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Experimental Investigation On The Compressive Strength Of Concrete By Partially Replacing Cement With GGBS

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ABSTRACT

Concrete is always expected to be stronger and more durable than in the past, while being cost and energy efficient. Moreover, the three major advantages that concrete possesses over other construction materials have to be conserved: the possibility of being fabricated practically anywhere; the ability to take the form imposed by the shape of a mould; and low cost of the components and the manufacture. These factors have driven the advances in improving the performance of concrete over years, and continue to do so. The need for improving the performance of concrete and concern for the environmental impact arising from the continually increasing demand for concrete, has led to the growing use of alternative materials component. It is now clear that materials such as silica fume, rice hush ash ,fly ash, ground granulated blast furnace blast furnace slag and metakaolin be produced from abundant natural material which are waste material have to be used to partially substitute cement or to complement it when high performance is needed.

Concrete is a composite construction material, composed of cement (commonly Portland cement) and other cementinious materials such as fly ash and slag cement, aggregate (generally a coarse aggregate made of gravel or crushed rocks such as limestone, or granite, plus a fine aggregate such as sand), water and chemical admixtures.

The word concrete comes from the Latin word "concretes" (meaning compact or condensed), the perfect passive participle of "concrescere", from "con-" (together) and "crescere" (to grow).

Concrete solidifies and hardens after mixing with water and placement due to a chemical process known as hydration. The water reacts with the cement, which bonds the other components together, eventually creating a robust stone-like material. Concrete is used to make pavements, pipe, architectural structures, foundations, motorways/roads, bridges/overpasses, parking structures, brick/block walls, footings for gates, fences and poles and even boats.

The present investigation is aimed to study the mechanical properties of GGBS concrete .Regarding mechanical properties of hardened concrete such as 28-day compressive strength and are improved up to 30% replacement.

The efficiency factors of the concrete has been evaluated for M20 and M40 grade with GGBS as a replacement upto 40% in the concrete at regular intervals of 10%. .

INTRODUCTION

GENERAL

Concrete is the most widely used construction material having several advantages such as high strength, good mould ability durability weather and fire resistance. The use of ground granulated blast furnace slag (GGBS) in mortar has increased in recent years. Records indicate that blast furnace cement was used for the mortar during the construction of the Empire State Building in the 1930s.

On its own, ground granulated blast furnace slag (GGBS) hardens very slowly and, for use in concrete, it needs to be activated by combining it with Portland cement. Atypical combination is 50 per cent GGBS with 50 per cent Portland cement, but percentages of GGBS anywhere between 20 and 80 per cent are commonly used. The greater the percentage of GGBS, the greater will be the effect on concrete properties

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1.2 DESCRIPTION OF GGBS

1.2.1 Ground granulated blast furnace slag (GGBS)

Ground blast furnace slag is obtained during the manufacturing process of pig iron in blast furnace. The slag is a mixture of lime, silica, and alumina, the same oxides that make up Portland cement, but not in the same proportion. The composition of blast-furnace slag is determined by the ores, fluxing stone and impurities in the coke charged into the blast furnace. the silicon, calcium, aluminum, magnesium and oxygen constitute 95% or more of the blast furnace slag. This material is rapidly cooled to form a granulate and then ground to a fine white powder (GGBS), which has many similar characteristics to Portland cement. When GGBS is blended with Portland cement further recognized cementations materials such as Portland-slag cement and blast furnace cement are produced. In the UK, GGBS is manufactured and generally sold as a separate powder which is then batched and blended within the mixer. It is used extensively in the construction industry to produce concretes, grouts and mortars.

1.2.2 Reaction mechanism

The hydration mechanism of a combination of GGBS and Portland cement is slightly more complex than that of a Portland cement. This reaction involves the activation of the GGBS by alkalis and sulfates to form its own hydration products. Some of these combine with the Portland cement products to form further hydrates which have a pore blocking effect. The result is a hardened cement paste with more of the very small gel pores and fewer of the much larger capillary pores for the same total pore volume. Generally, the rate of strength development is slower than for a Portland cement mortar.

1.2.3 GGBS Utilization

GGBS has been used in mortars for many years, generally in ready-to-use retarded mortars. Increasingly, the dry silo system is coming into use and GGBS is also being used in this method of producing mortar. Typically, GGBS has been used at between 25 and 50% replacement of the Portland cement with or without the addition of lime

1.2.4 Specification

Factory made cements should conform to the requirements of BS EN 197-1 Common cements: CEM_2/A-S, CEM_2/B-S or CEM_3-A or to the requirements in BS EN 197-4 for Type C_3A. Combinations should conform to the requirements of BS 8500-2:2006:Annex A for Type C_2-S or C_3A.

1.2.5 Use with admixtures

Where retarding admixtures are used to produce ready-to-use retarded mortars the incorporation of GGBS reduces the dosage rate required to achieve the desired level of retardation. The degree of reduction is dependent on the proportion of GGBS used, however, trials indicate that a 35% reduction can be achieved with high proportions of GGBS.

1.2.6 Pigmentation

GGBS is off-white in colour, which results in the production of a lighter mortar. This has an advantage when incorporating pigments, as the lighter colour results in improved colour depth and a potential reduction in the quantity of pigment required to produce the desired colour.

Data indicates that with high proportions of GGBS, pigment dosage may be reduced by approximately 20% without a discernible change in colour as measured by a spectrophotometer.

1.2.7 **Efflorescence**

The pozzolanic secondary reactions associated with the hydration of GGBS utilize some of the excess calcium hydroxide in the pores and may reduce the risk and extent of any efflorescence.

1.5.3 **Lower heat of hydration**

The hydration of Portland cement leads to the production of portlandite crystal [$Ca(OH)_2$] and amorphous calcium silicate hydrate gel[$C_3S_2H_3$](C-S-H) in large amounts. Hydrated cement paste involves approximately 70% C-S-H, 20% Ca $(OH)_2$; 7% sulpho-aluminates and 3% secondary phases. The $Ca(OH)_2$ which appears as the result of the chemical reactions affect the quality of the concrete adversely by forming cavities as it is partly soluble in water and lacks enough strength. The use of GGBS has a positive effect on binding the $Ca(OH)_2$ compound, which decreases the quality of the concrete. At the end of the reaction of the slang and $Ca(OH)_2$, hydration products, such as C-S-H gel,are formed. As a net result, incorporation of GGBS in concrete can contribute a great deal to reduce the adverse effect due to the "locked-in stresses and micro cracking arising from the heat evolved during cement hydration. The chemical reaction of the Portland cement is expresses as follows:

$$\text{Cement}(C_3S, C_2S) + H_2O\,(H) \longrightarrow \text{CSH-gel} + Ca\,(OH)_2\,(CH)$$

The pozzolantic reaction is

$$Ca\,(OH)_2\,(CH) + SiO_2\,(S) + H_2O\,(H) \longrightarrow CSH$$

It can be observed from the above reactions; Calcium hydroxide is produced by the hydration of Portland cement and consumed by the pozzolanic reaction. So it can be said that the pozzolanic reaction can only takes place after the hydration of Portland cement starts.

1.5.4 Reduced permeability

Permeability is the key factor affecting the chemical attacks on the concrete and the reinforced steel. Many studies have shown that the concrete containing GGBS has much more reduced pore structure than OPC Concrete due to denser gel formation during Hydration Process.

1.5.5 **High resistance to sulphate attack**

Chemical reaction between sulphate ions in soil/water and C_3A content in cement results in the formation of ettringite which can lead to excessive expansion and cracking in the concrete. Partial replacement of OPC by GGBS increases the resistance of concrete to sulphate attack and this is acknowledged in all major European Codes of Practice. The major factors influencing the increased resistance are:

a) The ratio of GGBS to OPC in the Concrete

b) Low Permeability of the concrete

c) Low C_3A content in cement composite

d) Depletion of Calcium Hydroxide content due to reaction with GGBS in the concrete.

1.5.6 **Resistance to chloride attack**

Lower permeability of concrete is the only way that can reduce the intensity of chloride attack on a concrete structure. It is proved that concrete containing GGBS possesses much lower chloride permeability than the corresponding OPC Concrete. This reduction in diffusivity would appear to be due to two mechanisms:

a) The incorporation of GGBS reduces the permeability of the concrete. Hardened paste of GGBS bind greater amounts of chloride than that of the OPC, resulting in much lower proportion of free chloride in the pore solution

Hence, concrete containing GGBS provide greatly increased protection for steel reinforcement in environments that subjected to chloride attack.

1.5.7 Resistance to alkali-aggregate reaction(AAR)

Deleterious reactions between certain types of Reactive Aggregates in concrete with alkalies(K_2O and Na_2O) in cement/water are known to cause cracking, expansion and distress to concrete dams, bridges etc. Concrete made with GGBS has 85% less expansion due to Alkali-Aggregate Reaction than OPC. Low Alkali-ion diffusion rate and low permeability to water of GGBS Concrete reduces the harmful reaction. Because of these two factors any expansion that occur may develop 100 to 1000 times late in a GGBS can be used safely where Reactive Aggregates are used in the construction.

1.5.8 **Reduce leaching**

Calcium Hydroxide $Ca(OH)_2$ reacts with CO_2 in air to form Calcium carbonate ($CaCO_3$) which is in white colour and form white patches on the concrete finished surfaces. Development of white patches is more with high grade OPC due to high C_3S content and more liberation of Ca $(OH)_2$, than concrete with GGBS.

SCOPE AND OBJECT OF INVESTIGATION

3.1 SCOPE

India is one of the fast developing countries in the world. Various fields like Industry, Infrastructure, Construction, Agriculture etc., have a major role in achieving an all round development. This development has urged the industrial sector to produce various goods that are necessary. These industries and factories besides producing various useful goods have also become a source of waste products. And it has become necessary to find ways and means of disposing off or utilizing these waste materials, which may otherwise end up in polluting the surroundings. This led to the investigation of searching fields of utilization of these waste products for a better purpose. Research work was carried out on this subject not only in India but also all over the world. The results of such works showed that there could be no better place other than the construction field, where a large quantity of such materials can be utilized in a better and economical way.

On the other hand the field of Construction has also its role to play in the development of the country by not only in increasing the construction work but also in a more sophisticated manner. This in turn has an effect on the various materials and their quantities that are to be used. Therefore, this also led to the investigation of new materials, which can be utilized for the purpose even more economically. Especially work has done on the utilization of the by-products obtained from various industries. In this way the construction field and the industrial sector have been linked together, reducing the environmental hazards and serving the economical problems.

Products like foamed blast furnace slag, furnace clinker, cinder, pulverized fuel ash etc. are the waste products obtained from various industries. It has been found that each one of these has quite a good use in the construction field. These products are either used in their original form as are obtained or changed slightly so as to serve a better purpose. The pulverized fuel ash for example, is used in concrete either as a replacement to cement and sand or converted to sintered fly ash to be used as coarse aggregate.

A lot of work has been done on utilization 0f GGBS in concrete as replacement to cement. In the present investigation studies are made on GGBS concrete, replacing cement by GGBS. Therefore, its proper utilization will safeguard the environment from any disaster.

Based on the above facts, in this investigation an attempt has been made to use of GGBS as a replacement to cement ranging from 10% to 40% by weight.

OBJECTIVE:

The Objective of this experimental investigation is confined to the study and comparison of the effects of replacement of cement by fly ash and ggbs on the 28 days compressive strength and split tensile strength.

1. To evaluate the compressive strength of concrete by replacing cement with GGBS at varying percentages of 0,10, 20,30 and 40% for M20 grade of concrete.
2. To evaluate the compressive strength of concrete by replacing cement with GGBS at varying percentages of 0,10, 20,30 and 40% for M40 grade of concrete.
3. To evaluate the strength Efficiency factors for GGBS at varying percentages of 0,10, 20,30 and 40 for M20 and M40 grade of concretes.

EXPERIMENTAL INVESTIGATION

4.1GENERAL:

Experimental investigation was planned to study the effects of partial replacement of cement by GGBS on strength properties of concrete.

To achieve the objectives of the investigation the experimental program was planned to cast and test the cubes to study the compressive strength and the details of the experimental program for cubes are mentioned in Table no:1

4.2 MATERIALS USED

4.2.1 CEMENT

Ordinary Portland cement available in local market of standard brand was used in the investigation. The cement used has been tested for various properties as per IS 4031-1998 and found to conform various specifications as per IS 12269-1987. Cement was conformiong to 53 Grade having specific gravity 2.91.

4.2.2 COARSE AGGREGATE

Crushed angular granite metal of 10 mm size from local quarry was used as coarse aggregate.

The cleaned coarse aggregate was tested for various properties such as specific gravity, fineness modulus, bulk modulus etc.

4.2.3 FINE AGGREGATE

The locally available river sand was used as fine aggregate in the present investigation. The cleaned fine aggregrate was tested for various properties such as specific gravity, fineness modulus, bulk modulus etc and are conforming to standard specifications.

4.2.4 WATER

Fresh potable water was used in mixing the concrete. Water in the required quantities was measured using a graduated jar and added to the dry mixture.

4.2.5 MIXING

The work deals with the mixing and thereby, the preparation of M20 grade concrete as per the mix design given in below. Concrete were prepared with a partial replacement of cement by fly ash GGBS and percentages of 10,20,30,40 and by weight.

Initially all the materials were weigh batched. Cement and GGBS were mixed, to which coarse aggregate and fine aggregate were added and thoroughly mixed. Water was measured exactly and added to the dry mix and it was thoroughly mixed to get a cohesive concrete, which is demarcated by obtaining a uniform color all through the concrete.

the preparation of M40 grade concrete as per the mix design given in below. Concrete were prepared with a partial replacement of cement by fly ash GGBS and percentages of 10,20,30,40 and by weight.

Initially all the materials were weigh batched. Cement and GGBS were mixed, to which coarse aggregate and fine aggregate were added and thoroughly mixed. Water was measured exactly and added to the dry mix and it was thoroughly mixed to get a cohesive concrete, which is demarcated by obtaining a uniform color all through the concrete.

4.2.6 CASTING

The cubes were cast in moulds of size 150 x 150 x 150mm (internal) cylinders in moulds of size 150 x 300mm (internal).The standard cube moulds as mentioned above were placed on the table vibrator and the well-mixed concrete was poured into the moulds in three layers. Each layer was thoroughly compacted by means of a standard tamping rod. After filling the moulds up to the brim, vibration was effected for one minute using the table vibrator, which was maintained constant for all specimens.

It was seen that after the vibration process was completed, a thin layer of cement slurry is formed at the top surface, thus making the top surface level well finished. Similarly specimens of cylinders were also cast except for the table vibration. These specimens were subjected to manual compaction only. It is shown in photograph-1

4.2.7 CURING

The specimens cast were removed from moulds after 24hrs and were immersed in a clean water tank and left for curing. After the curing was complete, the specimens were removed and allowed to dry under shade, after which testing was done.

4.2.8 TESTING:

The cubes so cast and cured, are tested for compressive strength using a 200 ton compression-testing machine. The cube is placed in the testing machine with cast faces at right angles to that of compressive faces. The load is applied at a constant rate of 140-kg/sq cm/minute up to failure and the ultimate load is noted. It is shown photograph-2

4.3 MIX DESIGN:

To determine the specific gravity of cement, fine and coarse aggregate, fineness modulus of coarse and fine aggregate. Using data o design a mix using I.S Code method.

4.3.1 THEORY

Mix design can be defined as the process of selecting ingredients of concrete and determining their relative proportions with the object of producing concrete of certain minimum strength and durability as economically as possible. The first object of mix design is to achieve the stipulated minimum strength and the second object is to make the concrete in the most economical manner.

The design of concrete mix is based on the following factors.

a) Grade designation.
b) Type of cement.
c) Maximum nominal size of aggregate.
d) Minimum water-cement ratio.
e) Workability.
f) Minimum cement content.

The grade designation gives the characteristic strength requirement of cement. Type of cement is important mainly through its influence on the rate of development of compressive strength of concrete as well as durability under aggressive environment.

Larger the max-size of aggregate smaller is the cement requirement for a particular W/C ratio. Concrete mixes having higher shrinkage, cracking and creep of concrete.

4.3.2 PROCEDURE:

Specific gravity of cement: To determine specific gravity of cement a liquid of water free kerosene is used which does not react with cement.

4.3.3 CALCULATIONS:

1. Weight of the specific gravity bottle dry (W_1) = 21.395grams
2. Weight of the bottle + water (W_2) = 46.700grams
3. Weight of the bottle + kerosene (W_3) = 42.020 grams
4. Weight of the bottle + kerosene + 10 grams weight cement(W_4) = 49.350 grams

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5. Weight of cement (W_5) = 10.00 grams
6. Specific gravity of kerosene S_k = W_3-W_1 = 0.185 grams W_2-W_1
7. Specific gravity of cement S_c = W_5 X S_k = 3.052 (W_5+W_3-W_4)

1. Specific gravity of coarse aggregate:

S.NO	DESCRIPTION	TRAIL 1	TRAIL 2
1.	Weight of the container W_1	347	350
2.	Weight of the container with material W_2	1777	1781
3.	Weight of the container + material + water W_3	2330	2342
4.	Weight of the container + water W_4	1433	1435
5.	Bulk density(W_2-W_1) (W_4-W_1)	10317	1032
6.	Porosity = $\frac{W_3-W_2}{W_4-W_1}$ X 100	50.9%	51.76%
7.	Voids ratio $\frac{W_3-W_2}{(W_4-W_1)(W_3-W_2)}$ X 100	1.04	1.07
8.	Specific gravity $\frac{W_2-W_1}{(W_4-W_1)-(W_3-W_2)}$ X 100	2.68	2.73

TABLE 4.1

Average Specific gravity of coarse aggregate: 2.7

2.Specific gravity of fine aggregate

W_1 - Weight of jar empty = 549 grams

W_3 - Weight of the jar+ sand + water = 2143 grams

W_4 -Weight of the water+ jar = 2540 grams

Specific gravity = $\frac{W_2-W_1}{(W_4-W_1)-(W_3-W_2)}$ X 100

Specific gravity of fine aggregate is 2.46.

3.Fineness modulus of Coarse aggregate and Fine aggregate

Fineness modulus is an empirical factor obtained by adding the cumulative percentages of aggregate retained on each of the standard sieve ranging from 40mm to 150 and dividing this sum by arbitrary No.100. The larger the number the coarse the aggregate.

Fineness modulus of Coarse aggregate(5kgs)

Width of a size	Weight retained(Kg)	% Weight retained	Cumulative 1% Weight retained	% Passing
40mm	---	---	0	100%
20mm	0.043	0.86	0.86%	99.04%
10mm	3.034	60.68	61.54%	38.46%
4.75	1.674	33.48	95.02%	4.98%
2.36	0.15	3.00	98.02%	1.98%
1.18	0.05	1.00	99.02%	0.92%
600µ	0.03	0.6	99.62%	0.38%
300µ	0.01	0.2	99.82%	0.18%
150µ	0.009	0.18	100%	0

TABLE 4.2

$\sum C$ = 653.9

F.M = $\frac{\text{cumulative \% wt retained}}{100}$ = $\frac{653.9}{100}$ = 6.53

F.M. Coarse aggregate = 6.53

4.Fineness modulus of fine aggregate(1000grams)(sand)

Width of aperture	Weight retained(grams)	% Weight retained	Cumulative 1% Weight retained	% Passing	Remarks
4.75	4	0.4	0.4	99.6	
2.36	40	4.0	4.4	95.6	
1.18	214	21.4	25.8	74.2	
600µ	421	42.1	67.9	32.1	
300µ	226	22.6	90.5	9.5	
150µ	71.5	7.15	97.60	2.4	

TABLE 4.3

$\sum C$ = 286.8

Fineness modulus = $\frac{\sum C}{100}$ = $\frac{\text{cumulative \% wt retained}}{100}$ = $\frac{286.6}{100}$ = 2.87

Fineness modulus of sand = 2.87

Fineness modulus of coarse aggregate = 6.53

Specific gravity of cement = 3.052

Specific gravity of sand = 2.52

Specific gravity of coarse aggregate = 2.70

4.3.4 MIX DESIGN PROCEDURES I.S METHOD

The step-by-step procedure of mix proportioning in a following:

(a). The target mean strength (average) compressive strength at 28 days is given by

$f_c = f_{ck} + K.S$

f_{ck} = characteristic compressive strength at 28 days

S = standard deviation

K = statistical value on expected proportion of low results (risk factors (tables))

(b). The w/c ratio for the target mean strength it depends on various parameters like types of cement, aggregate, max. size of aggregate, surface texture of aggregate etc.. from tables.

(c). Estimation of entrapped air content is estimated for the nominal maximum size of aggregate used.

(d). Selection of water content and fine to total aggregate ratio for standard (I) crushed coarse aggregate (II) Fine aggregate in saturated surface dry conditions (III) W/C ratio of 0.60 and 0.35 for medium and high strength concrete's respectively (IV) Workability corresponding to compacting, factor of 0.80.

(e). Calculation of cement content: The cement content per unit volume of concrete are calculated from free water cement ratio and the quantity of water per unit volume of concrete.

(f). The coarse and fine aggregate content per unit volume of concrete are calculated from

V= (W+C/Sc +1/P X fa/Sca)/1000.

V= (W+C/Sc +1/(1-P) X Ca/Sca)/1000.

V = fresh concrete(m),

Sc = specific gravity of cement,

W = mass of water (Kg)/m,

C = cement(Kg)/m,

P = ratio of fine aggregate to total aggregate by absolute volume,

fa,Ca = total masses of fine aggregate and coarse aggregate (Kg)/m of concrete,

Sfa,Sca = specific gravity's of situated surface dry fine aggregate and coarse aggregate.

APPENDIX -A

MIX DESIGN BY ISI METHOD FOR M-20 GRADE OF CONCRETE:

A. DESIGN STIPULATIONS:

1. Characteristic compressive strength at 28 days = 20 N/mm2
2. Target mean strength, ft = 20+1.65 x 4.6 = 27.59 Mpa
3. Maximum size of aggregate = 20mm
4. Degree of workability = 0.8CF
5. Degree of quality control = GOOD
6. Type of exposure = Mild

B. TEST DATE FOR MATERIALS:

1. Specific gravity of Opc 53 grade = 3.12
2. Specific gravity of coarse aggregate = 2.8
3. Specific gravity of sand = 2.52
4. Fineness modulus of fine aggregate : 3.71
5. Fineness modulus of coarse aggregate: 7.55
6. Free (surface) moisture coarse aggregate Nill

Target mean strength of concrete:

fck=fck+t*s

fck=20+1.65*4.6

fck=27.59N/mm^2

Water-cement ratio:

For the target mean strength of 27.65N/mm^2 the water-cement ratio is 0.55

Air content%:

For nominal maximum size of aggregate 20mm=2%

Sand and water content:

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

For the change in values in water-cement ratio, compaction factor and sand belonging to zone II, the following adjustments are required:

Change in condition	Adjustment required in	
	Water content percent	Percentage sand in total aggregate
For decrease in w/c ratio(0.6-0.49)	0	-2.2%
For sand conforming to zone II	0	0
For compaction factor 0.8	0	0
Total	0	-2.2%

TABLE 4.4

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Required sand content as % of total aggregate by absolute volume =35-2.2 =32.8%
Required water content =181.5kg/m^3
Cement content =330kg/m^3

Fine aggregate:
$V=(W+C/S_C+1/P*fa/S_{fa})*1/1000$
0.98=(185.5+330/3.12+1/.328*fa/2.52)*1/1000
Fa = 660.02kg/m^3
Coarse aggregate:
$V=(W+C/S_C+1/(1-P)*ca/S_{ca})*1/1000$
0.98=(185.5+330/3.12+1/(1-0.328)*ca/2.8)*1/1000
Ca = 1320.01kg/m^3
MIX PROPORTION:

Water	cement	Fine aggregate	Coarse aggregate
181.5kg/m^3	330kg/m^3	660kg/m^3	1320kg/m^3
0.55	1	2.0	4.0

TABLE 4.5

MIX DESIGN BY ISI METHOD FOR M-40 GRADE OF CONCRETE:
A. DESIGN STIPULATIONS:
1. Characteristic compressive strength at 28 days = 40 N/mm2
2. Target mean strength, ft = 40+1.65 x 6.6 = 50.89 Mpa
3. Maximum size of aggregate = 20mm
4. Degree of workability = 0.8CF
5. Degree of quality control = GOOD
6. Type of exposure = Mild

B. TEST DATE FOR MATERIALS:
1. Specific gravity of Opc 53 grade = 3.12
2. Specific gravity of coarse aggregate = 2.8
3. Specific gravity of sand = 2.52
4. Fineness modulus of fine aggregate : 3.71
5. Fineness modulus of coarse aggregate: 7.55
6. Free (surface) moisture coarse aggregate Nill

Target mean strength of concrete:
fck=fck+t*s
fck=40+1.65*6.6
fck=50.89N/mm^2
Water-cement ratio:
For the target mean strength of 50.89N/mm^2 ,the water-cement ratio is 0.38
Air content%:
For nominal maximum size of aggregate 20mm=2%
Sand and water content:
For 20mm nominal maximum size of aggregate and sand conforming to grading zone II, water content per cubic meter of concrete= kg and sand content as percentage of total aggregate by absolute volume =35%.
For the change in values in water-cement ratio, compaction factor and sand belonging to zone II, the following adjustments are required:

TABLE 4.6

Change in condition	Adjustment required in	
	Water content percent	Percentage sand in total aggregate
For decrease in w/c ratio(0.6-0.49)	0	-2.2%
For sand conforming to zone II	0	0
For compaction factor 0.8	0	0
Total	0	-2.2%

Required sand content as % of total aggregate by absolute volume =35-2.2=32.8%
Required water content =163.4kg/m^3
Cement content =430kg/m^3
Fine aggregate:
$V=(W+C/S_C+1/P*fa/S_{fa})*1/1000$
0.98=(163.4+430/3.12+1/.328*fa/2.52)*1/1000
Fa = 516.02kg/m^3
Coarse aggregate:
$V=(W+C/S_C+1/(1-P)*ca/S_{ca})*1/1000$
0.98=(163.4+430/3.12+1/(1-0.328)*ca/2.8)*1/1000
Ca = 1118.021kg/m^3
MIX PROPORTION:

Water	cement	Fine aggregate	Coarse aggregate
163.4kg/m^3	430kg/m^3	516kg/m^3	1118kg/m^3
0.55	1	1.2	2.6

TABLE 4.7

4.4 EXPERMENTAL PROGRAM:
FOR M20 GRADE OF CONCRETE:

SL.NO	DESCRIPTION	MIX PROPORTION	W/C	GGBS	NO.OF CUBES
1	PLAIN	1:2.0:4.0	0.55	-	09
2	10%GGBS	1:2.0:4.0	0.55	10%	09
3	20%GGBS	1:2.0:4.0	0.55	20%	09
4	30%GGBS	1:2.0:4.0	0.55	30%	09
5	40%GGBS	1:2.0:4.0	0.55	40%	09

TABLE 4.8

FOR M40 GRADE OF CONCRETE:

SL.NO	DESCRIPTION	MIX PROPORTION	W/C	GGBS	NO.OF CUBES
1	PLAIN	1:1.2:2.6	0.38	-	09
2	10%GGBS	1:1.2:2.6	0.38	10%	09
3	20%GGBS	1:1.2:2.6	0.38	20%	09
4	30%GGBS	1:1.2:2.6	0.38	30%	09
5	40%GGBS	1:1.2:2.6	0.38	40%	09

TABLE 4.9

4.5 EVALUATION OF STRENGTH EFFICIENCY FACTORS

4.5.1 INTRODUCTION

Traditionally, concrete has been characterized by its compressive strength. Through the tremendous progress achieved over the last few years, high strength concrete was produced. However, for new concretes to solve some important engineering problems, many other properties had to be improved, thus leading to the production of high-performance concrete (HPC). The enhancement of two concrete properties basically required to identify a high performance concrete are rheological characteristics and durability. Even though these properties can be attained separately, but both properties are simultaneously achieved in HPC. A high-performance concrete which flows readily into places even in the presence of congested reinforcement, filling formwork eliminating the need for compaction and without undergoing any significant segregation.

Due to the densification of the matrix, mechanical properties considerably increased. Durability of concrete has increased because the permeability has been controlled by porosimetry modifications, thereby reducing the total porosity and pore range size, and closing all pore connections. It is not possible to produce HPC having improved rheological properties and durability using traditional concrete with OPC and normal aggregate proportioning. It is necessary to use supplementary cementitious products(SCM) and admixtures (mineral and chemical) of the latest generation.

It should be emphasized that appropriate mineral and chemical admixtures will produce HPC but they cannot, whatever the conditions , correct poor quality of materials, unsatisfactory proportioning of concrete and inappropriate setting and curing producers.

The use of GGBS combination as mineral admixtures in concrete is well accepted because of the possible strength and durability performance improvement in the concrete due to improved rheological and hardened properties. The presence work is an effort to quantify the 3,7 and 28-day cementitious efficiency of ground granulated blast furnace slang (GGBS) combination in concrete at various replacement levels.

The effect of the addition of GGBS on the strength of a concrete mix may be modeled by using a Cementing Efficiency Factor (k). The Cementing Efficiency Factor is defined as the ratio of the cementing efficiency of GGBS to the cementing efficiency of the cement to which the GGBS added. It was observed that this overall strength efficiency of GGBS concrete was found to be a combination of efficiency factor 'k_a' depending on the age and efficiency factor 'k_p' depending upon the percentage of GGBS replacement. This evaluation makes it possible to design GGBS concrete mix for a desired strength at any given percentage of replacement.

$k=k_a + k_p$

k= overall strength efficiency factor

k_a= efficiency factor depending on age

k_p = efficiency factor depending on percentage of replacement

Blast furnace slag cements are in use for a reasonable long period due to the overall economy in their production as well as their improved performance characteristics in aggressive environments.

It was reported that with the same content of cementitious material (the total weight of Portland cement plus GGBS), similar 28-day strengths to Portland cement will normally be achieved when using up to 40 per cent GGBS. In our studies it is observed that the strength gain in concrete, at 28 days, is maximum at 20% replacement of GGBS.

Research work till date suggests that GGBS improve many of the performance characteristics of the mix such as strength, workability, permeability, durability, and corrosion resistance. Due to the fact that the fineness of GGBS is far higher than OPC (e.g. GGBS: 420-450m^2/kg, OPC:330-350 m^2/kg), the GGBS-OPC mix has lower earlier strength, poor durability and ease of bleeding at early stage but continues to gain strength over a longer period. GGBS mix gains strength more steadily than equivalent concrete made with Portland cement.

For the same 28-day strength, a GGBS concrete will have lower strength at early ages but its long-term strength will be greater. The reduction in early-strength will be most noticeable at high GGBS levels and low temperatures.

The use of GGBS as partial replacement of cement enhances the long-term durability of concrete in terms of resistance to chloride attack, sulphate attack and alkali-silica reaction resulting which the structure would remain to be serviceable cost saving. Apart from the consideration of long-term durability, the use of GGBS results in the reduction of heat of hydration so that the problem of thermal cracking is greatly reduced. The enchanted control of thermal movement also contributes to better and long-term performance of concrete.

From the present research studies, an effort is made to understand the fact that the optimized GGBS combination enhances the strength and durability performance of concrete. So it is felt that efficiency concept can be used to understand the behavior of GGBS combination as admixture in concrete when compared to OPC alone.

In this study, the behavior of GGBS in concrete has been studied by evaluating the efficiency of GGBS combination in concrete at different percentages of replacement at 3,7,28 days. This is achieved by evaluating overall efficiency factor "k" for GGBS with different replacement dosages at 3,7,28-day compressive strength on M20 and M40mixes.

4.6 ESTIMATION OF STRENGTH EFFICIENCY FACTOR,K

A number of empirical expression are frequently used to describe or predict the strength of normal hardened cement paste. The more well-known expression of Bolomey's relates strength and water/cement ratio.

This Bolomey's empirical expression frequently used to predict the strength of concrete is theoretically well justifies when applied to hardened concrete. Strength data from experiments on normal hardened cement paste are frequently reported in the literature to be well fitted by Bolomey's empirical expression.

The concept of efficiency can be used for comparing the relative performance of GGBS when incorporated into concrete performance. Efficiency factors found from Bolomey's strength equation are used to describe the effect of the GGBS combination replacement in concrete in the enhancement of strength and durability characteristics. This factor will give only an indication of the added materials effect on concrete strength, since it does not distinguish between filler effect and/or chemical reactions.

The well known Bolomey's equation often used to relate strength and water/cement ratio is:

S=A[(C/W)]+B ……. (1)

S is the compressive strength in MPa,
C is the cement content in kg/m^3
W is the water content in kg/m^3
A and B are Bolomey's coefficients / or constants

Equation (1) has been shown to practically reduce to following two equations

S=A [(C/W) - 0.5] ……. (2)

S=A [(C/W) + 0.5] ……. (3)

From these above two normalized which represent two ranges of concrete strength based on the change in slope when P/W (powder-water ratio) is plotted against strength. However , it is found that the equation (2) is useful for most of the represent day concretes when an analysis was done on test results available and also the extensive data published by Larrard also mentions this equation in his famous book, on 'Concrete Mix Proportioning-A scientific approach'. Therefore, equation (2) can be generally used for re-proportioning GGBS RHA SCC.

The value of constant 'A' can be found out for the given concrete ingredients, by considering a concrete mix of any w/c ratio.

For structural concrete,Equation (1) can be simplified as

S= A [(C/W – 0.5)] …… (4)

A strength efficiency factor, k , can then be computed using modified Bolomey's equation.

S= A [((C+Kg)/W) – 0.5] …… (5)

Where S is the compressive strength in MPa,
C is the cement content in kg/m^3 **,**
G is the amount of GGBS replaced bwc.
W is the water content in kg/m^3 and k denotes efficiency factor of GGBS and RHA combination

By knowing the amounts of 'C', 'G', 'W' and the strength 'S' achieved for each GGBS dosage replacement from the finally arrived experimental values, efficiency factor "k" has been computed for each of the replacement dosages. Thus , W/(C+ kG) is the water/effective binder ratio and kG is the equivalent cement content of GGBS combination. 'GGBS/CEMENT ratio' is an important factor for determining the efficiency of GGBS inconcrete. So GGBS proportioning is arrived at based on the strength data experiments on different GGBS CEMENT Mixes.

Efficiency factors found from this strength equation are usedf to describe the effect of the GGBS replacement. Efficiency factors are generally used to describe the impact of GGBS replacement on the compressive strength and durability properties of hardened mixes. This factor describes the mineral admixture's ability to act as cementing material recognizing that mineral admixture's contribution to concrete strength which comes mainly from its ability to react with free calcium hydroxide produce during cement hydration(Pozzolanic Reaction (PR)). The rate of this reaction, when compared to cement hydration rate (CHR) determines the value of k.

When k=1, both PR and CHR would be same and the water-binder ratios of concretes with and without MA couyld be almost same. When k<1 PR would be slower than CHR and for equal strengths, the water-binder ratio of concrete with mineral admixture need to be less than that of concrete without mineral admixtures and also, at same water-binder ratio, the strength of concrete with mineral admixture would be less than that of concrete without mineral admixture. In this case, the mineral admixture is less efficient than Portland cement in imparting strength to concrete.

The GGBS has generally k<1 at early ages and k would reach a value of unity at later ages.

When k>1, PR would be faster than CHR and for equal strengths, the water-binder ratio of concrete with mineral admixture would be more than that of concrete without mineral admixture. However, at similar water-binder ratios, the strength of concrete with mineral admixture would be more than that of concrete without mineral admixture. In this case, the mineral admixture is more efficient that Portland cement in imparting strength to concrete.

GGBS combinations have generally k>1 even C are more than that of GGBS at similar water-binder ratios.

Computation of Bolomey's Coefficient (A) for Bolomey's Strength equation

Based on the compressive strength of the controlled mix, Bolomey's Coefficient 'A' value was calculated using Bolomey equation. Then Efficiency factors for GGBS mixes were determined for various percentage replacement levels.

Compute Bolomey Coefficient 'A' value from the equation (4) by substituting values for S,C and W at 0% replacement for M20 and M40 grades at 3,7 and 28 days. Using computed 'A' value, the strength efficiency factors 'k' at all ages for all percentages replacement levels of GGBS combination in concrete are calculated.

5.1 RESULTS OF THE EXPERIMENTAL INVESTIGATIONS:

Varying the percentage of GGBS were tried to study the effect of partial replacement of cement on the properties of concrete. Cement is replaced by GGBS in percentages of' 10,20,30 and 40% by weight. With cement, natural sand, coarse aggregate, GGBS constituting the basic materials, number of cubes were cast varying the percentages of GGBS. The mix design for M20 grade concrete and M40 grade concrete was done in accordance with IS method and the same was adopted for the work. Therefore, concrete with and without GGBS replacement was tested for cube compressive strength.

Based on the compressive strength of the controlled mix, Bolomey's Coefficient 'A' value was calculated using Bolomey equation. Then Efficiency factors for GGBS mixes were determined for various percentage replacement levels

5.2 DISCUSSION OF TEST RESULTS

Based on the studies done on blended concretes the following discussions are presented in the succeeding paragraphs:

5.2.1 EFFECT OF GGBS ON COMPRESSIVE STRENGTH FOR M20 GRADE CONCRETE:

It is seen that for plain concrete the 28-day compressive strength has maintained more the target concrete strength even upto 20% GGBS replacement. However, it is seen from table 5.1, that for plain concrete with 20% replacement of cement by GGBS, the compressive strength is 23.68 Mpa, which is in between the target mean strength of M20 concrete. Hence from economy consideration, cement can be replaced up to 20% by GGBS.

Results of 3 days compressive strength of cubes of plain and GGBS are shown in table: 5.1. It is observed that strength is gradually decreased from 17.861N/mm^2 to 10.71N/mm^2 at 40% replacement of cement with GGBS. It is graphically represented in fig no: 5.1

Results of 7 days compressive strength of cubes of plain and GGBS are shown in table: 5.1.It is observed that strength is 18.6N/mm^2 at plain and gradually decreased from 18.31N/mm^2 to 13.56N/mm^2 at 10% to 40% replacement of cement with GGBS respectively .It is graphically represented in fig no:5.2

Results of 28 days compressive strength of cubes of plain and GGBS are shown in table: 5.1.It is observed that strength is gradually increased from 23.12N/mm^2 to 24.56 at 10% and 23.68N/mm^2 at 20% and decreased to 15.69N/mm^2 at 40% replacement of cement with GGBS .It is graphically represented in fig no:5.3

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5.2.2 EFFECT OF GGBS ON COMPRESSIVE STRENGTH FOR M40 GRADE CONCRETE:

It is seen that for plain concrete the 28-day compressive strength has been decreasing upto 40% GGBS replacement. However, it is seen from table 5.2, that for plain concrete with 40% replacement of cement by GGBS, the compressive strength is 20.92 Mpa, which is in between the target mean strength of M40 concrete. Hence from economy consideration, cement can be replaced up to 40% by GGBS.

Results of 3 days compressive strength of cubes of plain and GGBS are shown in table: 5.2.It is observed that strength is gradually increasing from 26.59N/mm^2 to 28.76N/mm^2 at 10% replacement of cement with GGBS and then a gradual decrease of 20.92N/mm^2. It is graphically represented in fig no: 5.4

Results of 7 days compressive strength of cubes of plain and GGBS are shown in table: 5.2. It is observed that strength is 36.18N/mm^2 at plain and gradually decreased from 34.88N/mm^2 to 15.69N/mm^2 at 10% to 40% replacement of cement with GGBS respectively .It is graphically represented in fig no: 5.5

Results of 28 days compressive strength of cubes of plain and GGBS are shown in table: 5.2.It is observed that strength is gradually decreasing from 39.12N/mm^2 to 20.92N/mm^2 at 10% to 40% replacement of cement with GGBS .It is graphically represented in fig no:5.6

W/(C+G) Ratios of M20 grade concrete:

At various replacement percentages of GGBS

Mix No.	A-1	A-2	A-3	A-4	A-5
GGBS % (bwc)	0	10	20	30	40
Cement Kg	330	297	264	231	198
Water Kg	181.5	181.5	181.5	181.5	181.5
GGBS Kg	0	33	66	99	132

W/(C+G) Ratios of M40 grade concrete:

At various replacement percentages of GGBS

Mix No.	A-1	A-2	A-3	A-4	A-5
GGBS % (bwc)	0	10	20	30	40
Cement Kg	430	387	344	301	258
Water Kg	163.4	163.4	163.4	163.4	163.4
GGBS Kg	0	43	86	129	172

Computations of Bolomey's Coefficient (A) from Bolomey's equation for M 20 and M 40 grade Mixes

Age in Days	M20
3	A=13.56
7	A=14.11
28	A=17.53

Age in Days	M40
3	A=12.47
7	A=16.97
28	A=19.94

5.3 RESULTS OF COMPRESSIVE STRENGTH OF CUBES[M20]:

Days	Plain	10%G	20%G	30%G	40%G
3 days	17.87	15.11	12.25	11.72	10.71
7 days	18.60	18.31	17.53	15.33	13.56
28 days	23.12	24.56	23.68	19.62	15.69

W/(C+G) Ratios of M20 grade concrete:

At various replacement percentages of GGBS

Mix No.	A-1	A-2	A-3	A-4	A-5
GGBS % (bwc)	0	10	20	30	40
Cement Kg	330	297	264	231	198
Water Kg	181.5	181.5	181.5	181.5	181.5
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W/(C+G) Ratios of M40 grade concrete:

At various replacement percentages of GGBS

Mix No.	A-1	A-2	A-3	A-4	A-5
GGBS % (bwc)	0	10	20	30	40
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TABLE:5.1

5.4 RESULTS OF COMPRESSIVE STRENGTH OF CUBES[M40]:

Days	Plain	10%G	20%G	30%G	40%G
3 days	26.59	28.76	23.87	17.87	12.89
7 days	36.18	34.88	31.29	20.17	15.69
28 days	42.51	39.12	37.67	23.38	20.92

TABLE:5.2

5.5 EFFICIENCY FACTORS FOR M20GRADE CONCRETE MIX.

Days	10%G	20%G	30%G	40%G
3 days	0.28	0.21	0.18	0.11
7 days	0.68	0.48	0.30	0.21
28 days	1.21	0.95	0.43	0.32

5.6 EFFICIENCY FACTORS FOR M40GRADE CONCRETE MIX.

Days	10%G	20%G	30%G	40%G
3 days	0.45	0.32	0.26	0.19
7 days	0.88	0.40	0.37	0.32
28 days	1.45	1.05	0.62	0.41

4.5 EVALUATION OF STRENGTH EFFICIENCY FACTORS

4.5.1 INTRODUCTION

Traditionally, concrete has been characterized by its compressive strength. Through the tremendous progress achieved over the last few years, high strength concrete was produced. However, for new concretes to solve some important engineering problems, many other properties had to be improved, thus leading to the production of high-performance concrete (HPC). The enhancement of two concrete properties basically required to identify a high performance concrete are rheological characteristics and durability. Even though these properties can be attained separately, but both properties are simultaneously achieved in HPC. A high-performance concrete which flows readily into places even in the presence of congested reinforcement, filling formwork eliminating the need for compaction and without undergoing any significant segregation.

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It should be emphasized that appropriate mineral and chemical admixtures will produce HPC but they cannot, whatever the conditions , correct poor quality of materials, unsatisfactory proportioning of concrete and inappropriate setting and curing producers.

The use of GGBS combination as mineral admixtures in concrete is well accepted because of the possible strength and durability performance improvement in the concrete due to improved rheological and hardened properties. The presence work is an effort to quantify the 3,7 and 28-day cementitious efficiency of ground granulated blast furnace slang (GGBS) combination in concrete at various replacement levels.

The effect of the addition of GGBS on the strength of a concrete mix may be modeled by using a Cementing Efficiency Factor (k). The Cementing Efficiency Factor is defined as the ratio of the cementing efficiency of GGBS to the cementing efficiency of the cement to which the GGBS added. It was observed that this overall strength efficiency of GGBS concrete was found to be a combination of efficiency factor 'k_a' depending on the age and efficiency factor 'k_p' depending upon the percentage of GGBS replacement. This evaluation makes it possible to design GGBS concrete mix for a desired strength at any given percentage of replacement.

$k=k_a + k_p$

k= overall strength efficiency factor

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From the present research studies, an effort is made to understand the fact that the optimized GGBS combination enhances the strength and durability performance of concrete. So it is felt that efficiency concept can be used to understand the behavior of GGBS combination as admixture in concrete when compared to OPC alone.

In this study, the behavior of GGBS in concrete has been studied by evaluating the efficiency of GGBS combination in concrete at different percentages of replacement at 3,7,28 days. This is achieved by evaluating overall efficiency factor "k" for GGBS with different replacement dosages at 3,7,28-day compressive strength on M20 and M40mixes.

4.6 ESTIMATION OF STRENGTH EFFICIENCY FACTOR,K

A number of empirical expression are frequently used to describe or predict the strength of normal hardened cement paste. The more well-known expression of Bolomey's relates strength and water/cement ratio.

This Bolomey's empirical expression frequently used to predict the strength of concrete is theoretically well justifies when applied to hardened concrete. Strength data from experiments on normal hardened cement paste are frequently reported in the literature to be well fitted by Bolomey's empirical expression.

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GGBS when incorporated into concrete performance. Efficiency factors found from Bolomey's strength equation are used to describe the effect of the GGBS combination replacement in concrete in the enhancement of strength and durability characteristics. This factor will give only an indication of the added materials effect on concrete strength, since it does not distinguish between filler effect and/or chemical reactions.

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A and B are Bolomey's coefficients / or constants

Equation (1) has been shown to practically reduce to following two equations

S=A [(C/W) - 0.5] ……. (2)

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From these above two normalized which represent two ranges of concrete strength based on the change in slope when P/W (powder-water ratio) is plotted against strength. However , it is found that the equation (2) is useful for most of the represent day concretes when an analysis was done on test results available and also the extensive data published by Larrard also mentions this equation in his famous book, on 'Concrete Mix Proportioning-A scientific approach'. Therefore, equation (2) can be generally used for re-proportioning GGBS RHA SCC.

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For structural concrete,Equation (1) can be simplified as

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A strength efficiency factor, k , can then be computed using modified Bolomey's equation.

S= A [((C+Kg)/W) – 0.5] …… (5)

Where S is the compressive strength in MPa,

C is the cement content in kg/m^3 **,**

G is the amount of GGBS replaced bwc.

W is the water content in kg/m^3 and k denotes efficiency factor of GGBS and RHA combination

By knowing the amounts of 'C', 'G', 'W' and the strength 'S' achieved for each GGBS dosage replacement from the finally arrived experimental values, efficiency factor "k" has been computed for each of the replacement dosages. Thus , W/(C+ kG) is the water/effective binder ratio and kG is the equivalent cement content of GGBS combination. 'GGBS/CEMENT ratio' is an important factor for determining the efficiency of GGBS inconcrete. So GGBS proportioning is arrived at based on the strength data experiments on different GGBS CEMENT Mixes.

Efficiency factors found from this strength equation are usedf to describe the effect of the GGBS replacement. Efficiency factors are generally used to describe the impact of GGBS replacement on the compressive strength and durability properties of hardened mixes. This factor describes the mineral admixture's ability to act as cementing material recognizing that mineral admixture's contribution to concrete strength which comes mainly from its ability to react with free calcium hydroxide produce during cement hydration(Pozzolanic Reaction (PR)). The rate of this reaction, when compared to cement hydration rate (CHR) determines the value of k.

When k=1, both PR and CHR would be same and the water-binder ratios of concretes with and without MA couyld be almost same. When k<1 PR would be slower than CHR and for equal strengths, the water-binder ratio of concrete with mineral admixture need to be less than that of concrete without mineral admixtures and also, at same water-binder ratio, the strength of concrete with mineral admixture would be less than that of concrete without mineral

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Computation of Bolomey's Coefficient (A) for Bolomey's Strength equation

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Compute Bolomey Coefficient 'A' value from the equation (4) by substituting values for S,C and W at 0% replacement for M20 and M40 grades at 3,7 and 28 days. Using computed 'A' value, the strength efficiency factors 'k' at all ages for all percentages replacement levels of GGBS combination in concrete are calculated.

GRAPHS OF COMPRESSIVE STRENGTH OF CUBES

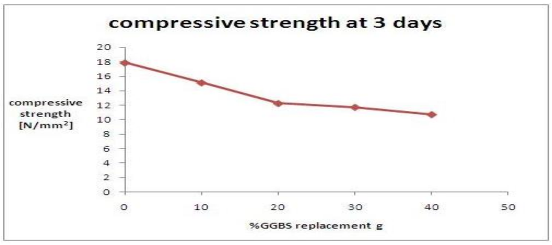

Fig 5.1 Variation of Compressive strength with % of GGBS replacement for M20 at 3 days.

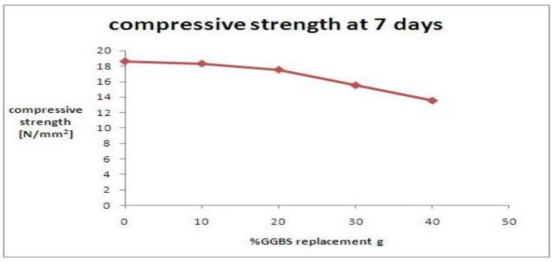

Fig 5.2 Variation of Compressive strength with % of GGBS replacement for M20 at 7 days.

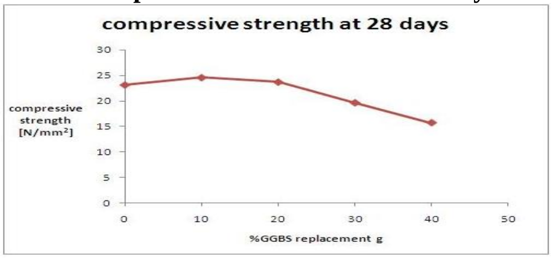

Fig 5.3 Variation of Compressive strength with % of GGBS replacement for M20 at 28 days.

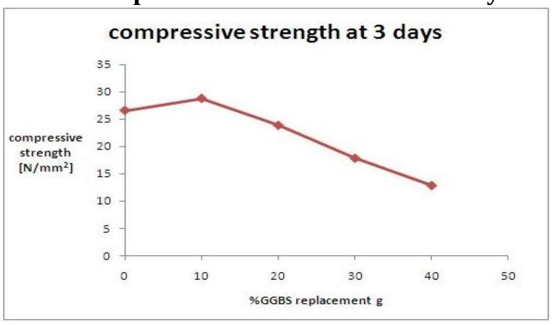

Fig 5.4 Variation of Compressive strength with % of GGBS replacement for M40 at 3 days.

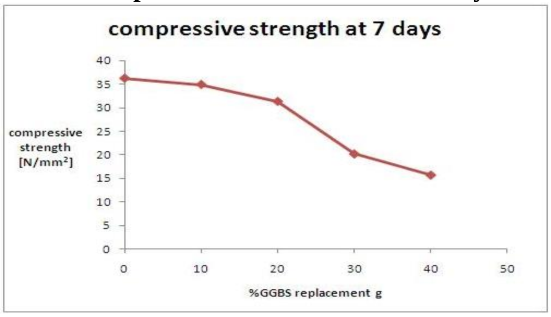

Fig 5.5 Variation of Compressive strength with % of GGBS replacement for M40 at 7 days.

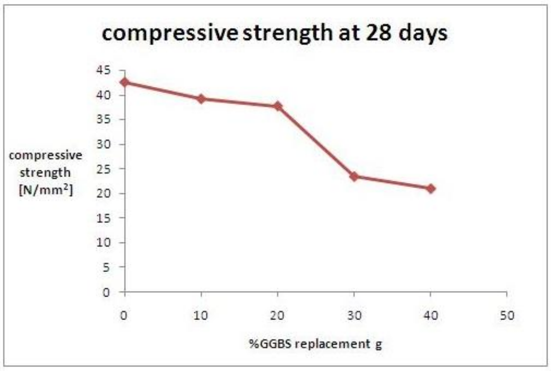

Fig 5.6 Variation of Compressive strength with % of GGBS replacement for M40 at 28 days.

GRAPHS OF STRENGTH EFFICIENCY FACOR OF CUBES

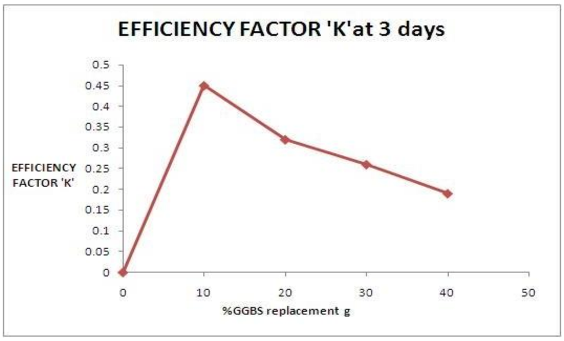

Fig 5.7. Relation between Efficiency Factor 'K' and % of GGBS replacement for M20 at 3 days

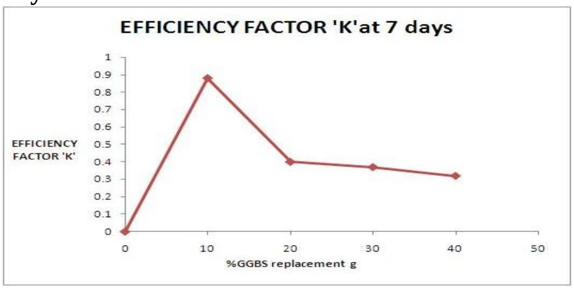

Fig 5.8. Relation between Efficiency Factor 'K' and % of GGBS replacement for M20 at 7 days

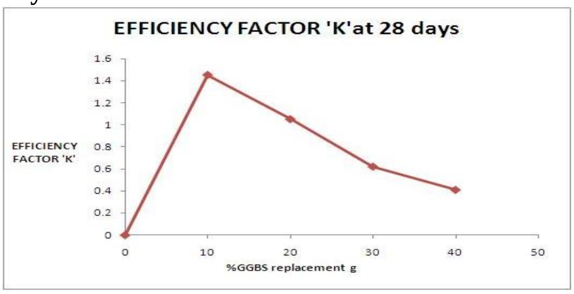

Fig 5.9. Relation between Efficiency Factor 'K' and % of GGBS replacement for M20 at 28 days.

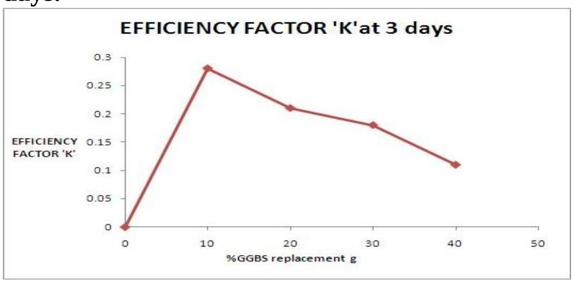

Fig 5.10. Relation between Efficiency Factor 'K' and % of GGBS replacement for M40 at 3 days.

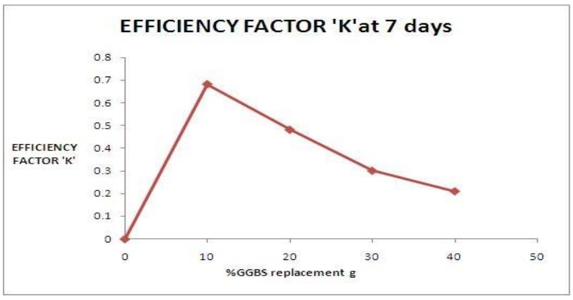

Fig 5.11. Relation between Efficiency Factor 'K' and % of GGBS replacement for M40 at 7 days.

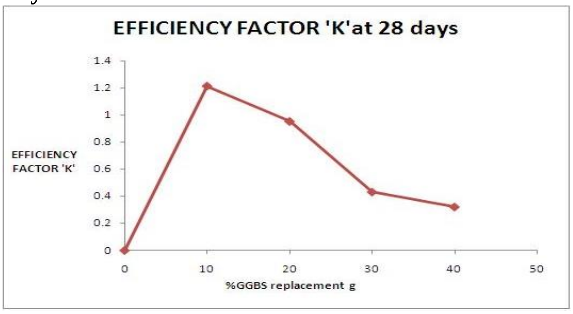

Fig 5.12. Relation between Efficiency Factor 'K' and % of GGBS replacement for M40 at 28 day

CONCLUSION

- The compressive strength for M20 grade of concrete was found to maximum at 20% replacement of cement with GGBS.
- The compressive strength for M40 grade of concrete was found to maximum at 10% replacement of cement with GGBS.
- The efficiency factor for M20 grade of concrete was found to be maximum at 10% replacement of cement with GGBS.
- The efficiency factor for M40 grade of concrete was found to be maximum at 10% replacement of cement with GGBS.

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