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An Investigation on Geopolymer Concrete with GGBFS and Fly Ash

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***Abstract*—The conventional concrete used for the construction of large structures releases greenhouse gases leading to ozone layer depletion and global warming. An alternative solution to conventional concrete has been sought by many researchers. Geopolymer concrete is the one in which cement in conventional concrete is replaced by mineral admixtures such as fly ash, GGBFS, metakaolin, micro silica etc and chemical solutions acting together as a binder. In this paper, geopolymer concrete is made using ground granulated blast furnace slag (GGBFS) and fly ash in alkaline solutions (sodium silicate and sodium hydroxide) is compared with conventional concrete. The strength parameters investigated are (i) 7 days compressive strength (ii) 28 days compressive strength (iii) 28 days split tensile strength (iv) 28 days flexural strength. Workability and cost analysis of different cases of geopolymer concrete is also investigated.**

Keywords—Geopolymer concrete; micro silica; ground granulated blast furnace slag; fly ash; alkaline solution

I. INTRODUCTION

The climatic change owing to global warming is a grave environmental dilemma having significant pessimistic impacts on all living beings of the world. The discharges of greenhouse gases such as CO_2, methane, nitrous oxide, chlorofluorocarbons, hydrofluorocarbons, etc. from diverse sources into the atmosphere are accountable for this critical impasse. One such cause of the release of primary greenhouse gas - CO_2 is the present production process for Ordinary Portland Cement (OPC). It was revealed that the world production of OPC had contributed almost 5–7% of the total CO_2 emission into the ambience. Estimation is assessed that the production of one ton of OPC is answerable to the almost equal quantity of discharge of CO2 into the atmosphere. For the year 2014, the global utilization of OPC in the world was 3.7 billion metric tons. Likewise, one ton of cement production releases one ton of carbon dioxide into the atmosphere and consumes almost 4GJ of energy. This is a severe hazard to humanity across the world. Therefore, research efforts towards the search for eco-friendlier materials for construction are going on.[2] The present production process of OPC is not merely high temperature and highly energy-intensive for which it needs to swallow restricted natural coal resources for calcination of limestone but also a solemn threat to The environment. Hence, it is also a need of the hour to search for an alternative of conventional OPC-concrete which should be user and eco-friendly and can be developed by conserving natural resources at low temperature and a cost of merely slim energy and of course, cost-effective. Moreover, the conventional fine and coarse ingredients of OPC concrete are also mined from limited natural resources hence the researches are essential for a type of concrete that can be developed by incorporating natural and industrial wastes to lower down environmental concerns.

Geopolymer is a novel inorganic binder produced by the polymerisation reaction between source materials (having higher silica and alumina content) of geological origin and alkaline solution in highly alkaline conditions at low temperatures and atmospheric pressure. Geopolymer concrete demonstrates excellent properties of resistance against sulphate, chloride, and acid attacks. In comparison with regular Portland cement concrete, it has strong prospective applications in the encapsulation of toxic solid waste and heavy metals. It functions as fire-resistant as it shows excellent high-temperature stability.

A. Polymerization

Polymerization is a procedure of responding monomer particles together in a substance response to shape polymer chains or three-dimensional systems. In substance mixes, polymerization happens through an assortment of response instruments that change in multifaceted nature because of practical gatherings introduce in responding compounds and their inalienable steric impacts. Polymerization, any procedure in which generally little particles, called monomers, consolidate chemically to deliver a vast chainlike or system atom, called a polymer. As a rule, no less than 100 monomer atoms must be consolidated to make an item that has certain remarkable physical properties, for example, versatility, high rigidity, or the capacity to frame filaments that separate polymers from substances made out of littler and easier particles frequently, a large number of monomer units are joined in a single molecule of a polymer.

B. Aim and Scope

The project aims to find a replacement for cement as cement manufacturing is one of the major contributors to air pollution. Cement industries release greenhouse gases into the atmosphere which causes global warming and other environmental problems. Industrial dust like fly ash, metakaolin, micro silica and GGBFS can be used to replace cement in concrete. This reduces the harmful industrial solid waste released into the environment and promotes sustainable development. The project helps to find out the constructions for which concrete can be replaced by geopolymer concrete depending on the workability and cost.

II. MATERIALS

A. *Fly Ash*

Fly ash is produced from the combustion of coal in electric utility or industrial boilers. There are four basic types of coal-fired boilers: pulverized coal (PC), stoker-fired or travelling grate, cyclone, and fluidized-bed combustion (FBC) boilers. The PC boiler is the most widely used, especially for large electric generating units. The other boilers are more common at industrial or cogeneration facilities. Fly ashes produced by FBC boilers are not considered in this document. Fly ash is captured from the flue gases using electrostatic precipitators (ESP) or in filter fabric collectors, commonly referred to as baghouses. The physical and chemical characteristics of fly ash vary among combustion methods, coal sources, and particle shape.[4]

B. *Ground Granulated Blast Furnace Slag*

Granulated Blast Furnace Slag is obtained by rapidly chilling (quenching) the molten ash from the furnace with the help of water. During this process, the slag gets fragmented and transformed into amorphous granules (glass), meeting the requirement of IS 12089:1987 (manufacturing specification for granulated slag used in Portland Slag Cement). The granulated slag is ground to desired fineness for producing GGBFS. It ensures higher durability of the structure and reduces the temperature rise and helps to avoid early-age thermal cracking and also improve workability. It is off-white and substantially lighter than Portland cement. Resultantly, it helps soften the visual impact of large structures such as bridges and retaining walls. [3]

C. *Sodium Hydroxide*

The most widely recognized soluble base activator utilized in the Geopolymer concrete is NaOH. As an activator, NaOH isn't that dynamic that as KOH particle. In any case, the particle of NaOH are small in size and accordingly, they can infiltrate inside the system with a simple exertion. Likewise, NaOH particles have a thickness of extremely high charge which offers extra zeolitic development vitality. The properties of the resultant glue of geopolymer concrete are liable to the centralization of NaOH arrangement. While framing folio high concentration of NaOH may help in synthetic disintegration however it opposes the development of ettringite and CH (carbon-hydrogen) bond. It has likewise been concentrated by the analysts that the high convergence of NaOH may give higher quality at early ages however for the matured examples it was discovered that the solid had poor morphology and non-consistency because of exorbitant OH particles. One of the upsides of utilizing NaOH as an activator is that the resultant Geopolymer concrete is increasingly crystalline and along these lines has more prominent soundness in unforgiving situations, for example, impervious to sulphates and acids.

D. *Sodium Silicate*

The point when at a high temperature of about 1100°C or more, sand is melded with sodium carbonate than Sodium silicate is shaped. A result of the above response is broken up with the high weight steam & semi-thick fluid is framed which are known as the water glass. The Sodium Silicate in its physical state can be found beneath. A Sodium silicate/water glass alone can't be utilized as an activator to start pozzolanic response since need enough initiations potential. In this way, it's constantly utilized without withstanding sodium hydroxide to improve the alkalinity quality of examples. Along these lines, NaOH & Na_2SiO_3 are the most regular salt activator utilized in the Geopolymer solid creation. Financially, sodium silicates can be found in various evaluations and states, for example, powder structures/ fluid structures, however fluid structure has progressively propensities to start response. It is found from the overview that Na_2SiO_3 having SiO_2 to Na_2O mass proportion of 2.0 blended with NaOH activator 24 hours preceding use offers better outcomes.

III. SPECIFIC GRAVITY

Specific gravity is the ratio of the weight of the volume of any material to the weight of the water of the same volume at a certain temperature. Specific gravity is a value to calculate whether a material will sink or float in water. Each material has some specific gravity. Specific gravity is calculated to know the behaviour of the material and it usually ranges from 0.1 to 100. Specific gravity test is carried out for binder materials like cement, fly ash, GGBFS, micro silica etc using a specific gravity bottle.[4]

Specific gravity is given by the following equation:

$$(W_2 - W_1) / (W_2 - W_1) - (W_3 - W_4) \times 0.79 \qquad (1)$$

where,

W_1 = Weight of bottle with stopper

W_2 = Weight of bottle with stopper + Weight of material

W_3 = Weight of bottle with stopper + Weight of material + Weight of kerosene

W_4 = Weight of bottle with stopper + Weight of kerosene

A. Observation

1) *Cement:*

$W_1 = 30$ g $W_2 = 45$ g $W_3 = 83$ g $W_4 = 70$ g

Specific gravity = (45 – 30) / (45 -30) - (83-70) x 0.79

= 3.15

2) *Fly Ash:*

$W_1 = 30$ g $W_2 = 38$ g $W_3 = 76$ g $W_4 = 70$ g

Specific gravity = (38 – 30) / (38 -30) - (76-70) x 0.79

= 2.45

3) *Ground granulated blast furnace slag:*

$W_1 = 30$ g $W_2 = 42$ g $W_3 = 80$ g $W_4 = 70$ g

Specific gravity = (42 – 30) / (42 -30) - (80-70) x 0.79

= 2.92

IV. MIX DESIGN

A. *Mix Design for Conventional Concrete*

The mix design of the geopolymer concrete is done in an entirely different manner compared to that of conventional concrete. In this project, the mix design of the geopolymer concrete is prepared.

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1) Materials replacing cement: Quantity and fineness of material used to replace cement-like fly ash, GGBFS and micro-silica plays an important role in the activation process of geopolymer. It was already pointed out that the strength of geopolymer concrete increases with an increase in the quantity and fineness of the material. Similarly, higher fineness shows higher workability and strength with an early duration of heating in the case of fly ash. So, the main emphasis is given on the quantity and fineness of fly ash in the development of the mix proportioning procedure of geopolymer concrete.[6]

2) Alkaline activators: In the project, sodium-based alkaline activators are used. The combination of sodium hydroxide and sodium silicate solutions are used for the activation of geopolymer concrete. It is observed that the compressive strength of geopolymer concrete increases with an increase in the concentration of sodium hydroxide solution and or sodium silicate solution with increased viscosity of the fresh mix. An increase in the concentration of sodium hydroxide solution in terms of molarity (M) makes the concrete more brittle with increased compressive strength. Secondly, the cost of sodium hydroxide solid is high and preparation is very caustic. Similarly, to achieve the desired degree of workability, extra water is required which ultimately reduce the concentration of sodium hydroxide solution. So, the concentration of sodium hydroxide was maintained at 10 M while the concentration of sodium silicate solution (10 M) contains Na_2O of 16.37 %, SiO_2 of 34.35 % and H_2O of 49.72 % is used as alkaline solutions.

3) Water: Water comes out from the mix during the polymerization process. The role of water in the geopolymer mix is to make workable concrete in a plastic state and do not contribute towards the strength in the hardened state. Similarly, the demand for water increases with an increase in the fineness of source material for the same degree of workability. So, the minimum quantity of water required to achieve the desired workability is selected based on the degree of workability, fineness of source material and grading of fine aggregate.

4) Aggregates: Aggregates are inert mineral materials used as filler in concrete which occupies 70–85 % volume. So, in the preparation of geopolymer concrete, fine and coarse aggregates are mixed in such a way that it gives the least voids in the concrete mass. This was done by grading fine aggregate and selecting a suitable fine-to-total aggregate ratio. The workability of geopolymer concrete is also affected by the grading of fine aggregate similar to cement concrete.

5) Water to geopolymer binder ratio: Water-to-geopolymer binder ratio The ratio of total water (i.e. water present in solution and extra water if required) to the material involved in the polymerization process (i.e. fly ash and sodium silicate and sodium hydroxide solutions) plays an important role in the activation process.

6) Solution to fly ash ratio: As solution (i.e. sodium silicate + sodium hydroxide) to fly ash ratio increases, strength is also increased. But the rate of gain of strength is not much significant beyond the solution to fly ash ratio of 0.35. Similarly, the mix was more and more viscous with higher ratios and unit cost also increases. So, in the present mix design method, the solution-to-fly ash ratio was maintained at 0.35.

7) Preparation of geopolymer concrete mixes: The preparation of geopolymer concrete is similar to that of cement concrete. Two types of coarse aggregates 12 mm and 20 mm, fine sand and source material (fly ash, GGBFS, micro silica) were mixed in the dry state. Then add prepared mixture solution of sodium hydroxide and sodium silicate along with extra water-based on water-to-geopolymer binder ratio and mix thoroughly for 3–4 min to give a homogeneous mix.

Six concrete cubes of side 150 mm, two cylinders of 300 mm height and 150 mm diameter and one beam of 100 mm x 100 mm x 500 mm are cast in three layers for each case. Each layer is well compacted by a tamping rod of diameter 12 mm. After compaction of concrete, the top surface was levelled by using a trowel. After 24 h of casting, all cubes were unmoulded and then placed at room temperature for curing. Fly ash geopolymer concrete is kept in an oven for thermal curing (heating) at 60^{o} C. To avoid the sudden variation in temperature, the concrete cubes were allowed to cool down up to room temperature in an oven.

TABLE I. QUANTITIES WORKED OUT

Material	***Quantity per meter cube***
Source material for replacing cement	405.92 kg/m^3
Fine sand	551.11 kg/m^3
Coarse aggregate (12 mm)	1015.7 kg/m^3
Coarse aggregate (20 mm)	276.74 kg/m^3
Sodium silicate solution	100.75 kg/m^3
Sodium hydroxide solution	40.89 kg/m^3
Additional water	20 kg/m^3
Sodium silicate concentration	10 M
Sodium hydroxide solution	10 M
(Sodium silicate + sodium hydroxide solution) / Source material content	0.35
Total water content including solution / Source material	0.40
Sodium hydroxide solution / Sodium silicate solution	0.40

The geopolymer concrete in this project is prepared by using the ratio **1: 1.3: 3.1**.[4]

V. CASES INVESTIGATED

28 days split tensile strength test, 28 days flexural tensile strength test and 7 and 28 days compressive strength test has to be conducted for all the trials. Therefore 3 cubes for 7 days, 3 cubes for 28 days, 2 cylinders for 28 days and 1 beam for 28 days are required. There are 9 specimens to be cast for each case. The volume of concrete to be prepared for each case is as follows;

Volume of 6 cubes $= 6 \times 0.150 \times 0.150 \times 0.150$

$= 0.02025$ m^3

Volume of 2 cylinders $= 2 \times \pi \times 0.075 \times 0.075 \times 0.300$

= 0.0105975 m^3

Volume of 1 cube = 1 x 0.010 x 0.010 x 0.050

= 0.005 m^3

Total volume = 0.036 m^3

Considering extra 2 % total volume = 0.03672 m^3

1) Case 1:

Ordinary concrete

Cement = 405.92 kg/m^3

Fine aggregate = 551.11 kg/m^3

Coarse aggregate (12 mm) = 1015.7 kg/m^3

Coarse aggregate (20 mm) = 276.74 kg/m^3

Water = 160 kg/m^3

Water cement ratio = 0.39

2) Case 2:

100 % replacement of cement by fly ash

Fly ash = 405.92 kg/m^3

Sodium silicate solution = 100.75 kg/m^3

Sodium hydroxide solution = 40.89 kg/m^3

Fine aggregate = 551.11 kg/m^3

Coarse aggregate (12 mm) = 1015.7 kg/m^3

Coarse aggregate (20 mm) = 276.74 kg/m^3

Water = 20 kg/m^3

3) Case 3:

100 % replacement of cement by GGBFS

GGBFS = 405.92 kg/m^3

Sodium silicate solution = 100.75 kg/m^3

Sodium hydroxide solution = 40.89 kg/m^3

Fine aggregate = 551.11 kg/m^3

Coarse aggregate (12 mm) = 1015.7 kg/m^3

Coarse aggregate (20 mm) = 276.74 kg/m^3

Water = 20 kg/m^3

VI EXPERIMENTATION

A. Workability

The slump test is carried out to determine the workability of concrete where the nominal maximum size of the aggregate does not exceed 38 mm. This test is used at a construction sites all over the world. It gives the idea of the water-cement ratio to be used for different works. Fresh unsupported concrete flows to the sides and the sinking in height takes place. The vertical settlement is known as a slump and is measured when supporting mould is removed. Concrete is said to be workable if it can be easily mixed, compacted and easily finished.

Slump Value:

Slump value indicates workability in the following manner.

1) 0 – 25 mm slump:

Indicates low workability suitable for mass reinforcement

2) 25 – 75 mm slump:

Indicates medium workability suitable for RCC work with less reinforcement.

3) 75 – 150 mm slump:

Indicates high workability suitable for RCC work with heavy reinforcement.

Slump Cone:

The mould for the test specimen shall be in the form of a frustum of a cone having the following internal dimensions.

- Bottom diameter (d_1) = 200 mm
- Top diameter (d_2) = 100 mm
- Height (h) = 300 mm

Observations:

TABLE II. SLUMP VALUE OF THE DIFFERENT CASES

Sl. no.	*Description of the case*	*Initial height of the slump (cm)*	*Final height of the slump (cm)*	*Slump Value (cm)*
1	Normal concrete	30	27	3
2	100% Fly ash	30	23	7
3	100% GGBFS	30	25.5	4.5

Inference:

All the geopolymer concrete cases above have medium workability suitable for RCC work with less reinforcement.

B. Tests Conducted

1) Compressive strength test:

Compressive strength test is conducted at 7 days and 28 days in CTM (compression testing machine) on 150mm x 150mm x150mm size cubes.

$$Load\ /Area = P/A \qquad (2)$$

2) Split tensile strength test:

Split tensile strength is conducted at 28 days on 300mm long and 150 mm diameter cylinders in a compression testing machine(CTM). Split tensile strength is calculated using the given formula:

$$2P/\pi DL \qquad (3)$$

where,

P is the load

L is the length of the cylinder and D is the diameter of the cylinder.

3) Flexural strength test:

Flexural strength is conducted on a beam of depth 100 mm, width 100 mm and length 500 mm in ultimate tensile strength testing machine (UTM). Flexural tensile strength test is given by the following formula

$$(f) = (M \times y)/I \qquad (4)$$

$$M = (P \times l)/4 \qquad (5)$$

$$I = (b \times d^3)/12 \tag{6}$$

$$y = d/2 \tag{7}$$

where,

M is the bending moment

f is the bending stress

I is the moment of inertia

y is the distance to the extreme fibre

P is the load

d is the depth of the beam

b is the width of the beam

l is the total length of the beam

C. Results

1) Case 1: Normal Concrete

TABLE III. 7 DAYS COMPRESSIVE STRENGTH TEST

Sl. No.	7 days compressive strength	
	Load (N)	***Strength (N/mm²)***
1	350×10^3	15.55
2	370×10^3	16.44
3	370×10^3	16.44

Average 7 days compressive strength = (15.55 + 16.44 + 16.44) / 3 = 16.14 N/mm^2

TABLE IV. 28 DAYS COMPRESSIVE STRENGTH TEST

Sl. No.	28 days compressive strength	
	Load (N)	***Strength (N/mm²)***
1	385×10^3	17.11
2	380×10^3	16.88
3	380×10^3	16.88

Average 28 days compressive strength = (17.11 + 16.88 + 16.88) / 3 = 16.96 N/mm^2

TABLE V. 28 DAYS SPLIT TENSILE STRENGTH TEST

Sl. No.	28 days split tensile strength	
	Load (N)	***Strength (N/mm²)***
1	455×10^3	6.51
2	460×10^3	6.44

Average 28 days split tensile strength = (6.51 + 6.44) / 2 = 6.47 N/mm^2

TABLE VI. 28 DAYS FLEXURAL STRENGTH TEST

Sl. No.	28 days flexural tensile strength	
	Load (N)	***Strength (N/mm²)***
1	10×10^3	7.5

$M = (P \times l) /4 = (10 \times 10^3 \times 500) /4 = 1250000$ N mm

$y = 100 / 2 = 50$ mm

$I = (b \times d^3) /12 = (100 \times 100^3) /12 = 8333333.33\ mm^4$

28 days flexural strength (f) = (M x y) / I

$= (1250000 \times 50) / 8333333.33 = 7.5\ N/mm^2$

2) Case 2: 100% Fly Ash Replacement of Cement

TABLE VII. 7 DAYS COMPRESSIVE STRENGTH TEST

Sl. No.	7 days compressive strength	
	Load (N)	***Strength (N/mm²)***
1	310×10^3	13.77
2	310×10^3	13.77
3	310×10^3	13.77

Average 7 days compressive strength = (13.77 + 13.77 + 13.77) / 3 = 13.77 N/mm^2

TABLE VIII. 28 DAYS COMPRESSIVE STRENGTH TEST

Sl. No.	28 days compressive strength	
	Load (N)	***Strength (N/mm²)***
1	460×10^3	20.44
2	460×10^3	20.44
3	455×10^3	20.22

Average 28 days compressive strength = (20.44 + 20.44 + 20.22) / 3 = 20.37 N/mm^2

TABLE IX. 28 DAYS SPLIT TENSILE STRENGTH TEST

Sl. No.	28 days split tensile strength	
	Load (N)	***Strength (N/mm²)***
1	210×10^3	2.97
2	220×10^3	3.11

Average 28 days split tensile strength = (2.97 + 3.11) / 2 = 6.47 N/mm^2

TABLE X. 28 DAYS FLEXURAL STRENGTH TEST

Sl. No.	28 days flexural tensile strength	
	Load (N)	***Strength (N/mm²)***
1	5×10^3	3.75

$M = (P \times l) /4 = (5 \times 10^3 \times 500)/4 = 625000$ N mm

y = 100 / 2 = 50 mm

I = (b x d^3) /12 = (100 x 100^3) /12 = 8333333.33 mm^4

28 days flexural strength (f) = (M x y) / I

= (625000 x 50) / 8333333.33 = 3.75 N/mm^2

3) Case 3: 100% GGBFS Replacement of Cement

TABLE XI. 7 DAYS COMPRESSIVE STRENGTH TEST

Sl. No.	7 days compressive strength	
	Load (N)	*Strength (N/mm^2)*
1	840 x 10^3	37.33
2	870 x 10^3	38.66
3	830 x 10^3	36.88

Average 7 days compressive strength = (37.33 + 38.66 + 36.88) / 3 = 37.63 N/mm^2

TABLE XII. 28 DAYS COMPRESSIVE STRENGTH TEST

Sl. No.	28 days compressive strength	
	Load (N)	*Strength (N/mm^2)*
1	950 x 10^3	42.22
2	960 x 10^3	42.66
3	980 x 10^3	43.55

Average 28 days compressive strength = (42.22 + 42.66 + 43.55) / 3 = 42.81 N/mm^2

TABLE XIII. 28 DAYS SPLIT TENSILE STRENGTH TEST

Sl. No.	28 days split tensile strength	
	Load (N)	*Strength (N/mm^2)*
1	750 x 10^3	10.61
2	760 x 10^3	10.75

Average 28 days split tensile strength = (10.61 + 10.75) / 2 = 10.68 N/mm^2

TABLE XIV. 28 DAYS FLEXURAL STRENGTH TEST

Sl. No.	28 days flexural tensile strength	
	Load (N)	*Strength (N/mm^2)*
1	15 x 10^3	11.25

M = (P x l) /4 = (10 x 10^3 x 500)/4 = 1875000 N mm

y = 100 / 2 = 50 mm

I = (b x d^3) /12 = (100 x 100^3) /12 = 8333333.33 mm^4

28 days flexural strength (f) = (M x y) / I

= (1875000 x 50) / 8333333.33 = 11.25 N/mm^2

VII COST ANALYSIS

Cost analysis is a summary of all the costs involved in doing particular work or unit work. In this project, case 1 (conventional concrete), case 2 (100% Fly ash) and case 3 (100% GGBFS) are cast. The mix design for M30 geopolymer concrete was derived and obtained a mix ratio of 1:1.3:3.1. NaOH solution (10 M) and Na_2SiO_3 solution (50.32%) are required in case 2 and case 3 for the polymerization reaction. Quantities of the materials required for 1 m^3 in all the cases and their rates are required for the cost analysis. Cost of cement, fine aggregate and coarse aggregate (12mm and 20mm) are obtained from the Schedule of Rates 2012: Volume 1.[5] The rates of the materials like NaOH, Na_2SiO_3, GGBFS and fly ash etc are obtained from the commercial market value.

TABLE XV. COST OF MATERIALS

Sl. No.	*Material*	*Rate (Rs.)*	*Per*
1	Fine aggregate	616	Cum
2	Coarse aggregate (20 mm)	942	Cum
3	Coarse aggregate (12 mm)	962	Cum
4	Cement	5940	Tonne
5	GGBFS	1950	Tonne
6	Fly ash	1700	Tonne
7	Sodium hydroxide flakes	28	Kg
8	Sodium silicate solution	8	Kg

TABLE XVI. COST PER m^3 OF CONCRETE

Sl. No.	*Cases*	*Cost per m^3 of concrete*
1	Conventional concrete	₹ 3453.50
2	100% Fly ash	₹ 2991.90
3	100% GGBFS	₹ 3094.40

VIII GRAPHICAL RESPRESENTATION OF RESULTS

TABLE XVII. RESULTS

Experiments	Results		
	Case 1	*Case 2*	*Case 3*
7 days compressive strength test (N/mm^2)	16.14	13.77	37.63
28 days compressive strength test (N/mm^2)	16.96	20.22	42.81
28 days split tensile strength test (N/mm^2)	6.47	3.04	10.68
28 days flexural strength test (N/mm^2)	7.5	3.75	11.25
Workability (mm)	30	70	45
Cost (Rs.)	3453.5	2991.9	3094.4

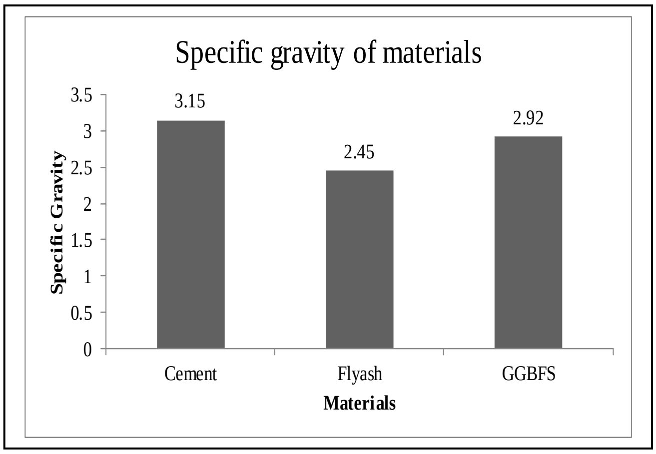

Fig 1. Graph showing specific gravity of materials

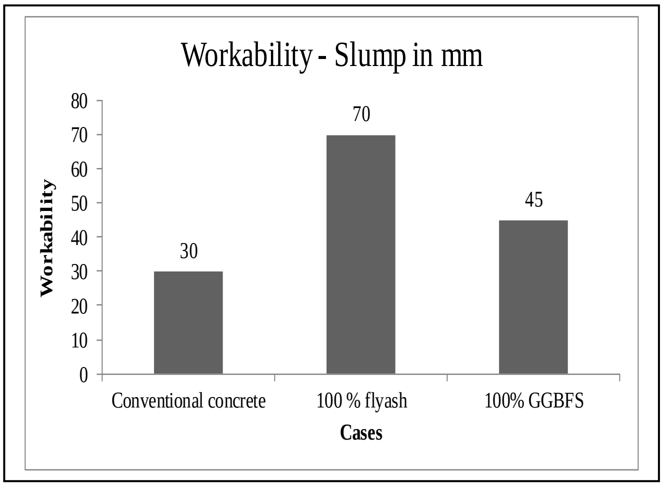

Fig 2. Graph showing workability

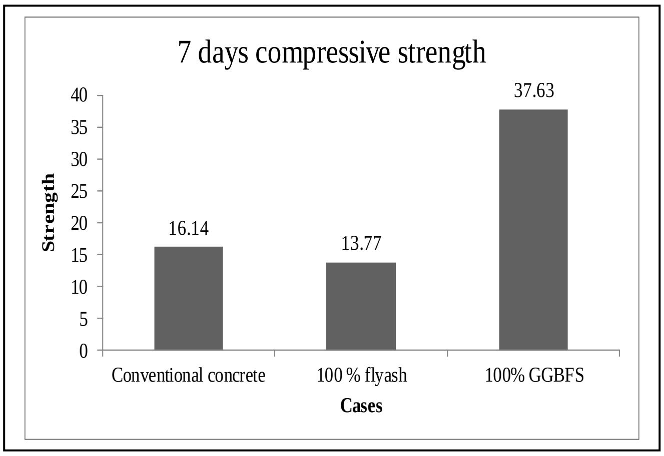

Fig 3. Graph showing 7 days compressive strength

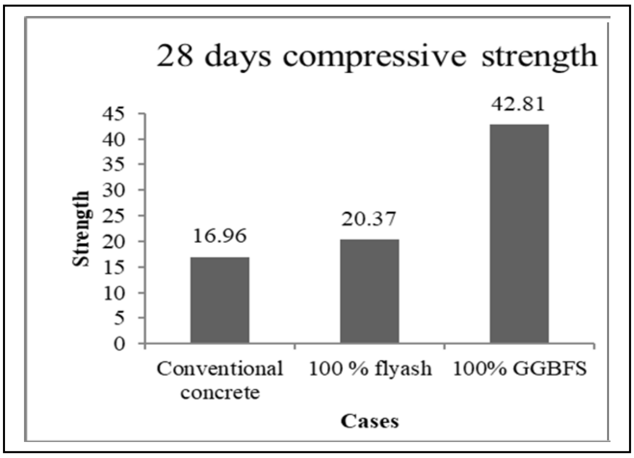

Fig 4. Graph showing 28 days compressive strength

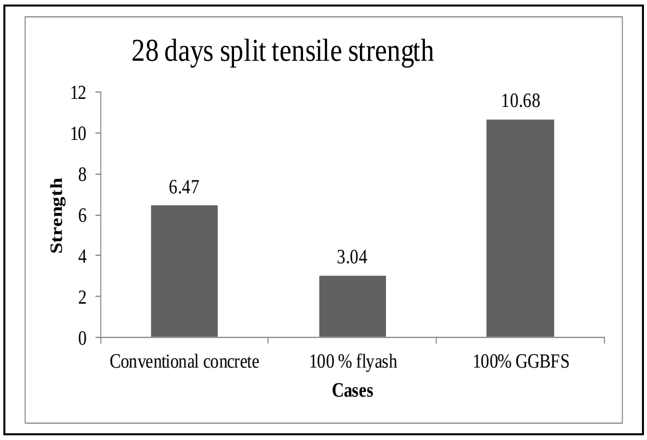

Fig 5. Graph showing 28 days split tensile strength

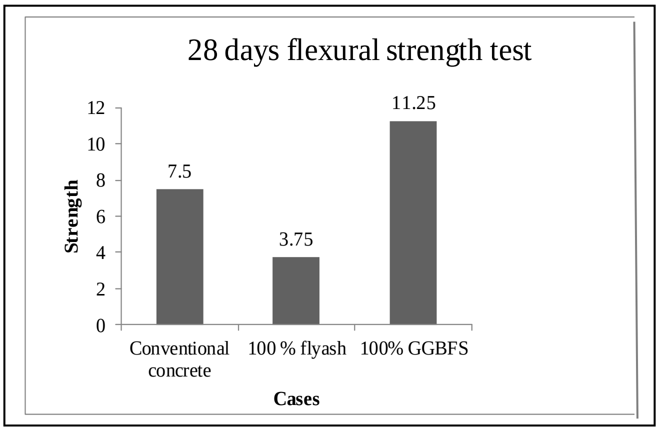

Fig 6. Graph showing 28 days flexural strength

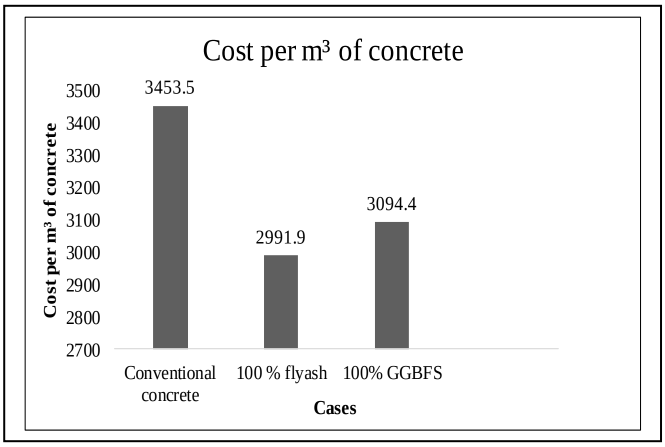

Fig 7. Graph showing cost analysis

IX CONCLUSION AND SCOPE FOR FUTURE WORKS

The concrete specimens were prepared in the ratio 1:1.3:3.1 for 7 and 28 days compressive strength, 28 days split tensile strength and 28 days flexural tensile strength. Cement was replaced by fly ash and GGBFS in the second and third case, respectively and NaOH / Na_2SiO_3 solutions were used for polymerization in the geopolymer concrete. The highest strength was obtained for 100% GGBFS geopolymer concrete. This shows considerably high strength compared to the 100% fly ash geopolymer concrete and normal cement concrete. The specific gravity of GGBFS and fly ash were found using a specific gravity bottle. The specific gravity of fly ash and GGBFS were found to be 2.45 and 2.92 respectively. Workability of all three cases was found using slump test and the slump value was obtained between 25 – 75 mm that gives medium workability suitable for RCC work with less reinforcement. Cost analysis was carried out for all the cases and the highest cost was obtained for conventional concrete and the lowest cost was for fly ash-based geopolymer concrete. This also shows that GGBFS based geopolymer concrete is economical as well as gives high strength to be used in various construction works. The study shows that usage of GGBFS increases the strength of geopolymer concrete and this reduces the harmful industrial solid waste released into the environment and promotes sustainable development. GGBFS can be collected from various industries and can be taken to a concrete mix plant or for making ready mix concrete which promotes a sustainable infrastructure in the country. Similar studies can be conducted on other aluminosilicates such as rice husk ash, metakaolin etc. The durability of different cases of geopolymer concrete can also be studied to find out where it can be used. GPC roads, runways, pavement blocks, LTGS bricks, precast industries, automotive applications and aircraft interior and cabin interior applications can be constructed or manufactured or fabricated in the future based on various investigations.

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