

Evaluation of Concrete Performance and Economic Viability Using Steel Fibers and GGBS as Cement Substitutes

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ABSTRACT

This experimental investigation is carried out to study the different strength characteristics of concrete with partial replacement of cement with ground granulated blast furnace slag (GGBS) and addition of steel fiber. In this investigation M30 grade of concrete is replaced with ground granulated blast furnace slag (15%, 25%, 35%, and 45%) by weight and addition of steel fiber having dimensions (0.45 x 25mm) in different percentage (1%, 1.5%, 2%, and 2.5%). Strength of concrete was determined by performing flexural strength (150mmx150mmx700mm) size beam. Economical and technical analysis of GGBS and steel fiber in concrete has been done. Finally, the strength performance of slag blended fiber reinforced concrete is compared with the performance of conventional concrete.

Keywords: Steel fiber, GGBS, Partial Replacement, Flexural strength, cost analysis.

I. INTRODUCTION

Concrete has basic naturally, cheaply and easily available ingredients as cement, sand, aggregate and water. After the water, cement is second most used material in the world. But this rapid production of cement creates two big environmental problems for which we have to find out civil engineering solutions. We know that CO₂ emission is very harmful which creates lots of environmental changes whatsoever. Ground Granulated Blast furnace slag (GGBS) is a by-product for manufacture of pig iron and obtained through rapid cooling by water or quenching molten slag. Here the molten slag is produced which is instantaneously tapped and quenched by water. This rapid quenching of molten slag facilitates formation of “Granulated slag”. Ground Granulated Blast furnace Slag (GGBS) is processed from Granulated slag. Fly ash is one of the residues created during the combustion of coal in coal-fired power plants. Fine particles rise with flue gasses and are collected with finely-divided mineral admixture, available in both incompact and compacted forms. This ultra-fine material will better fill voids between cement particles and result in a very dense concrete with higher compressive strengths and extremely low permeability.

II. MATERIALS AND METHODS

In this experimental work, various materials are used like....

- Cement- Ordinary Portland cement of 53 grade is used in this experimental work and its properties were tested as per Indian standards IS 4031. Ordinary Portland cement conforming to IS 12269:198711 with specific gravity 3.15 is used.
- Steel fibers can be defined as discrete, short length of steel having ratio of its length to diameter (i.e. aspect ratio) in the range of 30 to150. The addition of steel fibers reduces the workability of the concrete. The steel fibers have dimensions of 0.45 x 25mm, aspect ratio of 45, and density of 7.85 g/cm³. Collect from Stewols Pvt. Ltd. Nagpur.
- GGBS conforming to IS 12089-1981 was used in the investigation and is procured from Sri Sat guru Associates, Bhopal.
- Fine Aggregate- Locally available river sand passing through 4.75 mm IS sieve conforming to grading zone-II of IS: 383-1970 was used with a specific gravity of 2.74.
- Coarse Aggregate- Crushed stone aggregate with combinations of 12 mm and 10 mm in 60% and 40% respectively from a local source having the specific gravity of 2.74 conforming to IS: 383-1970 was used.
- Water- Potable water is used for mixing and curing concrete.
- Super Plasticizers- In order to improve the workability to high performance concrete, super plasticizer in the form of sulphonated Naphthalene Polymers complies with IS 516 – 1959 and ASTM C 642 type F as a high range water reducing admixture (VARAPLAST PC 100) was used.

III. CONCRETE MIX DESIGN

Mix design is made for M30 grade concrete accordance with the Indian Standard Recommended Method IS 10262-2009.

A total of 17 concrete mixes for each mixes were prepared; one of the mixes was made of 100% ordinary Portland cement (no GGBS and no steel fiber content). The remaining 16mixes were prepared by adding GGBS ground granulated blast furnace slag (15%, 25%, 35%, and 45%) by weight and addition of steel fibers having dimensions (0.45 x 25mm) in different percentage (1%, 1.5%, 2%, and 2.5%) to the weight of concrete. The amount of water, coarse aggregate and fine aggregate were calculated for all the mixes and are reported in the table 3.6 shown below

Table 1: Mixture proportions of GGBS and Steel fibers blended concretes.

Specimen	GGBS %	Steel Fiber %	Quantity (Kg/m ³)				
			Cement	GGBS	Steel Fiber	Coarse Aggregate	Fine Aggregate
1	0	0	380	0	0	1283	711
2	15	1	319.2	57	3.8	1283	711
3	25		281.2	95	3.8	1283	711
4	35		243.2	133	3.8	1283	711
5	45		205.2	171	3.8	1283	711
6	15	1.5	317.3	57	5.7	1283	711
7	25		279.3	95	5.7	1283	711
8	35		241.3	133	5.7	1283	711
9	45		203.3	171	5.7	1283	711
10	15	2	315.4	57	7.6	1283	711
11	25		277.4	95	7.6	1283	711
12	35		239.4	133	7.6	1283	711
13	45		201.4	171	7.6	1283	711
14	15	2.5	313.5	57	9.5	1283	711
15	25		275.5	95	9.5	1283	711
16	35		237.5	133	9.5	1283	711
17	45		199.5	171	9.5	1283	711

IV. EXPERIMENTAL PLAN

The experimental program was designed for the workability and for the mechanical properties i.e. flexural strength of concrete and modulus of elasticity of concrete of M30 grade of GGBS and steel fiber concrete and compare the results with conventional concrete. The program consists of casting and testing of total, 17 beam, standard beam of 150mm x150mmx700mm with and without Steel fiber and GGBS. Experimental and technical analysis of GGBS and steel fiber concrete has been done. Compressive testing machine (CTM) and UTM is used to test all the specimens.

Mixing

On the watertight platform, the concrete mixture was prepared by hand mixing. The cement, GGBS were thoroughly mixed in the dry state and the sand was added to the mixture. The mixture was again thoroughly mixed and placed over the Coarse aggregate. Then water was added carefully with chemical admixture during mixing. Mixing was carried out until a workable mixture was obtained.

Casting

After proper mixing, the mix poured in to the, beam of size 150mm x150mm x 700mm and then compacted manually using tamping rods. In this work we mainly prepared 17 different mixes of M30 Grade namely conventional aggregate concrete (CAC), concrete made by replacing cement with GGBS and by adding Steel fiber at different percentage.



Fig. 1: Casting of Beam

Curing

Curing is a procedure that is adopted to promote the hardening of concrete under conditions of humidity and temperature which are conducive to the progressive and proper setting of the constituent cement. Curing has a major influence on the properties of hardened concrete such as durability, strength, water-tightness, wear resistance, volume stability, and resistance to freezing and thawing. Concrete that has been specified, batched, mixed, placed, and finished can still be a failure if improperly or inadequately cured. Curing is usually the last step in a concrete project and, unfortunately, is often neglected even by professionals.

The beams were taken out from the mould after 1 day of casting and then kept in respective solutions for curing at room temperature with a relative humidity of 90% the beams are taken out from curing after 28 days for testing.

V. TEST CONDUCTED

Flexural strength test

Flexural strength test was conducted on beam specimens under two point loading as per I.S.516-1959. The average ultimate flexural tensile stress was determined from the failure flexural loads. For flexural strength test beam specimens of dimension 150mm x150mm x 700 mm were cast. The beam specimens were tested after 28 days curing



Fig. 2: Specimen loading for flexural strength test

Elastic modulus for concrete

The Elastic Modulus for Concrete test is the most common test conducted on hardened concrete, partly because it is an easy test to perform. Concrete is not really an elastic material, i.e., it does not fully recover its original dimensions upon unloading. Hence, the elastic constants are necessarily considered for conventional design of reinforced concrete structures.

The modulus of elasticity of FRC can be determined using the formula given by I.S. 456 (I.S. 456-2000) depending upon strength of concrete (f_{ck})

$$E_{fc} = 5000 \sqrt{f_{ck}} \text{ Mpa}$$

Where, f_{ck} is Compressive strength of concrete at 28 days

VI. RESULTS AND DISCUSSIONS

Flexural strength test

For each of the different dosages, 17 beams with the dimensions 150mm × 150mm × 700 mm were prepared. A tamping rod was used for compaction of concrete in prisms. All beams were taken out of the mould after one day and immersed in the curing tank for a period of 28 days to assure sufficient curing. After 28 days of curing, each beam was tested using the loading tests setup. The report shows that the strength gave good performance for 25 % replacement which is more than normal concrete.

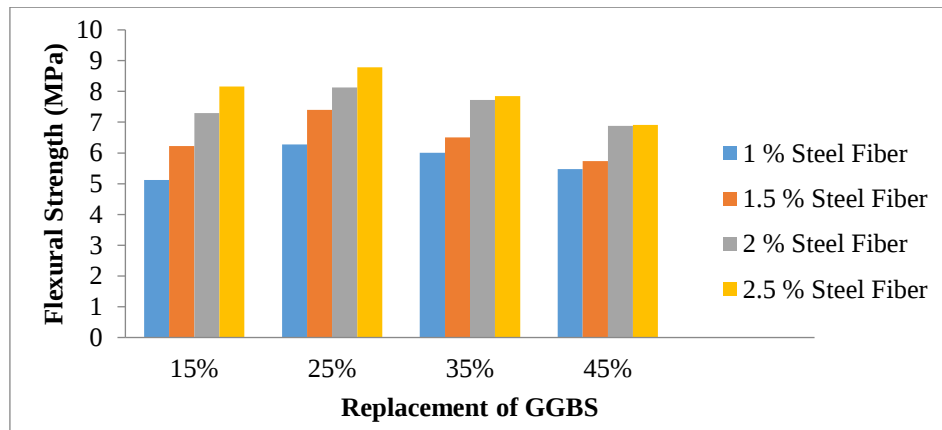


Fig. 3: Flexural Strength of M30 grade at 28 days curing

The maximum value of flexural strength at 25 % GGBS and 2.5 % fiber is 8.78 N/mm². Further addition of GGBS shows that flexural strength gradually decreases. So the maximum percentage of the GGBS and steel fiber on the replacement of cement should be 25 % and 2.5 %.

Elastic modulus

In the analysis of structure elastic constant viz. E, μ & G are always required.

The modulus of elasticity can be determined using the formula given by I.S. 456 (I.S. 456-2000) Depending upon strength of concrete (f_{ck})

$$E_{fc} = 5\sqrt{f_{ck}} \text{ GPa}$$

Where, f_{ck} is Compressive strength of concrete at 28 days

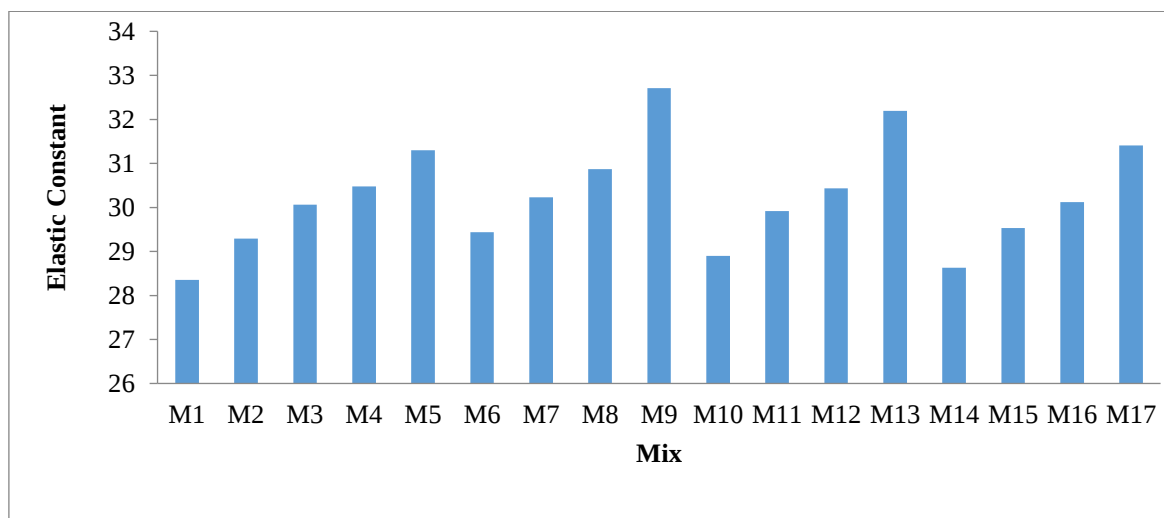


Fig. 4: Variation of Modulus of Elasticity

VII. COST ANALYSIS

Table 2 Cost of material per cubic meter of concrete for M30

Material	Rate	Conventional Concrete		M 30 (Optimum Steel fiber(2.5 %) and GGBS (25 %) Concrete)		% Saving
		Quantity	Cost	Quantity	Cost	
Cement	Rs400 per bag (50 Kg)	7.5 bags	Rs 3000	5.4 bags	Rs 2174	1.91 %
Steel fiber	Rs12/ kg	0	0	9.05 Kg	Rs108.6	
GGBS	Rs 6/Kg	0	0	90.57 Kg	Rs 543.42	
Fine Aggregate	Rs 860/m ³	0.4704 m ³	Rs 404.54	0.4704 m ³	Rs 404.54	
Coarse Aggregate	Rs 2400/m ³	0.796 m ³	Rs 1910.4	0.796 m ³	Rs 1910.4	
Super Plasticizer	Rs. 40/Kg	0	0	1.8 Kg	Rs. 72	
			Rs 5314.94		Rs5212.96	

From the above table we note that the use of GGBS and steel fiber in concrete saves money up 1.91 % over the conventional cement concrete for 1m³ volume. This is a significant saving of money. There are good prospects of obtaining a good concrete strength at relatively cheaper cost even while replacing part of the cement GGBS and steel fiber. Replacement of cement with GGBS and steel fiber can save huge cost where mass concreting has to be done.

VIII. CONCLUSION

The variation in the, flexural and modulus of elasticity with respect to changes in the GGBS and fiber content is observed. The purpose of introducing GGBS and steel fibers by partial replacing cement is to increase strength and performance of the concrete. And also durability properties of concrete can be enhanced by introducing the steel fibres.

The following conclusions could be drawn from the present investigation.

1. Use of GGBS as cement replacement increases consistency.
2. Increment of GGBS and steel fiber content up to 25 % and 2.5 % given good result in terms of flexural strength.
3. Increase in the steel fibers results in increasing the tensile strength and toughness of the composite.
4. Plain concrete is a brittle material and fails suddenly. Addition of steel fibers to concrete changes its brittle mode of failure into a more ductile one and improves the concrete ductility. The addition of GGBS and steel fiber increases the flexural strength of concrete at optimum content..
5. Addition of steel fibers reduces bleeding and it improves the surface integrity of concrete. Also it increases the homogeneity and reduces the probability of cracks.
6. This experimental investigation helps to know the properties and behaviour of steel fiber reinforced concrete.
7. From the mechanical properties, the optimum replacement by GGBS and steel fiber was found to be 25 % & 2.5 % and beyond 25 % all the strength values decreased when compared to normal concrete.
8. The maximum values of flexural strength at 25 % GGBS and 2.5 % fiber are 8.78 N/mm². So the maximum percentage of the GGBS and steel fiber on the replacement of cement should be 25 % and 2.5 %.
9. The increases in flexural strength are directly proportional to the fiber content and also the flexural deflection decreases with increase in steel fiber as compared to the normal concrete.
10. The elastic modulus of concrete shows better increase in strength up to 15-28% after attaining the full strength of concrete.
11. We note that the use of GGBS and steel fiber in concrete saves money up 1.91 % over the conventional cement concrete. This is a significant saving of money. There are good prospects of obtaining a good concrete strength at relatively cheaper cost even while replacing part of the cement GGBS and steel fiber. For mass concreting work we can use concrete with GGBS and steel fiber as partial replacement of cement.

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