can only be economically supplied in bulk. GGBS is not only used in concrete and other applications include the in-situ stabilization of soil.

## 2 LITERATURE SURVEY

**Formwork striking of GGBS concrete:** Irrespective of binder type, BS 8110 (1985) set out the minimum in-situ strength to be reached before striking concrete members as: 5 N/mm for members in compression to protect against possible frost damage 10 N/mm or twice the stress a member is subjected to for a member in flexure to withstand a load. Clear (1994) found that the higher proportion of GGBS slower the early age strength development of the concrete. This was concluded from an experiment designed to assess the formwork striking time of concretes with high levels of GGBS. Harrison (1995) presented tables of the recommended time to elapse before striking formwork for a specified grade of concrete, given the mean air temperature and cement type.

**Maturity methods and temperature models:** A strength development of concrete is dependent on the rate of hydration, which itself is dependent on the reaction temperature. Concrete strength can therefore be expressed as a function of time and temperature-the maturity function (Neville, 2002). Weaver and Sadgrove (1971) put forward the principle of Equivalent Age for Portland cements while others (Wimpenny & Ellis, 1991) verified the principle of Equivalent Age for a range of combinations of GGBS and Portland cement.

**Experimental verification of principles of underlying the proposed methodology:** During the fired earth brick manufacturing process for example, several gases (CO<sub>2</sub> etc.) are typically released from the brick kilns (US EPA, 2003) these emissions are becoming a major environmental concern for many countries including the UK. The energy usage of 1 tonne of GGBS is 1300 MJ, with a corresponding CO<sub>2</sub> emission of just 0.07 tonnes (Higgins, 2007) while the equivalent energy usage of 1 tonne of PC is about 5000 MJ with at least 1 tonne of CO<sub>2</sub> emitted to the 213 atmosphere (Wild, 2003).

## 3 MATERIALS AND MIX

The materials used in this investigation were: Ordinary Portland cement, Coarse aggregate of crushed rock with a maximum size of 20 mm, fine aggregate of clean river sand and portable water. 8mm dia HYSD bars were used as main reinforcement. 6mm dia MS bars were used as stirrups.

- Cement
- Fine aggregate
- Coarse aggregate
- Water

GGBS is obtained by quenching molten iron slag (a by product of iron and steel making) from a blast furnace in water or stream, to produce a glassy, granular product that is then dried and ground into a fine powder.

## 4 EXPERIMENTAL SETUP

### 4.1 Tests Conducted:

Before casting of cubes it is required to test the specific gravity, fineness of cement and the fine aggregate. Sieve analysis is done to find the fitness of cement and the fine aggregate. Specific gravity is found out by using pycnometer. In sieve analysis 1kg of fine aggregate and 100gms of cement is taken and tested separately. The amount of materials retained in each sieve analysis (4.75mm, 2mm, 1mm, 0.6mm, 300 $\mu$  and pan) is taken and weight is noted. By using the standard formulas fineness modules, uniformity coefficient and coefficient of curvature were found out.

To determine the specific gravity pycnometer is used. Initially mass of empty pycnometer is taken then followed by mass of sand with pycnometer, sand+water+pycnometer, pycnometer+water is taken in gram. Then by using the standard formulas the specific gravity and the moisture content were found out.

### 4.2 Casting and Curing:

In laboratory, ordinary methods (hand mixing) were used to mix the ingredients of concrete. Square shaped modules were used for casting and they having a dimension of 15x15x15cm. The mixing was done in the mixing tray using showels. The mix ratio that we adopted is 1:1.26:2.25. M25 grade concrete were used throughout the experiment. Before placing concrete into the mould, inside of it is painted with oil to reduce the adhesion of concrete on the mould. To avoid balling of fibres, the following procedure was followed in casting first; aggregates and cement were mixed for 5 minutes, water being added within 2 minutes. Then fibres were uniformly dispersed by hand throughout the mass with slow increment. Now concrete was allowed to mix for 10 minutes. All the specimens were well compacted using a table vibrator, and cured for 28 days.

The fibre is added in the increase in percentage of 0.5, 1.0, 1.5, and 2.0 with respect to the weight of cement added. There was no replacement of cement for the addition of fibre. The mix proportion kept constant throughout the the project. While placing the concrete in the mould, it was thoroughly compacted using equipments. A set of conventional concrete cube also made to find out the compressive strength and for further comparisons. The cubes are immersed fully on water after 24 hours from casting for proper curing. There are total 20 cubes including the conventional one.

### 4.3 Tests conducted for Cubes:

After proper curing for seven and 28 days they are tested to determine their compressive strength. Initially the compressive

sive strength of the conventional cubes are taken and then the other blocks are tested. For each percentage of fibre added four cubes are made. In that four cubes two of them are tested in seventh and the other two blocks in the 28<sup>th</sup> day. Then the compressive strength is compared with the compressive strength of the conventional cubes.

## 5 EXPERIMENTAL DETAILS

Seive analysis is to determine the fineness modules of cement, fine aggregate and GGBS.

### 5.1 Seive Analysis for Cement

Seive analysis is done to determine the particle size of cement. In this test about 100g of cement is taken and pass through the sieving machine.

TABLE 1  
OBSERVATION DETAILS

Si. No	Sieve dis-tribution	Wt. of the residue in gm.	% of wt. retained	Cumula-tive % of wt. re-tained	% of passing
1	4.75mm	0	0	0	0
2	2mm	0	0	0	0
3	1mm	1	1	1	99
4	.6mm	5	5	6	94
5	.003mm	39	39	45	55
6	.00212mm	29	29	74	26
7	.0015mm	17	17	92	8

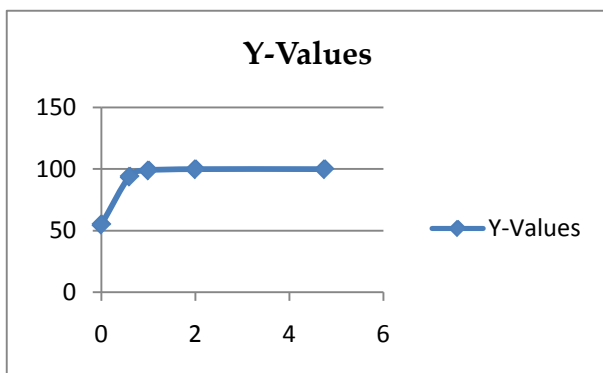


Fig. 1. Coefficient curvature analysis details for cement. The fineness modules, uniformity coefficient and the coefficient of curvature of cement are 3.18, 2.66 and 0.95 respectively.

The amount that retained in each sieve and the pan also the weight is taken. From the observation we can found the weight of the fineness of modules, uniformity coefficient and

the coefficient is determined.

### 5.2 Seive Analysis for Fine Aggregate

Seive analysis is done to determine the particle size for the fine aggregate. In this test about 1000g of the fine aggregate is taken and pass through the sieving machine. Then the analysis details can be found out. To find the coefficient of curvature the semilog graph is drawn and the values are taken.

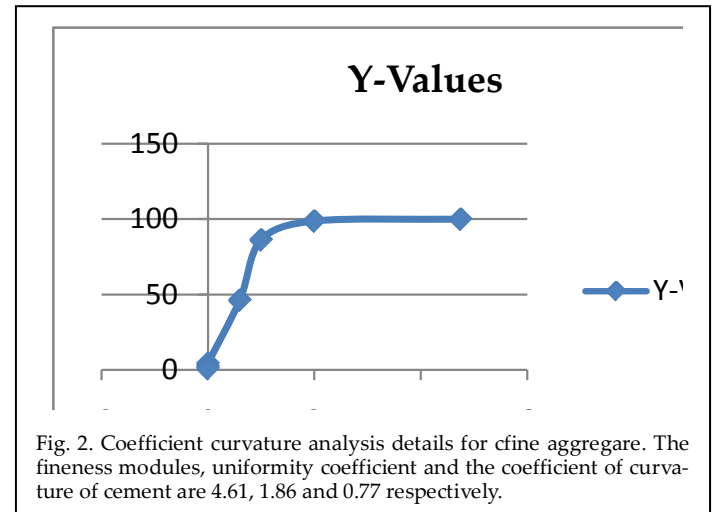


Fig. 2. Coefficient curvature analysis details for fine aggregate. The fineness modules, uniformity coefficient and the coefficient of curvature of cement are 4.61, 1.86 and 0.77 respectively.

### 5.3 Determination of specific gravity using pycnometer

Pycnometer is used to determine the specific gravity of specified material. It is a glass jar having standard dimension. The specified weight of fine aggregate is taken. Initially the dead weight of the pycnometer is taken. After that fine aggregate is placed in the pycnometer and the combined weight is taken. Then water is poured into the jar and the weight is taken and at the end.

$$\text{Mass of pycnometer (m1)} = 650\text{gm}$$

$$\text{Mass of pycnometer + sand (m2)} = 1400\text{gm}$$

$$\text{Mass of pycnometer + sand + water (m3)} = 1750\text{gm}$$

$$\text{Mass of pycnometer + water (m4)} = 1345\text{gm}$$

Thus the gravity of sand and the moisture content can be determined. Sieve analysis of GGBS is done to determine the particle size. In this test about 1000g of GGBS is taken and pass through the machine. Also the semilog graph is drawn for finding the coefficient of curvature.

### 5.4 Mix Design for Concrete

#### A) Target means strength for mix design

The target mean compressive strength at 28 days

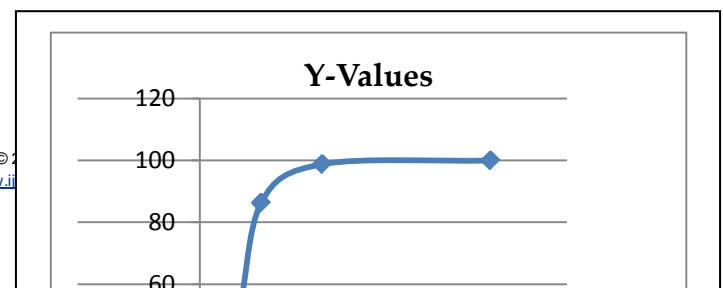
$$f_{ck} = f_{ck} + t_s$$

Where,

$f_{ck}$  = characteristics of compressive strength at 28 days

$s$  = standard deviation

The value of standard deviation has to be worked out from the trials conducted in the laboratory or field.



### B) Selection of water-cement ratio

Various parameters like types of cement, aggregate, max size of aggregate, surface texture of aggregate etc., are influence the strength of concrete when water cement ratio remain constant hence it is describe to establish a relation between concrete strength and free water cement ratio with materials and condition to be used actually at site.

### C) Estimation of entrapped air

The air content is estimated for normal max size of aggregate used for 20mm size of aggregate.

### D) Selection of water content and fine total aggregate ratio

The water content and percentage of sand in total aggregate by absolute volume are determined for medium (below grade m25) and high strength (above grade m25) concrete respectively.

### E) Selection of water and sand content

For 20mm max size aggregate, sand conforming to gradually zone II, water content per cubic meter of concrete = 186kg sand content as percentage of total aggregate by absolute volume = 35%.

Then coarse and fine aggregate content is determined. Therefore the actual quantity of different constituents required for one bag mix was found out.

## 6 RESULTS AND DISCUSSION

Investigations to overcome the brittle response and limiting post-yield energy absorption of concrete led to the development of fibre reinforced concrete using discrete fibres within the concrete mass. A wide variety of fibres have been proposed by the researchers such as steel, glass, polypropylene, carbon, polyester, acrylic, and aramid etc., Over half of the population around the world is living in slums and villages.

Since the use of steel fibre, glass fibre etc., are not economical because of that the use of natural fibre is getting importance. The earthquake damages in rural areas get multiplied mainly due to the widely adopted non-engineered constructions. On the otherhand, in many smaller towns and villages in southern part of india, materials such as nylon, plastic,

tyre, coir, sugarcane bagease and rice huskare available as waste. So, here an attempt has been made to investigate the possibility of reusing these locally available rural waste fibrous materials as concrete composites. Coconut fibres reinforced composites have been used as cheap and durable non-structural elements. The aim of this review is to spread awareness of coconut fibres as a construction material in civil engineering.

Concrete, in abroad sense, is any product or mass made by the use of a cementing medium. Generally this medium is the product of reaction between hydraulic cement and water. But these days, even such a definition would cover a wide range of product: concrete is made with several type of cement and also containing pazzolan, fly ash, blast furnace slag, a regulate set additives sulphur, admixtures, polymers, fibres and so on. There are mainly two criteria to make good concrete by which it can be so defined. It has to be satisfactory in its hardened state and also in its fresh state while being transported from the mixer and placed in the formwork.

**Fine and Coarse Aggregate:** Concrete is made with aggregate particles covering a range of sizes upto a maximum which usually lies between 10mm and 50mm; 20mm is typical. This particle size distribution is called grading. Sand is generally considered to have a lower size limit of about 0.07 mm or little less. Material between 0.06mm and 0.02mm is classified as silt and smaller particle are termed clay. Loam is a soft deposit consisting of sand, silt and clay in sbout equal propotions.

**Specific Gravity:** Since aggregate generally contains Pires, both permeable and impermeable according to ASTM C 127-93, specific gravity is defind as the ratio of mass (or weight in air) of a unit volume of a material to the mass of same volume of water at the stated temperature. The majority of natural aggregates are having apparent specific gravity in between 2.6 to 2.7. Pycnometer is used to determine the specific gravity of fine aggregate. Then specific gavity is determined. The pycnometer is a one little jar with a water tight metal conical screw top having a small hole at the apex. In this project the specific gravity of aggregate is obtained as 2.65.

**Sieve Analysis:** The process of dividing the sample of aggregate into fractions of same particle size is known analysis and its purpose to determine the grade or size or size distribution of the aggregate. The sieve analysis is done for the fine aggregate and cement and the fineness modules, uniformity coefficient and the coefficient of curvature is determined.

Usually fineness modules are calculated for the fine aggregate rather than for coarse aggregate. Typical value ranges from 2.3 to 3.0, a higher value indicating a coarse grading. The usefulness of the fineness modules lies in detecting slight variation in the aggregate from the same source, which could affect the workability of the fresh concrete. The mixing is made as per the Indian standard. It is based on the mix design that the amount of cement, fine aggregate and coarse aggregate that is to be added is determined and it was also from the mix design the amount of water



**TABLE 2**  
**ANALYSIS RESULTS**

Material	Fineness modules	Uniformity Coefficient	Coefficient of curvature
cement	3.18	2.66	0.95
Fine aggregate	4.61	1.86	0.77
GGBS	5.39	1.76	0.67

How GGBS is made in blast furnace:

- The purpose of a blast furnace is to reduce and convert iron oxides into liquid iron called 'hot metal'.
- The blast furnace is a huge, steel stack lined with refractory brick.
- Iron ore, coke and limestone are put into the top, and preheated air is blown into the bottom.

**TABLE 3**  
**RESULTS OF COMPRESSION STRENGTH TEST ON SEVENTH DAY CURING**

% of GGBS	Trial 1 (KN/M <sup>3</sup> )	Trial 2 (KN/M <sup>3</sup> )	Trial 3 (KN/M <sup>3</sup> )	Trial 4 (KN/M <sup>3</sup> )
10%	310	520	370	400
20%	450	630	420	500
40%	440	420	790	550
60%	650	770	680	700

**Conclusion**

GGBS is used to make durable concrete structure in combination with ordinary Portland cement and/or other pozzolona materials. In this project, sieve analysis is done for cement, Fine aggregate and Ground Granulated Blast Furnace Slag. Also For each material we can found out the result of fineness modules, uniformity coefficient, and coefficient curvature results. Then the results of compression strength test on seventh day curing also determined. Thus our project is compared with the compressive strength of PCC and GGBS used concrete can be tested. Here the amount of cement is reduced and thet the amount is replaced with GGBS.

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