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An Investigation on Combined Replacement of Cement by GGBS and Natural Sand by Slag Sand on Strength of Concrete

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***Abstract*: The utilization of waste materials from the industries has been continuously emphasized in the research work. In production of concrete, these wastes materials can be used as replacement to natural materials. GGBS (ground granulated Blast furnace slag) and slag sand are waste materials from steel and iron manufacturing industries. These waste material has plenty of availability and have disposal problem. Also these materials have large environmental problems. The present work is to use GGBS and Slag sand as partial replacement of ordinary Portland cement and river sand respectively. M20 grade of concrete with W/C 0.5 is carried out with two percentages of cement replacement by GGBS i.e., 35% GGBS and 45% GGBS. Along with this the slag sand is varied from 0% to 100% in step of 20%. In first variation, 35%GGBS is replaced by cement and slag sand is varied as 0%, 20%, 40%, 60%, 80% and100%. Similarly, in second variation 45% GGBS is replaced with cement and slag sand is varied as 0%, 20%, 40%, 60%, 80%, and 100%. For all mixes compressive strength, split tensile and flexural strength are determined at different days of curing. The strength of cube specimens varied from 21.55N/mm² to 33.61N/mm². The optimum strength of concrete mix A4 (30.19N/mm²) having 35%GGBS and 60% slag sand and strength of concrete mix B3 (33.16 N/mm²) having 45% GGBS and 40% slag sand replacements was considered to cast reinforced concrete beams. The beams are tested for flexure, under two-point loading condition. Different parameters were investigated.**

***Keywords*: slag, ggbs, cement, blast, fine aggregate, sand.**

1. Introduction

Concrete is the largest man made material on earth. It contains cement, fine aggregate, coarse aggregate & water. Among these 70% to 75% volume of concrete is occupied by coarse and fine aggregate, rest of about 25% to 30% is cement and water in form of cement paste. Beside these elements, chemical and mineral admixtures are added to enhance the properties of concrete. Chemical admixtures are added mainly for workability and to increase Initial Setting time. Also for high strength and high grades of concrete the chemical admixture becomes an essential component.

Mineral admixtures are added for so many reasons. Firstly, the mineral admixtures are the waste material product which has the problem of disposal, secondly these materials have cementitious property which helps in replacing the natural elements. Thirdly the cost of construction is reduced by use of mineral admixture. Therefore, attempts are continuous going on for using these waste material from industries. Cement is the third largest material used by human beings after food and water as per WHO (World health Organization). Around 230 million tons of cement is produce only in India. The gases and dust release during production of cement creates serious impact on the environment and greenhouse gases are rapidly growing in environment and the effect of climatic changes can be easily seen now a days. Many countries are trying to reduce the production of cement. America is fastest country which reduces around 36.5% cement production. GGBS having pozzolonic properties can be used as the replacement of cement. In India, we have been continuously using the natural available materials. The global consumption is also very high due to extensive use of concrete. In developing countries like India, the demand of natural sand is quite high due to the rapid infrastructural development. In India, the natural sand deposits are being depleted continuously which causes serious threat to the environment as well as society.

A. Ground Granulated Blast Furnace Slag

GGBS is a nonmetallic by-product obtained by rapid chilling/quenching the molten slag from the blast furnace by means of water or air. During production of iron or steel, the iron ore along with fluxes and coke is charged into the blast furnace. The coke is combusted at around 1500ºC to produce carbon monoxide, which reduce ore into the iron products. Fluxing agents separate slag & impurities. Slag is obtained as floating agent on top. This is periodically taken off and collected for manufacturing GGBS. The slag which is collected from top is send to undergo slag granulated process or air cooling process.

Air Cooling Slag: The molten slag is cooled slowly by natural cooling or by spraying water. The slag obtained is of crystalline, rock like dense and hard. The assembling of crystalline form gives Ca-Al-Mg silicates. This is suitable as a coarse aggregate.

Granulated Slag: It is obtained by quenching the molten slag at below 800ºc by means of high water pressure jets. The slag obtained is of vitreous, granular or glassy shape structure. The size of the granular is varying and is suitable for using as a fine aggregate. Upon further processing, the granulated slag is formed as a powder, which can be used as cement replacement.

Applications and advantages of GGBS:

- The use GGBS in Concrete will definitely going to give required strength.
- The slag has high load bearing carrying. Therefore, in structural components GGBS can be replaced in concrete with assured strength.
- Slag has no risk of alkali aggregate reaction.
- Slag does not contain any clay and organic impurities.
- Slag cement helps in saving the cement of around 60% to 70%.
- The slag has low heat of hydration and also have high chemical durability.

B. Slag sand

Natural sand is depleting day by day. Some of the disadvantages of depletion of natural river bed are as follows:

- Due to continuous extraction of natural sand, the river bed goes down. The water retaining strata is depleting. Hence water storage capacity is reduced.
- The Banks near river slides due to over extraction of sand. The vegetation near river bed also get reduced.
- The aquatic life gets disturbed.
- Water table get lowered, etc.

1) Chemical composition of slag sand

The primary components are limestone, silica, alumina and glass. The approximate percentage of chemical composition present in slag sand are given below:

Table 1
Chemical composition of slag sand

Constituents	Approximate percentage(%)
Cao	30-45
SiO_2	30-38
Al_2O_3	15-25
Fe_2O_3	0.5-2.0
MgO	4.0-17.0
MnO_2	1.0-5.0
Glass	85-95
Specific gravity	2.0-2.9

Thus the slag sand having the components which are good for concrete. Therefore, slag sand is used in this project work as a replacement of natural sand.

Applications of slag sand:

- Replacement of natural sand by slag sand is the major application of slag sand.
- The replacement of slag sand upto100% gives good results from previous research work. Thus for in availability of natural sand, slag sand is the ideal material.
- The structural components such as beams and slabs can be made by slag sand.
- In road works, the slag sand is using as complete replacement for cement concrete roads.
- PWD (Public works department) of Karnataka state is using slag sand. The road work and for other buildings the slag sand is completely replacing. Thus natural sand is saving.
- The cost of construction is reduced to a large extent.

C. Aim of the present study

- To reduce the use of cement.
- To utilize the waste material which can give desired strength.
- To save natural sand which is already in shortage.
- GGBS in powder form and slag in fine aggregate form helps in replacing cement and fine aggregate respectively. Thus the natural sand is saving and cement production is reduced.
- By replacing two components the cost of the construction is reduced.
- To compare the strength of concrete using waste material.

2. Objective and scope of present study

Objective of the present study:

This project work is to emphasized on the replacement of cement and Natural sand. Cement is replaced by GGBS and Natural sand is replacing with slag sand. Both these materials are easily available from Jindal steel industry, Bellary. The cost of these materials is also less. In this project work, the cement is replaced with GGBS of two percentages i.e,35% and 45%. These percentages are obtained by trial and error by carrying various slump test. The slag sand of 100% replacement is varied with GGBS percentages as 10%, 20%, 30%, 35%, 40%, 45% and 50%. The required slump is obtained in the range of 30% to 50%. Therefore 35% and 45% GGBS is chosen for cement replacement. Thus for 35% GGBS, the slag sand is varied from 0%% to 100% by 20%, variation, i.e,0%, 20%, 40%, 60%, 80% and 100%. Similarly, 45% GGBS replaced with cement, and slag sand is varied as 0%, 20%, 40%, 60%, 80%, and 100% as replacement of natural sand. This will have called as test specimen. Mix design is as per IS: 10262:2009. For each mix, 6 cubes, 3 cylinder and 3 prisms is going to cast. The casted test specimen is keeping in water tank for 7, 28 days respectively. Cubes are testing at 7 and 28 days, prism and cylinder are at 28 days. After curing, the test specimens and control specimen (conventional concrete) is testing. The optimum percentage of replacement of GGBS and slag sand is noticed and compared with conventional concrete.

Based on the optimum percentage, the beams of size (150x150x700) mm is going to cast. This beams will again test after 28 days of curing. The beams are testing in flexure under

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two-point loading. The load deflection characteristics of beams is noticed. Different parameters such as experimental and theoretical Cracking and ultimate moments are compare. Also the co-relationship between split tensile strength and flexural strength is obtain along with co-relation equation and co-relation co-efficient.

Objective of the present study:

The present study is to replaced cement and natural sand by GGBS and slag sand respectively. The replacement can give many scope for construction purpose. Some of the advantages and scope of this study are:

- Cement utilization can be reduced upto35%to 45%. Cement production is reduced, which is good for environment.
- GGBS and slag sand have problem of disposal. This problem for future is also reduced.
- Natural sand can be saved to a large extent. In future natural sand can be available easily which is now depleting very rapidly.
- Cost of cement is increasing very fast. Using slag cement or replacement of GGBS in cement can reduced the cost of cement.
- Similarly cost of natural sand is also very high and now only there is a large demand of natural sand. In Future, slag sand takes the place of natural sand.
- From this project work, the optimum percentage of replacements are obtained as35% GGBS and 60% slag sand and as-45%GGBS and 40% slag sand. Thus the combined effect of replacement reduces the use of cement and Natural sand to a large extent.
- The replacement of coarse aggregate along with this project work will again be an economical by many folds.
- If 100% replacement of slag sand along with 50% replacement of GGBS and 50% replacement of coarse aggregate is done, this will be a scope for future study. If this combination gives good results, the Cost as well as saving of Natural materials can be up to 50% to 60%.

A. Experimental programme

Materials, preparation and testing

The performance of concrete depends on various parameters such as physical properties of ingredients, mix proportion, water cement ratio, compaction factor, quality control, and period of curing. The material used in this investigation are cement, natural sand, coarse aggregate. GGBS, slag sand and water. To determine the physical properties of materials various tests specified by the Indian Standard were conducted and suitability for use were checked.

1) Cement

Cement is the material which is possess very good adhesive and cohesive properties which make a bond with other material to form compact mass. Higher the grade higher the strength of concrete and better packing properties. In this project work, OPC 53 grade cement is used. The physical and chemical properties of cement is shown in below tables:

Ground granulated blast furnace slag

In this work, GGBS is added in two varying percentages: 35% and 45%. The chemical and physical properties of GGBS is shown in below table:

Table 4
Chemical composition of GGBS

Constituents	Approximate Percentage (%)
Sio_2	34.4%
Al_2O_3	21.0%
Fe_2O_3	0.25%
Cao	33.2%
K_2O	0.39%
Mgo	10.0%
SO_3	0.7%
Na_2O	0.35%

Table 2
Physical properties of OPC

S. No.	Properties	Chart Result	Requirements of IS : 12269-1987
1	Specific Gravity	3.03	
2	Setting time in minutes Initial setting time Final setting time	75min. 170min.	Should not be less than 30min Should not exceed 600min.
3	Soundness :By Le Chatarlier mould	1.0mm	Should not exceed 10mm
4	Finesses (specific surface)	$303m^2/kg$	Should not be less than $225m^2/kg$
5	Normal consistency	31%	
6	Compressive Strength, 28 days	58.388Mpa	Should not be less than 53Mpa

Table 3
Chemical Properties of OPC

S. No.	Properties	Chart Result	Requirements of I.S.12269-1987
1	Lime Saturation Factor (L.S.F)	0.92	Should not be less than 0.8 and not exceed 1.02
2	Alumina Iron ratio	1.16	Should not be less than 0.66
3	Loss on Ignition (LOI)	1.29%	Should not exceed 4%
4	Insoluble Residue(I.R.)	0.84%	Should not exceed 2%
5	Sulphuric Anhydride (SO_3)	2.03%	Should not exceed 3%
6	Magnesia (MgO)	1.16%	Should not exceed 6%
7	Alkalies	0.46%	Should not exceed 0.6%
8	Chlorides	0.0162%	Should not exceed 0.05%

2) Fine Aggregate

Fine aggregate plays an important role in concrete. It manages to fill the voids between the paste and the coarse aggregate. Sand should be well graded as from particle point of view and fill the voids to give dense concrete.

3) Test on slag sand

Slag Sand/Artificial Sand /Steel Slag / M Sand are the names of artificial Sand. They are obtained from industrial waste products of steel and iron ore. The slag sand used in this project having chemical properties and physical properties are shown below:

4) Coarse Aggregate

In this Investigation Coarse Aggregate used is 20mm down size crushed angular shape is used as per IS: 10262-2009 Codal provisions.

5) Water (IS: 456-2000)

Water used for mixing should be free from injurious amount of deleterious materials. Potable water is generally considered satisfactory for mixing. In the present work potable tap water is used. The experimental Programme consisted of casting and testing of 78 cubes, 39 cylinders, 39 prisms. Cubes are Casted and tested at 7 and 28 days, cylinders and prisms are tested for

Table 5
Sieve analysis of natural sand

S. No.	I.S.Sieve size	Weight retained (gm)	Correct ion	Corrected weight	Cumulative % wt. retained	Cumulative weight retained	Cumulative % passing
1	4.75mm	18	+0.36	18.36	1.836	1.836	98.164
2	2.36mm	22	+0.44	22.44	2.244	4.08	95.92
3	1.18mm	209	+4.18	213.18	21.318	25.398	74.602
4	600µ	320	+6.40	326.40	32.64	58.038	41.962
5	300µ	361	+7.22	368.22	36.822	94.86	5.14
6	150µ	50	+1.0	51.00	5.1	99.960	0.04

Table 6
Properties of Fine Aggregate (Natural Sand)

Fineness modulus of fine aggregate	Cumulative % wt retained / 100
Fineness modulus	284.172/100=2.84
Specific gravity	2.63
Water absorption	1.2%
Moisture content	2.0%
Bulk density	1616.8 kg/m^3
Grading	well graded (zone II)

Table7
Chemical composition of slag sand

Constituents	Approximate percentage (%)
Cao	30-45
SiO_2	30-38
Al_2O_3	15-25
Fe_2O_3	0.5-2.0
MgO	4.0-17.0
MnO_2	1.0-5.0
Glass	85-95
Specific gravity	2.0-2.9

Table 8
Sieve analysis of fine aggregate (Slag Sand)

S. No.	I.S. Sieve size	Weight retained (gm)	Correction	Corrected weight	Cumulative % wt. retained	Cumulative weight retained	Cumulative % passing
1	4.75mm	14	+0.336	14.336	1.4336	1.4336	98.5664
2	2.36mm	22	+0.528	22.528	2.2528	3.6864	96.3136
3	1.18mm	320	+7.68	327.768	32.768	36.4544	63.5456
4	600µ	240	+5.76	245.76	24.576	61.0304	38.9696
5	300µ	327	+7.848	334.848	33.4848	94.5152	5.4848
6	150µ	53	+1.272	54.272	5.4272	99.9424	0.0576

Table 9
Properties of fine aggregate (Slag Sand)

Fineness modulus of fine agg.	Cumulative % wt. retained / 100
Fineness modulus	297.062/100=2.97
Specific gravity	2.61
Water absorption	3.0%
Moisture Content	1.01%
Bulk density	1288.935kg/m^3
Grading	well graded (zone II)

28 days. To study the structural behavior of concrete, the test specimen containing optimum percentages is going to cast beams and comparing with the conventional concrete beams. The Beams are testing under two-point loading under flexure after 28 days of curing.

B. Workability characteristics

1) Slump Cone Test

This is a test used extensively in site work all over the work. The slump test does not measure the workability of concrete although ACI 116R–90 describes it as a measure of consistency, but the test is very useful in detecting variations in the uniformity of a mix of given nominal proportions. The slump test is prescribed by IS:456-2000 and BS 1881 Part 102: 1983. The mould for the slump test is a frustum of a cone, 300 mm high. The size is standard by Indian Standard. The concrete is filled in 3 layers; each layer is tamped 25 times with 16mm tamping rod. The top surface concrete is removed. The cone is lifted immediately after filling. The decrease in the height of concrete is the measure of Slump. True Slump is that which makes the concrete to flow evenly. If one half of the cone is slides down, it is shear slump. If the concrete is totally fall down it is called collapse. For good concrete, true slump is recommended. If shear or collapse occurs, the test value is discarded.

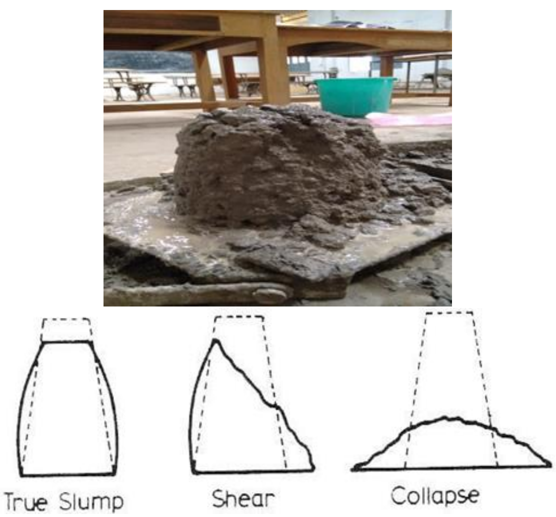

Fig. 1. Slump: True, Shear and Collapse

Table 10
Description of workability and magnitude of slump

Description of workability	Slump(mm)
No slump	0
Very low	5-10
Low	15 – 30
Medium	35 – 75
High	80 – 155
Very high	160 to collapse

2) Compaction factor test

The ratio of the density of partially compacted concrete to the density of the same concrete of fully compacted concrete is called compaction factor. The test of compaction factor is described in BS 1881: Part 103 :1993 and in ACI 211.3-75 (Revised 1987) (Reapproved 1992). The code permits the maximum size aggregate upto 40mm. The apparatus consists essentially of two hoppers, each in the shape of a frustum of cone, and one cylinder, the three being above one another. The hoppers have hinged doors at the bottom, as shown in figure. All inside surfaces are polished to reduce friction. The concrete is fully compacted in layers in cylinder and the weight is noted. Now the concrete is poured into the upper hopper filled with concrete, this being placed gently so that at this stage no work is done on the concrete to produce compaction. The bottom door of the hopper is then released and the concrete falls into the lower hopper. This hopper is smaller than the upper one and is, therefore, filled to overflowing, and thus always contains approximately the same amount of concrete in a standard size, this reduces the influence of the personal factor in filling the top hopper. The bottom door of the lower hopper is then released and the concrete falls into the cylinder. Excess concrete is cut by two floats slid across the top of the mould. The weight of cylinder containing partially compacted concrete is noted. Ratio of fully compacted concrete to partially compacted concrete will give compaction factor.

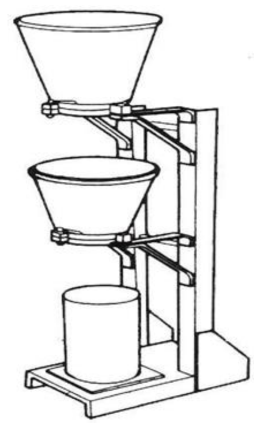
Fig. 2. Compaction factor tests apparatus

Table 11
Description of workability and compaction factor

Description of workability	Compaction factor	Corresponding slump mm
Very low	0.78	0-25
Low	0.85	25-50
Medium	0.92	50-100
High	0.952	100-175

3) Test on fresh concrete

Slump cone test and compaction factor test is carried out for each mix. The cement is replaced with GGBS of 35% along with slag sand variation from 0% to 100% in step of 20%. i.e., 0%, 20%, 40%, 60%, 80% and 100%. In the next variation, cement is replaced by 45% GGBS and slag sand is varied as 0%, 20%, 40%, 60%, 80%, 100%. The test result is shown in table.

Table 12
Results of slump and compaction factor (35% GGBS+SS combination)

Specimen Type	Slump(mm)	Compaction factor
CVC	95	0.93
Mix A1	84	0.94
Mix A2	88	0.913
Mix A3	80	0.882
Mix A4	74	0.862
Mix A5	69	0.851
Mix A6	65	0.855

Based on the above test results, the slump of 75mm is kept for mix design of concrete.

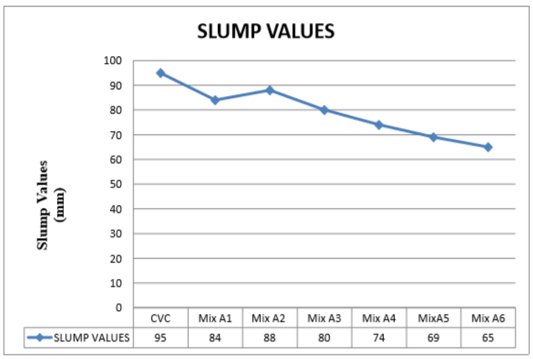

Fig. 3. Graph 1: Slump Values for Mixes A1 to A6 and CVC

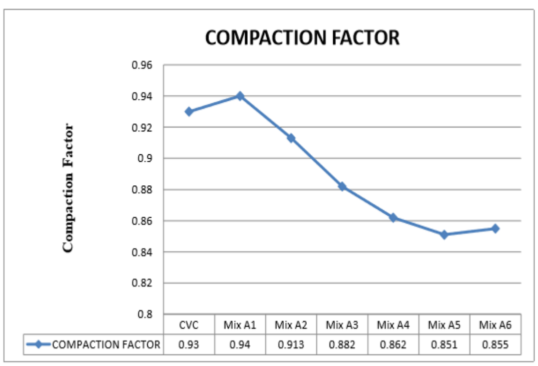

Fig. 4. Graph 2: Compaction Factor for Mixes A1 to A6 and CVC

Table 13
Results of slump and compaction factor (45% GGBS+SS combination)

Specimen Type	Slump(mm)	Compaction factor
CVC	95	0.93
Mix B1	92	0.932
Mix B2	86	0.901
Mix B3	86	0.893
Mix B4	76	0.870
Mix B5	70	0.860
Mix B6	70	0.86

Based on the above test results, the slump of 75mm is kept for mix design of concrete.

Here, Mix B1 represents 45% GGBS replaced by cement and 0% slag sand replaced by natural sand. Similarly, Mix B2-GGBS 45% SS 20%, Mix B3-GGBS 45%SS40%, Mix B4-GGBS 45% SS 60%, Mix A5-GGBS 45% SS 80% and Mix A6-GGBS 45% SS 100%.

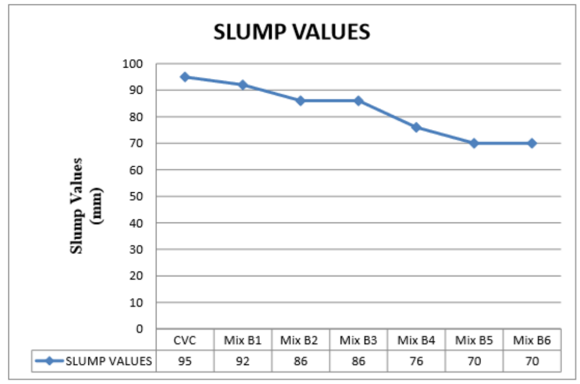

Fig. 5. Graph 3: Compaction Factor for Mixes B1 to B6 and CVC

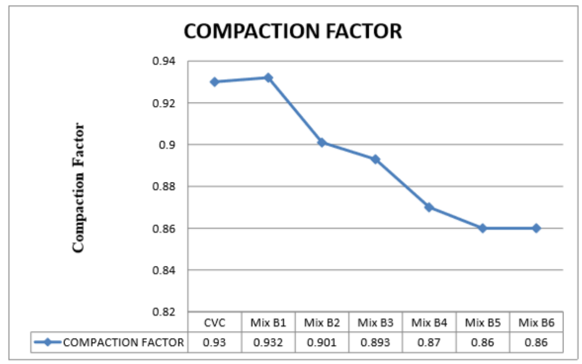

Fig. 6. Graph 4: Compaction Factor for Mixes B1 to B6 and CVC

C. *Mix design methodology*

Mix design for M20 grade concrete [Conventional concrete] Indian Standard Recommended Method (IS 10262 – 2009):

Design Parameters:

Characteristic Strength required = 20 N/mm^2

Maximum size of aggregate = 20mm

down size Specific gravity of OPC = 3.03

Specific gravity of coarse aggregate = 2.72

Specific gravity of fine aggregate = 2.63

Degree of quality control = good Type of exposure = mild

Grading of aggregate:

Fine aggregate = confirming to zone II of IS: 383-1970 (Table 4).

Coarse Aggregate = confirming to IS: 383-1970 (Table 2).

1) Determination of Target Mean Strength

Fck = fck + (t x S)

fck = 20 N/mm^2

t = 1.65 (From IS: 10262 – 2000 Table – 1)

S = 4.0N/mm2 (Std. Deviation as per IS: 456-2000 clause 9.2.42)

Fck = 20 + (1.65 x 4) = 26.6 N/mm^2

2) Selection of water cement- ratio:

From Table 5 of IS:456-2000, for mild exposure condition,

Maximum W/C ratio=0.55 Adopting W/C ratio=0.5 (< 0.55)

3) Selection of Water Content:

From Table 2 of IS:10262-2009

Max. Water content =186 litres

(For 25-50mm slump) For 75mm slump,

Water content =186 + [(3/100) x 186] =191.58 litres.

4) *Selection of cement content*

W/C =0.5 Cement Content =191.58/0.5 = 383.16 kg/m³

(>300 kg/m³, Minimum cement content as per IS:456-2000)

5) *Proportion of volume of coarse aggregate and fine aggregate*

From Table 3 of IS:10262-2009, Volume of Coarse aggregate for 20 mm maximum size aggregate and fine aggregate (Zone II) for W/C ratio of 0.5=0.62.

(No correction for W/C and Non-Pumpable concrete is used)

Volume of coarse aggregate=0.62

Volume of fine aggregate =1-0.62=0.38

6) *Mix calculations*

a) Volume of concrete = 1 m³
b) Volume of Cement = Mass of Cement/(specific gravity*1000)
= 383.16/(3.03*1000)
= 0.1265 m³
c) Volume of water = Mass of water/(specific gravity*1000)
= 191.58/(1.00*1000)
=0.19156 m³
d) Volume of all aggregate = 1-(0.1265+0.1916)
= 0.6819 m³
=0.682 m³

7) *Mass of coarse aggregate*

= d x (vol.of CA) x (specific gravity of CA) x 1000

= 0.682 x 0.62 x 2.72 x 1000

=1150.125 kg. Mass of fine aggregate

= 0.682 x 0.38 x 2.63 x 1000

= 681.591 kg The mix proportion per cubic meter of concrete then becomes,

Cement	Fine aggregate	Coarse aggregate	Water
383.2 kg	681.591 kg	1150.125 kg	191.58 lts
1	1.78	3.00	0.5

Characteristic Strength required	=	20 N/mm^2
Maximum size of aggregate	=	20mm down size
Specific gravity of OPC	=	3.03
Specific gravity of coarse aggregate	=	2.72
Specific gravity of Slag Sand	=	2.61
Specific gravity of GGBS	=	2.72
Degree of quality control	=	good
Type of exposure	=	mild
Grading of aggregate:		
Fine aggregate	=	confirming to zone II of
		IS: 383-1970 (Table 4).
Coarse Aggregate	=	confirming to IS: 383-1970,
		(Table 2).

1) *Determination of target mean strength*

Fck	=	fck + (t x S)
fck	=	20 N/mm^2
t	=	1.65 (From IS: 10262 – 2000 Table – 1)
S	=	4.0N/mm^2 (Std. Deviation as per IS:10262-2009 and
		IS: 456-2000 Clause 9.2.42)
Fck	=	20 + (1.65 x 4)
	=	26.6 N/mm^2

2) *Selection of water cement- ratio:*

From Table 5 of IS: 456-2000, for mild exposure condition,

Maximum W/C ratio = 0.55

Adopting W/C ratio = 0.5 (< 0.55)

3) *Selection of water content*

From Table 2 of IS: 10262-2009 Max.

Water content = 186 litres, For 75mm slump,

Water content = 186+ [(3/100) *186] = 191.58 litres.

4) *Selection of cement content*

W/C = 0.5

Cement Content =191.58/0.5 = 383.16 kg/m³

(>300 kg/m³, Minimum cement content IS:456-2000) For first trial mix, no increased in Cementitious material is carried.

Therefore,

a) 35% GGBS = 134.106 kg/m³ and 65% Cement = 249.054 kg/m³
b) 45% GGBS = 172.422 kg/m³ and 55% Cement = 210.738 kg/m³

5) *Proportion of volume of coarse aggregate and fine aggregate*

From Table 3 of IS:10262-2009, Volume of Coarse aggregate for 20mm maximum size aggregate and fine aggregate (Zone-II) for W/C ratio of 0.5=0.62.

(No correction for W/C and Non-Pumpable concrete is used)

Volume of coarse aggregate=0.62

Volume of fine aggregate =1-0.62=0.38

6) *Mix calculations*

[For 35%GGBS + SLAG SAND COMBINATION]

a) Volume of concrete = 1 m³
b) Volume of Cement = Mass of Cement/(specific gravity*1000)
= 249.054/(3.03*1000)
= 0.0822m³
c) Volume of water = Mass of water/(specific gravity*1000)
= 191.58/(1.00*1000)
= 0.19156 m³
d) Volume of GGBS = Mass of GGBS/(Specific gravity*1000)
= 134.106/(2.72*1000)
= 0.0493 m³.
e) Volume of all = 1-(0.0822 + 0.1916 + 0.0493) aggregate = 0.6769 m³ = 0.677 m³

7) *Mass of coarse aggregate*

= e x (vol. of CA) x (specific gravity of CA) x 1000

= 0.677 x 0.62 x 2.72 x 1000

= 1141.693 kg.

Mass of fine aggregate = 0.677 x 0.38 x 2.61 x 1000

= 671.45 kg

The mix proportion per cubic meter of concrete then becomes,

Cement	Fine aggregate	Coarse aggregate	Water
383.16 kg	671.961 kg	1141.693 kg	191.58 lts
1	1.75	2.98	0.5

Similarly, for 45%GGBS and Slag sand combinations, the Mix Proportion we obtain as,

Cement	Fine aggregate	Coarse aggregate	Water
383.16 kg	669.961 kg	1139.163 kg	191.58 lts
1	1.75	2.97	0.5

Details of quantities obtained for various mixes

Table 14
Quantities for conventional concrete are tabulated

		Cement	FA	CA	Water
6 CUBES	CVC	7.98 kg	14.22 kg	23.94 kg	4.02 Lts
3 CYLINDER	CVC	6.27 kg	11.16 kg	18.81 kg	3.15 Lts
3 PRISM	CVC	5.91kg	10.53 kg	17.73 kg	2.96 Lts

Table 15
Quantities of Materials containing 35% GGBS and Slag Sand variation

Specimen	Mix Design at ion	Cement (65%) (Kg)	GGBS (35%) (Kg)	Natural Sand (Kg)	Slag Sand (Kg)	Coarse Aggregate (Kg)	Water (Litres)
CUBES (6 Each)	MIX A1	5.23 kg	2.81 kg	14.10	0.00	23.94	4.02
	MIX A2	5.23 kg	2.81 kg	11.28	2.82	23.94	4.02
	MIX A3	5.23 kg	2.81 kg	8.46	5.64	23.94	4.02
	MIX A4	5.23 kg	2.81 kg	5.64	8.64	23.94	4.02
	MIX A5	5.23 kg	2.81 kg	2.82	11.28	23.94	4.02
	MIX A6	5.23 kg	2.81 kg	0.00	14.10	23.94	4.02
CYLINDE R (3 Each)	MIX A1	4.11	2.22	11.07	0.00	18.87	3.18
	MIX A2	4.11	2.22	8.86	2.21	18.87	3.18
	MIX A3	4.11	2.22	6.64	4.43	18.87	3.18
	MIX A4	4.11	2.22	4.43	6.64	18.87	3.18
	MIX A5	4.11	2.22	2.21	8.86	18.87	3.18
	MIX A6	4.11	2.22	0.00	11.07	18.87	3.18
PRISM (3 Each)	MIX A1	3.88	2.09	10.44	0.00	17.79	3.00
	MIX A2	3.88	2.09	8.35	2.09	17.79	3.00
	MIX A3	3.88	2.09	6.26	4.18	17.79	3.00
	MIX A4	3.88	2.09	4.18	6.26	17.79	3.00
	MIX A5	3.88	2.09	2.09	8.35	17.79	3.00
	MIX A6	3.88	2.09	0.00	10.44	17.79	3.00

For Table 14, Mix A1 represents 35% GGBS replaced by cement and 0% slag sand replaced by natural sand, Similarly Mix A2-GGBS35%SS20%, Mix A3GGBS35%SS40%, Mix A4-GGBS35%SS60%, Mix A5-GGBS35%SS80% and Mix A6-GGBS35%SS100%.

For Table 15, Mix B1 represents 45% GGBS replaced by cement and 0% slag sand replaced by natural sand. Similarly, Mix B2-GGBS45%SS20%, Mix B3GGBS45%SS40%, Mix B4-GGBS45%SS60%, Mix A5-GGBS45%SS80% and Mix A6-GGBS45%SS100%.

Table 16
Quantities of Materials containing 45%GGBS and Slag Sand variation

Specimen	Mix Designa tion	Cement (55%) (Kg)	GGBS (45%) (Kg)	Natural Sand (Kg)	Slag Sand (Kg)	Coarse Aggregate (Kg)	Water (Litres)
CUBES (6 Each)	MIX B1	4.42	3.62	14.10	0.00	23.94	4.02
	MIX B2	4.42	3.62	11.28	2.82	23.94	4.02
	MIX B3	4.42	3.62	8.46	5.64	23.94	4.02
	MIX B4	4.42	3.62	5.64	8.64	23.94	4.02
	MIX B5	4.42	3.62	2.82	11.28	23.94	4.02
	MIX B6	4.42	3.62	0.00	14.10	23.94	4.02
CYLIND ER (3 Each)	MIX B1	3.48	2.85	11.07	0.00	18.87	3.18
	MIX B2	3.48	2.85	8.86	2.21	18.87	3.18
	MIX B3	3.48	2.85	6.64	4.43	18.87	3.18
	MIX B4	3.48	2.85	4.43	6.64	18.87	3.18
	MIX B5	3.48	2.85	2.21	8.86	18.87	3.18
	MIX B6	3.48	2.85	0.00	11.07	18.87	3.18
PRISM (3 Each)	MIX B1	3.28	2.69	10.44	0.00	17.79	3.00
	MIX B2	3.28	2.69	8.35	2.09	17.79	3.00
	MIX B3	3.28	2.69	6.26	4.18	17.79	3.00
	MIX B4	3.28	2.69	4.18	6.26	17.79	3.00
	MIX B5	3.28	2.69	2.09	8.35	17.79	3.00
	MIX B6	3.28	2.69	0.00	10.44	17.79	3.00

3. Testing and results of specimen

A. *Tests on Concrete*

Tests on Concrete: Slump cone test and compaction factor test are carried as fresh concrete tests. This tests are carried before mix design calculation. Based on slump and compaction factor values mix design is carried. The test results are shown in Table 14 and Table 15.

Test on Hardened concrete: Compressive strength test, split tensile strength test and flexural strength test are carried as per BIS Specifications and IS codal provisions.

1) Tests for compressive strength

The compressive strength of concrete is one of the most important properties of concrete in most structural application. Concrete is checked primarily to resist compressive stress.

In this investigation, conventional concrete and test specimens concrete cube were used for testing the compressive strength. The cubes are tested in a compressive testing machine of capacity 200KN. The load has been applied at the rate of 315KN/min. The load applied in such a way that the two opposite sides of the cube are compressed. The load at which the control specimens and tests specimens ultimately fail is noted. The average of 3 cubes is taken as compressive strength. Compressive strength is calculated by dividing load by area of specimen.

$Fc = P/A$

Where

Fc = cube compressive strength in N/mm^2

P = cube compressive causing failure in N

A = cross section area of cube.

Table 17
Compressive Strength of M20 Grade (35%GGBS+SS Combinations)

Mix Designation	No of Cubes	Days of Curing	Compressive loads (Tons)	Compressive strength (N/mm2)	Average Compressive Strength (N/mm2)
CVC	3	7	33.00 34.25 33.50	14.388 14.933 14.606	14.642
Mix A1	3	7	36.00 35.75 34.25	15.696 15.587 14.933	15.41
Mix A2	3	7	36.75 37.00 37.00	16.023 16.132 16.132	16.096
Mix A3	3	7	40.50 40.50 39.75	17.658 17.658 17.331	17.549
Mix A4	3	7	43.75 44.50 44.00	19.075 19.402 19.184	19.22
Mix A5	3	7	36.25 36.25 37.25	15.805 15.805 16.241	15.95
Mix A6	3	7	33.00 32.50 31.75	14.388 14.170 13.843	14.134

Here, Mix A1 represents 35% GGBS replaced by cement and 0% slag sand replaced by natural sand, Similarly Mix A2-GGBS35%SS20%, Mix A3-GGBS35%SS40%, Mix A4-GGBS35%SS60%, Mix A5-GGBS35%SS80% and Mix A6-GGBS35%SS100%.

Table 18
Compressive Strength of M20 Grade (35%GGBS+SS Combinations)

Mix Designation	No of Cubes	Days of Curing	Compressive loads (Tons)	Compressive strength (N/mm2)	Average Compressive Strength (N/mm2)
CVC	3	28	49.75 48.50 50.00	21.691 21.146 21.800	21.55
Mix A1	3	28	52.00 54.00 57.50	22.672 23.544 25.070	23.762
Mix A2	3	28	54.5 56.00 56.50	23.762 24.416 24.634	24.27
Mix A3	3	28	65.75 65.75 65.00	28.667 28.667 28.340	28.56
Mix A4	3	28	69.25 68.50 70.00	30.193 29.866 30.520	30.193
Mix A5	3	28	58.25 59.25 63.25	25.397 25.833 27.577	26.269
Mix A6	3	28	50.25 51.50 50.75	21.909 22.454 22.127	22.163

Here, Mix A1 represents 35% GGBS replaced by cement and 0% slag sand replaced by natural sand, Similarly Mix A2-GGBS35%SS20%, Mix A3-GGBS35%SS40%, Mix A4-GGBS35%SS60%, Mix A5-GGBS35%SS80% and Mix A6-GGBS35%SS100%.

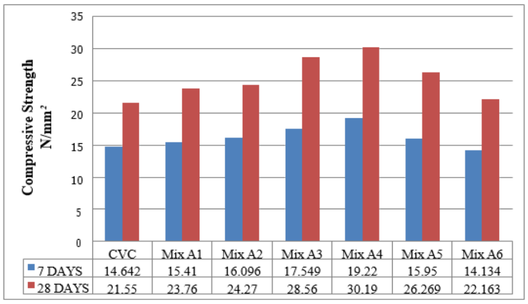

Fig. 7. Compressive strength of M20 grade of CVC and Mixes A1 to A6

Discussion: From the results obtained above, it can be seen that the test specimen having 35%GGBS and 60% slag sand (Mix A4) have highest strength as compared to conventional concrete. At 100% replacement of slag sand and 35% GGBS (Mix A6), the strength of concrete is nearly same as that of conventional concrete. Hence it can be concluded that the Mix A6 (35%GGBSand 100% slag sand) can be replaced in place of conventional concrete. However, the optimum percentage of replacement should be used for durability and other environmental effects. Therefore, Mix A4 is selected as optimum percentage of replacement.

2) Test for split tensile strength

The tensile strength of concrete is most often evaluated using a split cylinder test, in which a cylindrical specimen is placed on its side and loaded in diametrical compression, so to induce transverse tension. Practically, the load applied on the cylindrical concrete specimen induces tensile stresses on the plane containing the load and relatively high compressive stresses in the area immediately around it. When the cylinder is compressed by the two plane-parallel faceplates, situated at two diametrically opposite points on the cylinder surface then, along the diameter passing through the two points, the major tensile stresses are developed which, at their limit, reach the fracture strength value, "fcs"

$$fcs = 2F/\pi dL$$

Where: F is the fracture compression force acting along the cylinder generatrix, d is the cylinder diameter, L is the cylinder length. The table shows the test results of split tensile strength obtained for different mixes.

Table 19
Split Tensile strength of M20 Grade (35%GGBS+SS Combinations)

Mix Designation	No of Cubes	Days of Curing	Compressive loads (Tons)	Split Tensile strength (N/mm2)	Average Tensile Strength (N/mm2)
CVC	3	28	14.75 15.50 14.25	2.047 2.151 1.978	2.059
Mix A1	3	28	15.25 15.00 15.75	2.116 2.082 2.186	2.13
Mix A2	3	28	15.75 16.50 16.25	2.186 2.290 2.255	2.244
Mix A3	3	28	17.00 18.25 17.50	2.359 2.533 2.429	2.44
Mix A4	3	28	21.75 20.00 20.25	3.019 2.776 2.810	2.87
Mix A5	3	28	16.00 17.00 16.50	2.221 2.359 2.290	2.290
Mix A6	3	28	13.75 14.00 14.75	1.908 1.943 2.047	1.966

Here, Mix A1 represents 35% GGBS replaced by cement and 0% slag sand replaced by natural sand, Similarly Mix A2-GGBS35%SS20%, Mix A3-GGBS35%SS40%, Mix A4-GGBS35%SS60%, Mix A5-GGBS35%SS80% and Mix A6-GGBS35%SS100%.

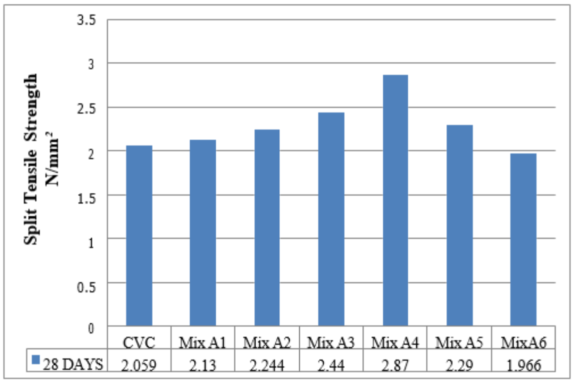

Fig. 8. Graph 6: Split tensile strength of M20 Grade of CVC and Mixes A1 to A6

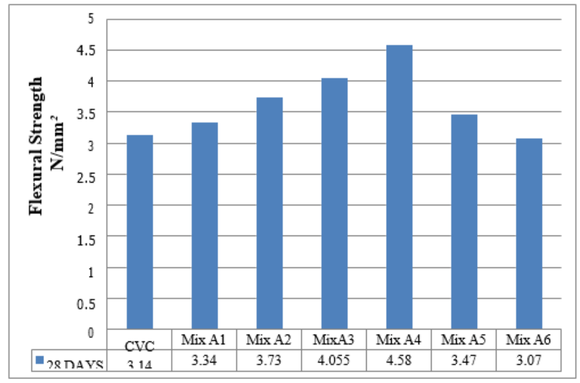

Fig. 9. Graph 7: Flexural strength of M20 Grade of CVC and Mixes A1 to A6

Discussion: From the results obtained and graph above, it can be seen that the split tensile strength of concrete is increased as the replacement percentage increase upto Mix A4, after that that the strength is decreased. It can be concluded that the optimum percentage of replacement is 35% GGBS and 60% slag sand (Mix A4). However, the Mix A6 shows the similarity of strength as that of conventional concrete.

3) Tests for flexural strength

This test is performed according to IS 516 – 1959. The flexural strength of the specimen shall be expressed as the modulus of rupture fb, which, if 'a' equals the distance between the line of fracture and the nearer support, measured on the centre line of the tensile side of the specimen, in cm, shall be calculated to the nearest 0.5 kg/sq cm as follows:

$$fb = p*l/ bd^2$$

b = measured width in cm of the specimen,

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

l = length in mm of the span on which the specimen was supported,

p = maximum load in kg applied to the specimen

The table and Charts shows the test results data for flexural strength for control and test specimens.

Table 20
Flexural strength of M20 Grade (35%GGBS+SS Combinations)

Mix Designation	No of Cubes	Days of Curing	Crushing loads (Tons)	Flexural strength (N/mm2)	Average Flexural Strength (N/mm2)
CVC	3	28	0.75	2.943	3.14
			0.85	3.335	
			0.80	3.139	
Mix A1	3	28	0.80	3.139	3.34
			0.90	3.532	
			0.85	3.335	
Mix A2	3	28	1.00	3.924	3.73
			0.90	3.532	
			0.95	3.728	
Mix A3	3	28	1.00	3.924	4.055
			1.10	4.316	
			1.00	3.924	
Mix A4	3	28	1.10	4.316	4.58
			1.20	4.709	
			1.20	4.709	
Mix A5	3	28	0.85	3.335	3.47
			0.95	3.728	
			0.85	3.335	
Mix A6	3	28	0.75	2.943	3.07
			0.8	3.139	
			0.8	3.139	

Discussion: Flexural behaviour of concrete is important is important from structural point of view. The results obtained by prisms of CVC and test specimens are noted and graphs are plotted. After 28 days of curing, the test specimens shows god results with CVC result. The optimum of 4.58N/mm² is obtained for Mix A4. The strength from Mix A1 to A4 is increase gradually and then A5 and A6 the strength is decrease. This may be because of high glass content in slag sand. It can be concluded that the replacement having 35% GGBS and 60% slag sand gives good results as compared to CVC and other Mixes. Hence this combination (Mix A4) can be used for replacement of cement and Natural sand.

B. *Testing and result of beams*

Testing Procedure: After the curing 28 days the beams are kept for 24 hours in a dry state. After drying they are cleaned to remove all grit and dirt with sand paper and white painting was done on all side of beams. White painting was done to facilitate easy detection of crack propagation. Mid span is marked to observe the surface cracks in concrete. After 28 days of curing the beams were surface dried, they were cleaned with a wire brush to remove all grit and dirt. The beams are tested for pure flexure on a uniform testing machine of 60 Tones capacity, the beam is kept on two girders, so as to obtain the clear span of 600 mm. On the beam two rods are kept at a distance of 100mm from center of the beam on either side so that it acts as a two-point loading over which an I – Section is placed by using a plum bob.

A dial gauge is placed exactly below the center of the beam i.e. at the mid- span. With the help of dial gauge the deflections at different load levels can be measured at the beam center. The test results with graphs is shown in below tables. The designation of beams are:

1) 3 Beams- B1. B2, B3 represents CVC Beams.

2) 3 Beams –B4, B5, B6 represents Mix A4 (containing 35% GGBS and 60% Slag Sand) 3 3 Beams –B7, B8, B9 represents Mix B3 (45% GGBS +40% SS).

Table 21
Load deflection characteristics of RCC beam conventional concrete (M20 grade) [B1, B2, B3]

LOADS KN	DEFLECTION MM	LOADS KN	DEFLECTION MM
0	0	0	0
12	0.8	11	0.7
25*	0.95	22*	0.95
32	1.2	30	1.1
40	1.4	39	1.4
55	1.6	59	1.6
78	1.8	71	1.8
100	2.0	94	2.0
113	2.4	104	2.2
125	2.6	116	2.3
141**	2.9	128	2.6
		137**	2.7

LOADS KN	DEFLECTION MM
0	0
12	0.8
23.5*	0.9
32	1.2
42	1.4
59	1.6
70	1.8
90	2.0
110	2.2
120	2.4
130	2.6
139**	2.7

*first crack load **Ultimate crack load

Fig. 10. Graph 8: load deflection curve for CVC RCC beam

4. Results and discussion

Concrete of M20 grade was prepared to cast the cubes, cylinders, prisms and beams for studying the compressive, split tensile, flexural strength characteristic and flexural behavior of beams for combined replacement of GGBS as Cement and Slag Sand as Natural Sand. The following observations were drawn from the experimental work.

1) By addition of GGBS and Slag Sand, the strength of concrete is increased upto certain percentages, after that the decrease in strength is noticed.
2) Addition of GGBS upto35%and slag sand 60% shows an initial strength increase. Also for 45% GGBS and 40% slag sand, the strength is higher.
3) For 7 days, Mix A1 to Mix A4 and Mix B1 to Mix B3 Shows greater strength. Mix A5and A6 and Mix B4 to B6 shows less strength and it is as that of conventional concrete.
4) Mix A4 (35%GGBS+60%SS) and Mix B3 (45% GGBS+40%SS) have higher compressive strength of 30.193N/mm^2 and 330.608N/mm^2 respectively for 28 days.
5) Mix A4 (35%GGBS+60%SS) has 23.81% increase in compressive strength for 7 days.
6) Mix A4 (35%GGBS+60%SS) has 31.94% increase in initial compressive strength for 28 days.
7) Mix B3(45%GGBS+40%SS) has 28.16% increase in initial compressive strength for 7 days.
8) Mix B3(45%GGBS+40%SS) has 35.88% increase in initial compressive strength for 28 days.
9) Similarly, for Split tensile strength, Mix A4 (35% GGBS+60%SS) has 28.26% increase in strength for 28 days.
10) Mix B3(45%GGBS+40%SS) has 34.30% increase in Split tensile strength for 28 days as compared to CVC.
11) For Flexural Strength, Mix A4 (35%GGBS+60%SS) has 31.44% increase in flexural strength for 28 days.
12) Mix B3(45%GGBS+40%SS) has 35.12% increase in Flexural strength for 28 days as compared to CVC.
13) It is also noticed that the slump value decreases as GGBS and slag sand percentages increases.
14) The Workability of concrete decreases as replacement percentages increases. For 100% slag sand replacement, the workability is least.
15) For the beams, the load deflection characteristics are noticed. The conventional concrete has 139 KN average ultimate load carrying capacity.
16) The Mix A4 (35%GGBS+60%SS) has 11.46% increase in ultimate load carrying capacity of beams as compared with conventional concrete.
17) The Mix B3 (45%GGBS+40%SS) has 16.43% increase in ultimate load carrying capacity as compared to conventional concrete.
18) The cost of construction is reduced to a large extent.
19) In general, both combinations A4 and B3 has satisfactory results. Therefore, Mix designer can go either with 35% GGBS and 60% Slag sand replacement or 45%GGBS and 40%Slag sand replacement.

5. Conclusions

1) The Workability of concrete property decreases as the percentage of replacement of slag sand increases. The slump varies from 65mm to 100mm for different mixes. The compaction factor also reduced.
2) By addition of GGBS, the slump is slightly improved and all the concrete mixes were homogenous and cohesive in nature.
3) The compressive strength of cubes are increased with addition of GGBS and Slag Sand. The Optimum percentages of replacements obtained are – 35%GGBS replaced by cement and 60% slag sand replaced with Natural

sand. Similarly, for 45% GGBS and 40% slag sand replacement the compressive strength is higher than all other mixes.

4) Split tensile strength of Mix A4 (35%GGBS+60%SS) and Mix B3(45%GGBS+40%SS) has highest strength as compared to conventional concrete.
5) The Flexural strength of concrete is also maximum for 35% replaced by cement and 60% slag sand replaced by natural sand. However, 45%GGBS and 40% slag sand shows highest flexural strength values.
6) For cubes, cylinder and prism, the conclusion is that the optimum replacement can be done in two combinations:
7) The two Combination Can be used as, A- 35% GGBS can be replaced by cement along with 60% slag sand by natural sand. B- 45% GGBS can be replaced by cement along with 40% slag sand by natural sand.
8) Due to high glass content, the higher replacements show decrease in strength of concrete (Mix A5, A4, B4, B5, B6). Therefore, A4 mix and B3 mix is incorporated in beams to study flexural behavior of singly reinforced RC beams.
9) All beams were designed as per IS:456-2000 and under reinforced section is designed. The beams fail under flexure.
10) The flexural crack propagated from tension fibre to compression. No horizontal cracks were observed at the level of replacement, indicating no bounding failure.
11) The flexural results there is an increase in cracking moment of about 12.96% for A4 mix and 28.79% for B3 mix, for same tensile reinforcement.
12) The experimental ultimate moment carrying capacity of test beams are greater than the theoretical moment carrying capacity. 13. The load carrying capacity of A4 mix and B3 mix have more than the conventional concrete. The first crack appears for CVC is earlier than other mixes (A4 and B3).
13) The cost of material is reduced to a large extent.
14) The waste materials GGBS and Slag sand can be satisfactorily utilize in the concrete. Thus the disposal problem gets solved and the environmental pollution is reduced.

6. Scope for further study

1) In this investigation, M20 grade of concrete is designed and tested. Further work can be carried out by testing higher grades of concrete. i.e., M25, M30, M35, M40 etc.
2) This work is carried with 20% variation of slag sand. The same work can be carried with 10% slag sand variation.
3) Further increase in strength can be check by adding other admixture such as silica fume.
4) Coarse aggregate can also be replaced along with this investigation.
5) The slag sand has high glass content which have a major problem of handling and workability .The further study on reducing the glass effect by using other admixtures can be done.
6) Slag Cement, slag sand and the coarse aggregate containing slag can be checked for further studies.
7) Flexure behavior of large size beams can also be studied.
8) Structural behavior of columns and slabs can also be studied with this replacement and further suggestion for improvement can be given.

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