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Mineral Admixtures for High Performance GGBS Concrete

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Abstract: Cement is a binding material or substance that sets and harderns independently and can bind other materials together. The word cement traces to the romans who used the term opus caementicium to describe masonry resembling modern concrete. GGBS (Ground Granulated Blast furnace Slag).It is obtained by quenching molten iron slag a product of iron and steel making. It is obtained from steel furnace and the waste liberated is called as GGBS. It has the character to bind materials together as in the case of cement in cement concrete. Therefore, it may be possible to replace cement by GGBS in concrete making such an approach will help to reduce the cement requirements in construction industry. Hence, a study was under taken to investigate the possibility of replacing cement by GGBS without having the compressive strength. Different proportions of replacement such as 30%, 50% and 70% of cement by GGBS have been attempted and the results are presented here. Chemical admixture by adding super plasticizer to increase the initial setting time by using the chemical B233, ACE30IT

Keywords: Concrète, GGBS, Admixture, Super Plasticizer, Compressive Strength,

1. INTRODUCTION

1.1. Introduction

Concrete is being used for all major constructions, like dams, towers, water tanks, houses, roadways, and railway sleepers etc. Long-term performance of structures has become vital to the economies of all nations. Concrete has been the major instrument for providing stable and reliable Infrastructure. Deterioration, long term poor performance, and inadequate resistance to hostile environment, coupled with greater demands for more sophisticated architectural form, led to the accelerated research into the microstructure of cements and concretes and more elaborate codes and standards. As a result, new materials and composites have been developed and improved cements evolved. One major remarkable quality in the making of high performance concrete (HPC) is the virtual elimination of voids in the concrete matrix, which are mainly the cause of most of the ills that generate deterioration. Recently, composites are fastly replacing the conventional concrete. With many major developments in concrete industry, the waste material utilization in the manufacturing of concrete, being used as a replacement material for the ingredients, is also growing. India has an enormous growth in the steel industries and copper industries. The Following are major by products in these industries. Ground granulated blast furnace slag (GGBS) - a by-product in the manufacture of iron in steel industry.

Concrete is the most widely used construction material in India with annual consumption exceeding 100 Mm^3. It is well known that conventional concrete designed on the basis of compressive strength does not meet many functional requirements such as impermeability, resistance to frost and thermal cracking adequately. Conventional Portland cement concrete is found deficient in respect of: Durability in severe environs (Shorter service life and require maintenance); time of construction (longer release time of forms and slower gain of strength); energy absorption capacity (for earthquake-resistant structures); and repair and retrofitting jobs High performance concrete (HPC) successfully meets the above requirement. HPC is an engineered concrete possessing the most desirable properties during fresh as well as hardened concrete stages. HPC is far superior to conventional cement concrete as the ingredients of HPC contribute most optimally and efficiently to the various properties. High performance concrete (HPC) is a specialized series of concrete designed to provide several benefits in the construction of concrete structures that cannot always be achieved routinely using conventional ingredients, normal mixing and curing practices. In other words, a high performance concrete is a concrete in which certain characteristics are developed for a particular application and environment so that it will give an excellent performance in the structure in which it will be placed, in the environment to which it will be exposed, and with the loads to which it will be subjected during its design life. It includes concrete that provides either substantially improved resistance to environmental influences (durability in service) or substantially increased structural capacity while maintaining adequate durability. It may also include concrete, which significantly reduces construction time without compromising long-term serviceability. While high strength concrete, aims at enhancing strength and consequent advantages owing to improved strength, the term high-performance concrete (HPC) is used to refer to concrete of required performance for the majority of construction applications.

The American Concrete Committee on HPC includes the following six criteria for material selections, mixing, placing, and curing procedures for concrete.

(i) Ease of placement;
(ii) Long term mechanical properties;
(iii) Early-age strength
(iv) Life in severe environments;
(v) Volumetric stability.
(vi) Toughness

The above-mentioned performance requirements can be grouped under the following three general categories.

(i) Attributes that benefit the construction process
(ii) Attributes that lead to enhanced mechanical properties
(iii) Attributes that enhance durability and long-term performance

1.2. Scope of study

The Experimental investigation is planned as under.

- To obtain Mix proportions of Control concrete by IS 10262 method
- To conduct Compression test on GGBS and Control concrete on
- Standard IS Specimen size 150 x 150 x 150 mm.

Compared to ordinary Portland cement the ground granulated blast furnace slag has the following.

Advantages:

- High resistance to chemical attack.
- Low heat of hydration.
- High early strength and continued strength development.
- High workability and control of slump.
- Low water binder ratio.
- Low bleeding and plastic shrinkage.

1.3. Objectives of study

The following are the objectives:

(i) to investigate the possibility of replacing cement by GGBS; and
(ii) to study the influence of mineral admixtures in the performance of the above concrete.

2. Methodology

2.1. Properties of Aggregates

The aggregate used in manufacturing of concrete should be free from debris, fungi and chemical attack. It place a vital role in concrete, so it should be durable, angular and sharp edges then only it gives a rich mix concrete and good workability. Then well graded aggregates are controlled the maximum voids and minimizing the cement content and it leads to good concrete with high strength, economy, low shrinkage and greater durability.

Physical Properties of Aggregates

Particle Shape and Texture

The physical characteristics such as shape, texture and roughness of aggregate significantly influence the workability of fresh concrete, bond between the aggregate and mortar phase(As per IS 2386-part: 111-1963). In general there are four categories namely rounded, irregular, angular and flaky (Table 3.1).

Table 2.1 Visual characteristics of material

Sl.No.	Material	Visualization	Shape
1	Natural river sand	Smooth surface	Angular and round edges
2	Coarse aggregate	Round surface	Irregular and Sharpe edges

Grading of aggregate

The particle size distribution of an aggregate as determined by sieve analysis is termed as grading of aggregate (As per IS 2386-Part 111-1963). If all the particles of an aggregate are of uniform size, the compacted mass will contain more voids; whereas aggregate comprising particles of various sizes will give a mass contains lesser voids. The particle size distribution of a mass of aggregate should be such that the smaller particles fill the voids between the larger particles. The proper grading of an aggregate produces a dense concrete and needs less quantity of fine aggregate, cement paste. Therefore it is essential that the coarse aggregate and fine aggregate be well graded to quality of concrete. The grading of an aggregate is expressed in terms of percentage by weight retained or passing percentage through a series of sieves (Table 3.2) taken in order of 4.75 mm, 2.00mm, 1.00 mm, 0.600 mm, 0.425 mm, 0.300 mm and 0.150 mm, pans for fine aggregate and 20 mm, 12.5 mm, 10 mm, 4.75 mm and 2.00 mm pans for coarse aggregate.

Fineness Modulus

By the particle size distribution of an aggregate to calculate the fineness modulus value (As per IS 386-Part III – 1963). The fineness modulus value gives an idea of the mean size of the particles present in the aggregates. The object of finding the fineness value is to grade the aggregate for the most economical mix for the required strength and workability with minimum quantity of cement. If the tested aggregate gives higher fineness modulus means the mix will be harsh and of gives a lower fineness modulus, it gives an economic mix. For workability, a coarse aggregate requires less W/C ratio.

Fineness modulus of natural river sand : 2.63
Fineness modulus of coarse aggregate : 8.65

Specific Gravity

It is defined as the ratio of the mass of void in a given volume of sample to the mass of an equal volume of water at the same temperature (As per IS 2386- Part: III – 1963). If the volume of aggregates includes the voids, the resulting specific gravity is called as “apparent specific gravity”, it refers the volume of aggregate includes impermeable voids. The specific gravity most frequently and easily determine and it is based on the saturated dry condition of the aggregate because the water absorbed aggregate in the pores of the aggregate does not take part in the chemical reaction of the cement. Therefore it is considered as a part of the aggregate. The specific gravity is required for the calculation of the yield of concrete or the required quantity of aggregate for the given volume of concrete.

Specific gravity of natural river sand : 2.60
Specific gravity of coarse aggregate : 2.83

Bulk Density

The mass of the material in given volume and it is expressed in kg/lit (As per IS 2386-Part: III – 1963). The bulk density of aggregates depends upon how densely the aggregate is packed in the measured volume. The factors affecting bulk density are particle shape, size, grading of aggregates and moisture content. The bulk density value can be used for judge the quality of aggregates by comparing with normal density. And it also required for converting proportions by weight into the proportion by volume. Density of natural granite is 2700 kg/m^3.Bulk density (γ) = net weight of the aggregate in kg / volume of sand
(Ref. Table 2.3).

Table 2.2 Bulk density of aggregate

Sl. No.	Property	Natural river sand		Coarse aggregate	
1	Bulk density(kg/m^3)	Loose State	Compacted State	Loose State	Compacted state
2		1.825	2.095	1.655	1.955

Percentage of Voids in Aggregate

The empty space between the aggregate particles is termed as “voids”. It is the difference between the aggregate mass and volume occupied by the particles alone.(Table 2.3).

Percentage of voids = $(G_s-\gamma) / G_s)$ x 100

Table 2.3 Percentage of voids in aggregates

Sl. No.	Property	Natural River Sand
1	% of voids	22%

Water Absorption

The permeability and absorption affect the bond between the aggregate and cement paste (As per IS 2368 - - Part III – 1963). The aggregate which is saturated in water but it contains no surface free moisture is termed as "saturated surface dry aggregate". If the aggregate is dried in an oven at 150^{o} c to a constant weight before being immersed in water for 24 hours, the absorption is referred to an oven dry basis. On the other hand, the percentage of water absorbed by an air dried aggregate, when it is immersed in water for 24 hours is termed as "absorption of aggregate" (air dry basis) the knowledge of the absorption of an aggregate is important for concrete mix design.(Table 2.4).

Table 2.4 Percentage of absorption of aggregates

Sl. No.	Property	Natural river sand	Coarse aggregate
1	% of Absorption	0 .94	0.54

Chemical Properties of Aggregates

The rocks which contain reactive constituents include traps, andesitic, hyalites, siliceous limestone and certain types of sand stones. The reactive constituents may be in the form of opals, cheers, chalcedony, volcanic glass and zeolites etc., the reaction starts with attacks on the reactive siliceous minerals in the aggregate by the alkaline hydroxide derived from the alkalis cement. The lime stones and dolomites containing chart nodules would be high reactive and stone contain silica minerals like chalcedony, crypto to microcrystalline quartz and opal are formed to be reactive. Geographically India has very extensive deposits of volcanic rocks. The aggregates from these rocks should be studied continuously, some type of aggregates which contain reactive silica in particular proposition and particular fineness are found to exhibit tendencies for alkali aggregate reaction. It is possible to reduce its tendency by alerting either the proposition of reactive silica or its fineness.

Table 2.5 presents the chemical properties of an aggregate.

Table 2.5 Percentage chemical composition in aggregate

Sl. No.	Property	Natural fine aggregate Aggregate	Coarse aggregate Aggregate
1	Silica (SiO_2)	90.0 – 95.0	65.48 - 65.50
2	Iron (Fe_2O_2)	2.682 - 8.25	5.78 - 6.54
3	Titanium(TiO_2)	--	1.10 - 1.31
4	Aluminum(Al_2O_3)	0.005 - 0.010	16.12 - 19.10
5	Calcium (CaO)	--	4.10 - 4.92
6	Magnesium(MgO)	0.02	2.00 - 2.78
7	Sodium(Na_2O)	0.00	0.00 - 0.78
8	Potassium(K_2O)	0.00	3.10 - 3.78

Properties of Water

Water is an important ingredient of concrete as it actively participates in the chemical reactions with cement. The strength of cement concrete comes mainly from the binding action of the hydration of cement get the requirement of water should be reduced to the required chemical reaction of un-hydrated cement as the excess water would end up in only formation undesirable voids (or) capalirreies in the hardened cement paste in the hardened cement paste in concrete The suitable for drinking, but they are not good for cement concrete, as the sugar wood adversely affect the hydration process. The limits of the content of water have to be determined from the following considerations. Therefore, attention is required to see that the initial hydration rate of cement should not be significantly affected; and The salt in water would not interface with the development of strength of later ages. Apart from the strength considerations, the durability characteristics such as porosity, degree resistance to diffusion of CO_2, $CaSO_4$, moisture, Oxygen, etc., should also be investigated after specified curing period. Table 2.6 Presents the percentage of particles present in water.

Table 2.6 Percentage of particles present in water

Sl. No.	Particles	Values(mg/lit)	% of Particles	Standard values
1	P^H	6.5 - 6.7	6.5 - 6.7	6.5 – 8.0
2	Organic	Nil	Nil	0.02
3	Inorganic	300	0.30	0.30
4	Sulphates	200	0.02	0.05
5	Alkali chlorides	78	0.078	0.10

Properties of cement

Cement used in the experimental work is Ordinary Portland cement conforming to IS: 269 -1987. The Ordinary Portland cement was classified into three grades, 33 grade, 43 grade and 53 grade depending upon the strength of the cement at 28 days when tested as per IS 4031-1988 are given in Table 2.7.

Table 2.7Properties of cement

Sl. No.	Properties of a cement	Value
1	Specific gravity	3
2	Fineness	97.80
3	Initial setting time	68 minutes
4	Final setting time	9 hours 28 minunits
5	Standard consistency	30%
6	Compressive strength	54.28 N/mm^2

Mineral admixtures

The ground granulated blast furnace slag (GGBS) has been used widely as supplementary cementitious materials in high performance concrete. Thes mineral admixtures reduce the permeability of concrete to carbon dioxide (CO2) and chloride-ion penetration without much change in the total porosity and thereby reduces the permeablity. The important physical and chemical properties of GGBS are shown in Table 2.8 and Table 2.9

Table 2.8 Physical and chemical properties of GGBS

Sl. No.	**Description**	**Value**
1	Physical state	Hazardous
2	Appearance	Very fine powder
3	Particle size	25 microns-mean
4	Color	Grey
5	Odour	Odourless
6	Specific Gravity	2.3

Table 2.9Chemical Properties of GGBS

Sl. No.	Chemical analysis	Value of percentage
1	SiO_2	34.35-35.04
2	Al_2O_3	11.80-15.26
3	Fe_2O_3	0.29-1.40
4	TiO_2	0.42
5	CaO	36.80-41.40
6	MgO	6.13-9.10
7	Na_2O	0.34
8	K_2O	0.39
9	P_2O_5	<0.10
10	M_nO	0.43
11	SO_3	0.05-2.43

Super plasticizers

The super plasticizers are extensively used in HPCs with very low water cementitious material ratios. In addition to deflocculation of cement grains and increase in the fluidity, the other phenomena that are likely to be present are the following. The main objectives for using super plasticizers are the following.

- To produce highly dense concrete to ensure very low permeability with adequate resistance to freezing-hawing.
- To minimize the effect of heat of hydration by lowering the cement content.
- To produce concrete with low air content and high workability to ensure high bond strength.
- To lower the water-cement ratio in order to keep the effect of creep and shrinkage to a minimum.
- To produce concrete of lowest possible porosity to protect it against external attacks.
- To keep alkali content low enough for protection against alkali-aggregate reaction and to keep sulphate and chloride contents as low as possible for prevention of reinforcement corrosion.
- To produce pumpable yet non-segregating type concrete.
- To overcome the problems of reduced workability in fibre reinforce concrete and shotcrete.
- To provide high degree of workability to the concretes having mineral additives with very low water-cementitious material ratios.
- To produce highly ductile and acid resistant polymer (acrylic latex) concrete with adequate workability and strength.

2.2. Slump Test On Concrete Procedure

- The internal surface of the slump moulded is thoroughly cleaned.
- The moulded is placed on a smooth, horizontal and non-absorbent, such as a carefully leveled metal plate.
- A concrete mix of 1:2:4 is prepared with an initial water-cement ratio of 0.5.
- The mould is filled with freshly prepared concrete in three layers, each layer is approximately one third of the height of the mould. Each layer is given with 25 uniformly distributed strokes over the entire area with the round end of the damping rod.
- The top surface of the concrete is leveled with trowel in leveled with the top of the mould.
- Immediately the mould is slowly raised vertically.
- The slump which is the difference in height in mm between the top of the mould and the highest point on the subsided concrete is measured.
- The above procedure is repeated for different water-cement ratio , and the corresponding slump are measured and recorded. Table 2.10 presents slump test results.

Table 2.10 Slump values for various water-cement ratios

Sl. No.	Water cement ratio	Slump value (mm)
1	0.50	0
2	0.55	0
3	0.60	25
4	0.65	50

2.3. Slump Test on GGBS Replaced Concrete Procedure

- The internal surface of the slump moulded is thoroughly cleaned.
- The moulded is placed on a smooth, horizontal and non-absorbent, such as a carefully leveled metal plate.A concrete mix of 1:2:3 is prepared with an initial water-cement ratio of 0.4
- The mould is filled with freshly prepared concrete in three layers, each layer is approximately one third of the height of the mould. Each layer is given with 25 uniformly distributed strokes over the entire area with the round end of the damping rod.
- The top surface of the concrete is leveled with trowel in leveled with the top of the mould.
- Immediately the mould is slowly raised vertically.
- The slump which is the difference in height in mm between the top of the mould and the highest point on the subsided concrete is measured.
- The above procedure is repeated for different water-cement ratio, and the corresponding slump are measured and recorded in table 2.11.

Table 2.11The slump values for various water-cement ratios

Sl. No.	Ratio concrete	Required slump value (mm)	Actual slump value for (B223) (mm)	Actual slump value for (ACE30IT) (mm)
1	70:30	120	110	115
2	50:50	120	120	115
3	30:70	120	110	110

2.4. Casting and Compression Test on Cement Concrete Cubes

Casting of Concrete Cubes

- The required quantity of cement, sand and coarse aggregate of 20mm size is taken for concrete mix 1:2:3
- Cement and sand is mixed to form dry mortor then coarse aggregate is mixed with this dry mortor.
- Required quantity of water is added and mixed thoroughly to get a uniform colour.
- Oil is applied to the inner surface of the mould and wet concrete is placed inside the mould in three layers and compacter well top surface is leveled.
- After 24 hours the concrete cube is removed from the mould and is immersed in water for curing.

Testing of Concrete Cubes

- At the end of curing period, the cubes are taken out from the water and is wiped with cloth or waste cotton.The dimensions of the compression faces of the cubes is measured.
- The cubes is placed in the compression testing machine and the load is applied gradually over the cube.
- The load at which the needle gets back is noted as ultimate or crushing load.

Table 2.12 presents compressive strength of normal concrete. Compressive strengths of partial replacement by GGBS after 7 days, 14 days and 28 days curing are presented in Tables 2.13 - 2.14 respectively.

Table 2.12Compressive strength of standard concrete

Sl. No.	No. of curing days	Number of specimen	Initial crack load (kN)	Ultimate load (kN)	Ultimate compressive strength (N/mm^2)
1	7	3	13500	392300	17.43
2	14	3	17500	522000	23.25
3	28	3	44200	818500	36.40

Table 2.13 Compressive strength of 30% partial replacement by GGBS withB233

Sl. No.	No of days of curing	Number of specimen	Initial crack load (kN)	Ultimate load (kN)	Ultimate compressive strength (N/mm^2)
1	7	3	24000	709500	31.53
2	14	3	30500	745500	37.64
3	28	3	40800	1091500	48.54

Table 2.14 Compressive strength of 50% partial replacement by GGBS with B233

Sl. No.	No of days of curing	Number of specimen	Initial crack load (kN)	Ultimate load (kN)	Ultimate compressive strength (N/mm^2)
1	7	3	27000	513000	22.96
2	14	3	24500	643600	28.63
3	28	3	35000	885000	39.38

Table 2.15 Compressive strength of 70% partial replacement by GGBS with B233

Sl. No.	No of days of curing	Number of specimen	Initial crack load (kN)	Ultimate load (kN)	Ultimate compressive strength (N/mm^2)
1	7	3	19500	534000	23.75
2	14	3	20300	565000	25.41
3	28	3	42000	1111300	49.41

Table 2.16 Compressive strength of 30% partial replacement by GGBS withACE30IT

Sl. No.	No of days of curing	Number of specimen	Initial crack load (kN)	Ultimate load (kN)	Ultimate compressive strength (N/mm^2)
1	7	3	22000	584000	26.00
2	14	3	21500	595000	26.45
3	28	3	20800	584300	26.00

Table 2.17 Compressive strength of 50% partial replacement by GGBS withACE30IT

Sl. No.	No of days of curing	Number of specimen	Initial crack load (kN)	Ultimate load (kN)	Ultimate compressive strength (N/mm^2)
1	7	3	18300	503300	22.38
2	14	3	22500	614000	27.32
3	28	3	13800	503000	22.38

Table 2.18 Compressive strength of 70% partial replacement by GGBS with ACE30IT

Sl. No.	No of days of curing	Number of specimen	Initial crack load (kN)	Ultimate load (kN)	Ultimate compressive strength (N/mm^2)
1	7	3	19500	516000	22.96
2	14	3	21000	578500	25.72
3	28	3	19200	516000	22.96

3. Result, Discussion and Conclusion

3.1 Test results of hardened concrete

Compression Test

Compressive strength test of conventional concrete and GGBS for 7, 14 and 28 days are shown in Tables 3.1-3.7 and in bar charts in Figures 3.1- 3.9

Table 3.1 Compressive strength of standard concrete

Sl. No.	No of curing days	Number of specimen	Initial crack load	Ultimate load (kN)	Ultimate compressive strength
1	7	3	13500	392300	17.43
2	14	3	17500	522000	23.25
3	28	3	44200	818500	36.40

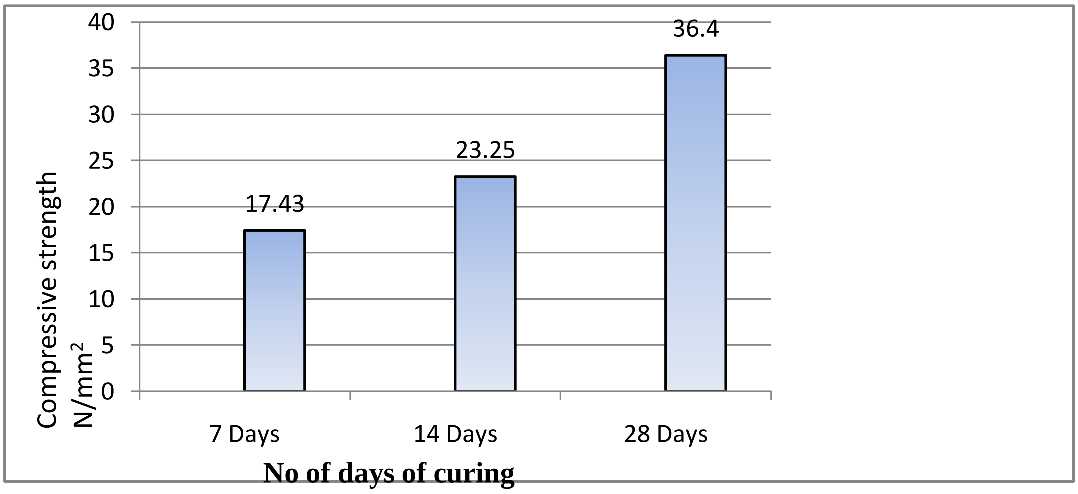

Fig 3.1 Compressive strength of standard concrete

Table 3.2 Compressive strength of 30% partial replacement by GGBS with B233

Sl. No.	No of days of curing	Number of specimen	Initial crack load (kN)	Ultimate load (kN)	Ultimate compressive strength (N/mm^2)
1	7	3	24000	709500	31.53
2	14	3	30500	745500	37.64
3	28	3	40800	1091500	48.54

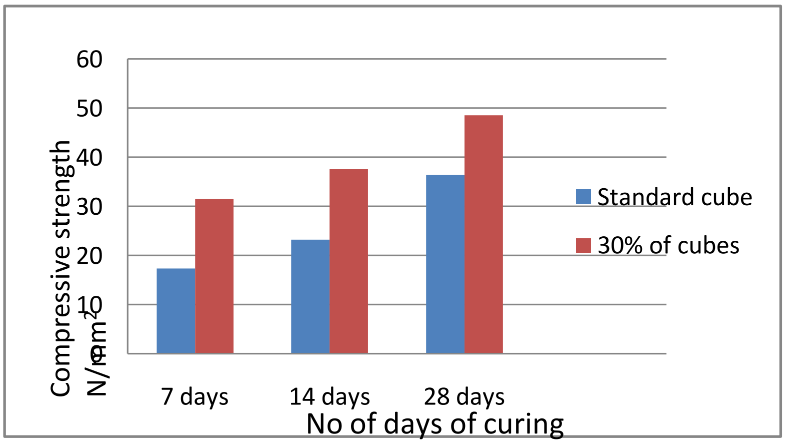

Fig 3.2 Compressive strength of 30% partial replacement by GGBSwith B233

Table 3.3 Compressive strength of 50% partial replacement by GGBS with B233

`Sl. No.	No of days of curing	Number of specimen	Initial crack load (kN)	Ultimate load (kN)	Ultimate compressive strength (N/mm^2)
1	7	3	27000	513000	22.96
2	14	3	24500	643600	28.63
3	28	3	35000	885000	39.38

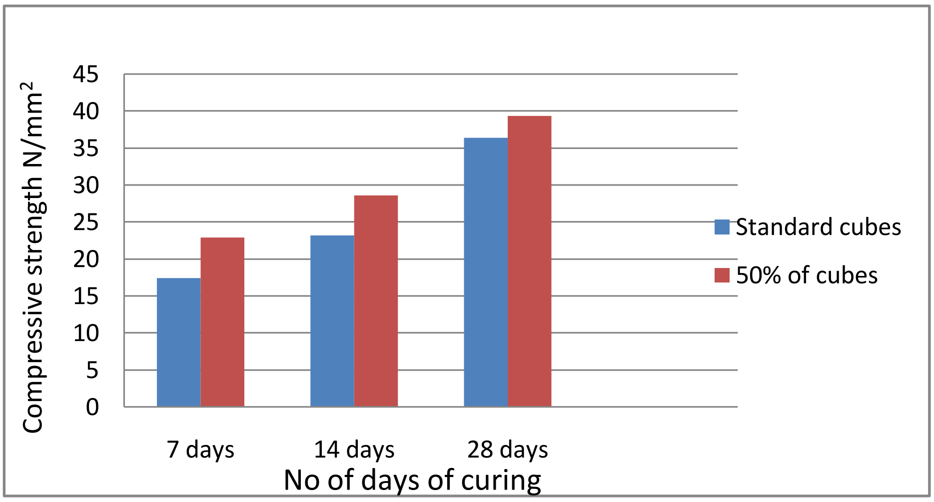

Fig 3.3 Compressive strength of 50% partial replacement by GGBS with B233

Table 3.4 Compressive strength of 70% partial replacement by GGBS with B233

Sl. No.	No of days of curing	Number of specimen	Initial crack load (kN)	Ultimate load (kN)	Ultimate compressive strength (N/mm^2)
1	7	3	19500	534000	23.75
2	14	3	20300	565000	25.41
3	28	3	42000	1111300	49.41

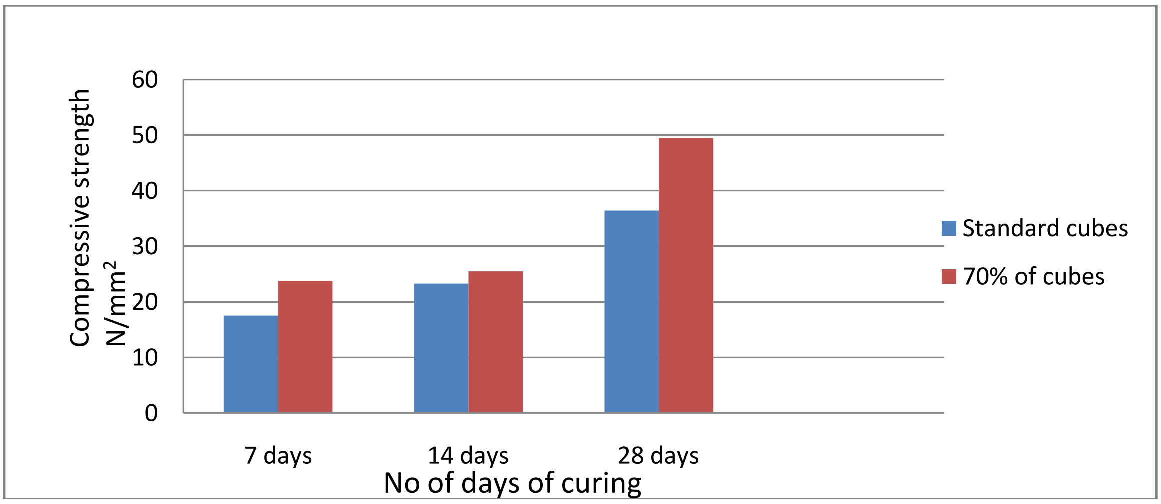

Fig3.4 Compressive strength of 70% partial replacement by GGBSwith B233

Table 3.5 Compressive strength of 30% partial replacement by GGBS withACE30IT

Sl. No.	No of days of curing	Number of specimen	Initial crack load (kN)	Ultimate load (kN)	Ultimate compressive strength (N/mm^2)
1	7	3	22000	584000	26.00
2	14	3	21500	595000	26.45
3	28	3	20800	584300	26.00

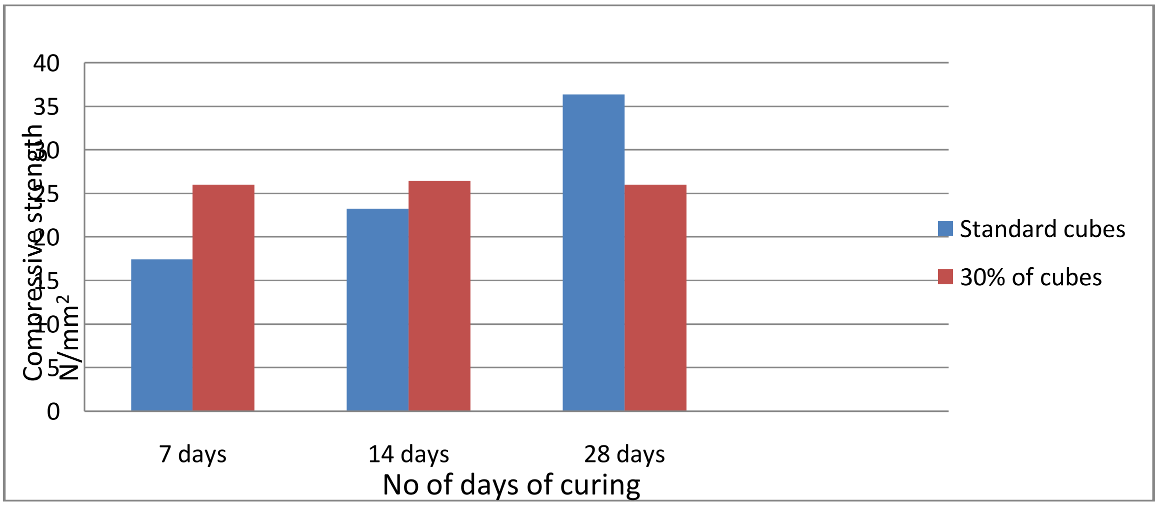

Fig3.5 Compressive strength of 30% partial replacement by GGBS with ACE30IT

Table 3.6 Compressive strength of 50% partial replacement by GGBS with ACE30IT

Sl. No.	No of days of curing	Number of specimen	Initial crack load (kN)	Ultimate load (kN)	Ultimate compressive strength (N/mm^2)
1	7	3	18300	503300	22.38
2	14	3	22500	614000	27.32
3	28	3	13800	503000	22.38

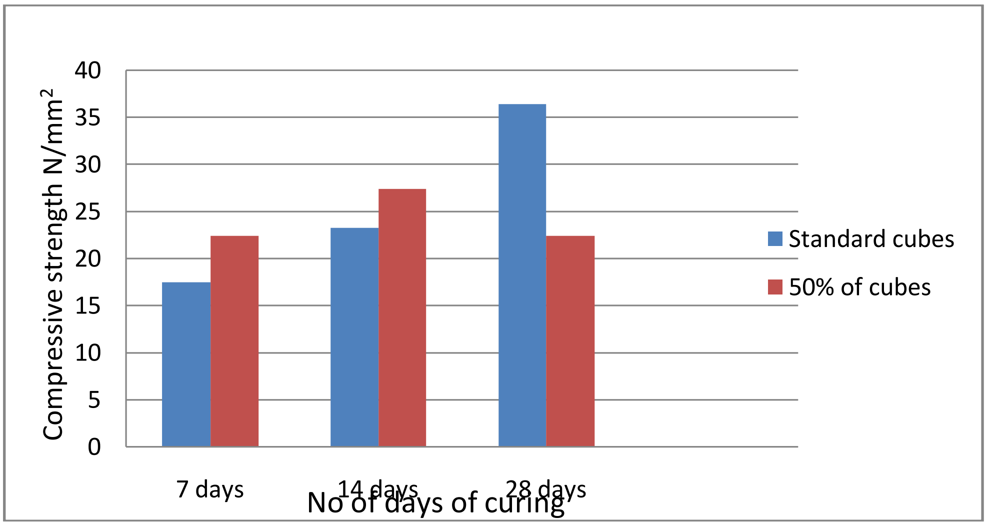

Fig 3.6 Compressive strength of 50% partial replacement by GGBS with ACE30IT

Table 3.7 Compressive strength of 70% partial replacement by GGBS with ACE30IT

Sl. No.	No of days of curing	Number of specimen	Initial crack load (kN)	Ultimate load (kN)	Ultimate compressive strength (N/mm^2)
1	7	3	19500	516000	22.96
2	14	3	21000	578500	25.72
3	28	3	19200	516000	22.96

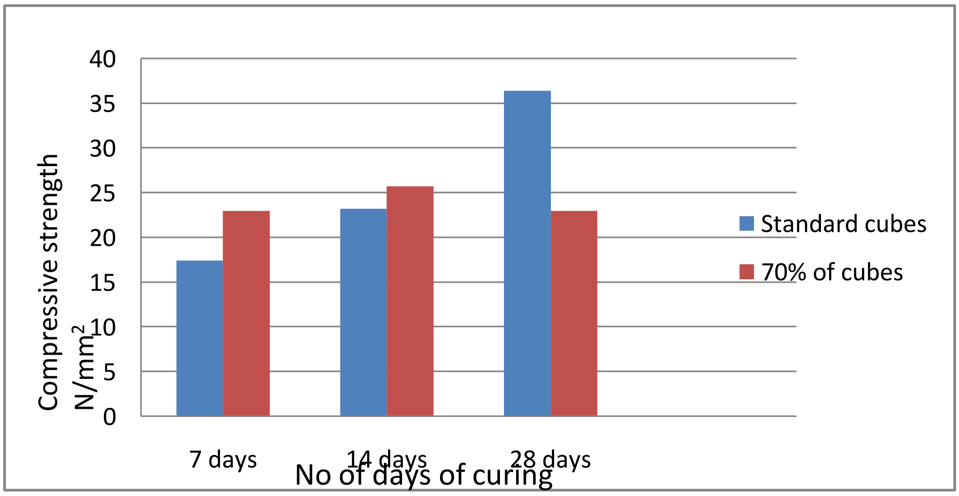

Fig3.7 Compressive strength of 70% partial replacement by GGBS withACE30IT

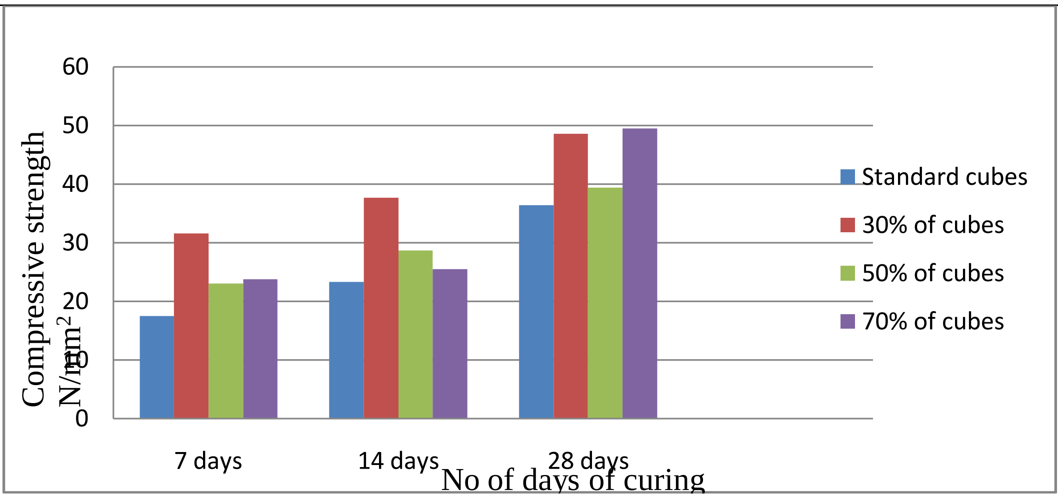

Fig3.8 Compressive strength of normal, 30, 50 and 70 % partial replacement by GGBS with B233

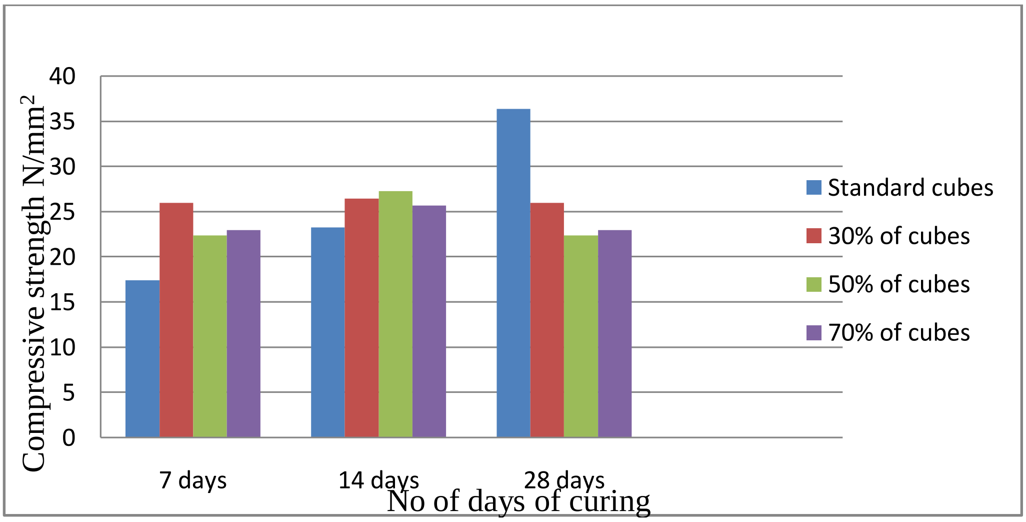

Fig 3.9 Compressive strength of normal, 30, 50 and 70 % partial replacement by GGBS with ACE30IT

3.2 Discussion

- As per IS-456 2000, the compressive strength of M40 standard concrete after 28 days is 40 N/mm^2. In the present study the compression strength for 28 days is 36.40 N/mm^2. Therefore the design can be acceptable.
- From the results presented in Tables 3.1, 3.2, 3.3, 3.4, 3.5, 3.6, and 3.7 and in Figures 3.1, 3.2, 3.3, 3.4, 3.5, 3.6, 3.7, 3.8, and 3.9, it can be seen that the concrete with 30% replacement of cement by Ground Granulated Blast Furnace Slag uniformly produce higher compressive strengths at 7 days, 14 days and 28 days compared to other replacements. Therefore, it can be concluded that 30% replacement of cement by Ground Granulated Blast Furnace Slag s safe and acceptable.
- In order to prepare 1 m^3 of cement concrete of 1:2:3, 6.4 bags (320 kg) of cement is needed, as per IS – 456: 2000. The present study recommends that 10% of cement can be replaced by Ground Granulated Blast Furnace Slag without losing the required strength of the concrete. Therefore, 32 kg of cement can be saved whose market value is Rs.200/- approximated. This will lead to a savings of 10% cost on concrete making, which is quite high in the present context of construction.
- Furthermore, the present study also indicated that the workability as well as the durability of the GGBS mixed concrete are increased, which are good for the construction. The environmental pollution, otherwise will be created by the disposal of ground granulated blast furnace slag can be avoided.The study undertaken here brought out the advantage of replacing cement by the Ground Granulated Blast Furnace Slag e tune of 30%.

3.3 Conclusions

- At all the cement replacement levels of Ground Granulated Blast Furnace Slag, there is a gradual increase in compressive strength from 3 days to 7 days. However, there is a significant increase in compressive strength from 7 days to 28 days followed by gradual increase from 7 days to 28 days.
- At the initial ages, with the increase in the percentage replacement of both Ground Granulated Blast Furnace Slag, the flexural strength of Ground Granulated Blast Furnace Slag concrete is found to decrease gradually till 30% replacement. However, as the age advances, there is a significant decrease in the flexural strength of Ground Granulated Blast Furnace Slag concrete.
- The technical and economic advantages of incorporating Ground Granulated Blast Furnace Slag in concrete should be exploited by the construction and rice industries, more so for the rice growing nations of Asia.

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