

Strength Studies On Geopolymer Concrete With Flyash And GGBS

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ABSTRACT

Geopolymer concrete is an example of a more sustainable and environmentally friendly concrete. Unlike traditional concrete, geopolymer concrete incorporates heavy aluminum and silica manufacturing byproducts such as fly ash and GGBS etc. In this study a combination of fly and GGBS was used to assess the strength development of geopolymer concrete along with the high sodium silicate ratio to sodium hydroxide 2:1. The study focusses on the basic and an elementary part for the better development of geopolymer concrete. The results at 50% of fly ash and 50% of GGBS gave satisfactory results and maximum compressive strength and split tensile strength were obtained at this combination. In our project considering the sodium hydroxide as 12M for ambient curing of geopolymer concrete. The shifting of Na₂SiO₃: NaOH from 2:1 gave a significant change in the compressive strength and Tensile strength of the geopolymer concrete.

Keywords: Geopolymer Concrete, GGBS, Alkaline Solution, Fly Ash, GPC Mix Design

I.INTRODUCTION

1.1 GENERAL

All the constructions around the world are constructed with the help of concrete such as Buildings, Roadways, Bridges, and Dams etc. concrete is a costly material and due to which the cost of the construction increases with the increase in the quantity of the concrete. Overcome this problem, we have used industrial waste materials as a fine aggregate and coarse aggregate. Waste foundry sand is used as a fine aggregate and steel slag is used as a coarse aggregate. In India like fast developing countries, the growth of construction industry is on the hike, with increase in demand for concrete materials. It remains a threat to the environment as the main ingredients of concrete are derived from non-renewable natural resources and the manufacturing ingredients highly releases CO₂. Efforts are being made to make the concrete more sustainable. In such a need, this research work focuses on replacing the major component of concrete, the coarse aggregate and fine aggregate. Also, the research work continues to study the performance of this scrap steel slag and foundry sand in geo- polymer concrete, which makes it even more environmentally friendly and sustainable. Concrete is an artificial material which is widely used in all the construction sectors.

1.2 GEOPOLYMER

The term, geopolymer was first introduced by Davidovits in 1978 to describe a family of mineral binders with chemical composition similar to zeolites but with an amorphous micro structure. Unlike ordinary Portland cements, geopolymer do not form calcium- silicate hydrates for matrix formation and strength, but utilize the poly condensation of silica and alumina precursors to attain structural strength. Two main constituents of geopolymer are source materials and alkaline liquids. The source materials on alumina-silicate should be rich in silicon (Si) and aluminum (Al). They could be by- product materials such as fly ash, silica fume, slag, rice-husk ash, red mud, etc. Geopolymers are also unique in comparison to other alumina-silicate materials.

The geopolymer technology may reduce the total energy demand for producing concrete, lower the CO₂ emission to the atmosphere caused by cement and aggregates industries by about 80%, thereby reducing the global warming. They possess the advantages of rapid strength gain, elimination of water curing, good mechanical and durability properties and can serve as eco-friendly and sustainable alternative to Ordinary Portland cement concretes.

1.3 FLYASH

Coal-based thermal power installations in India contribute about 65% of the total installed capacity for electricity generation. In order to meet the growing energy demand of the country, coal-based thermal

power generation is expected to play a dominant role in the future as well, since coal reserves in India are expected to last for more than 100 years. The ash content of coal used by thermal power plants in India varies between 25 and 45%. However, coal with an ash content of around 40% is predominantly used in India for thermal power generation. As a consequence, a huge amount of fly ash (FA) is generated in thermal power plants, causing several disposal-related problems. In spite of initiatives taken by the government, several non-governmental organizations and research and development organizations, the total utilization of FA is only about 50%.

India produces 130 million ton of FA annually which is expected to reach 175 million ton by 2012 and may exceed 225 million tons by 2017. Disposal of FA is a growing problem as only 15% of FA is currently used for high value addition applications like concrete and building blocks, the remainder being used for land filling. Globally, less than 25% of the total annual FA produced in the world is utilized. FA has been successfully used as a mineral admixture component of Portland cement for nearly 60 years. There is effective utilization of FA in making cement concretes as it extends technical advantages as well as controls the environmental pollution.

1.4 GGBS

Ground granulated blast furnace slag (GGBS) is a by-product from the blast-furnaces used to make iron. GGBS is a glassy, granular, non metallic material consisting essentially of silicates and aluminates of calcium. GGBS has almost the same particle size as cement. GGBS, often blended with Portland cement as low cost filler, enhances concrete workability, density, durability and resistance to alkali-silica reaction.

Alternative utility of fine aggregates and GGBS in construction industry that has emerged in recent years is in the form of Geopolymer concrete (GPC), which by appropriate process technology utilize all classes and grades of FA and GGBS, therefore there is a great potential for reducing stockpiles of these waste materials. Geopolymer concrete (GPC) are inorganic polymer composites, which are prospective concretes with the potential to form a substantial element of an environmentally sustainable construction by replacing or supplementing the conventional concretes. GPC have high strength, with good resistance to chloride penetration, acid attack, etc. These are commonly formed by alkali activation of industrial alumina- silicate waste materials such as FA and GGBS, and have a very small Greenhouse footprint when compared to traditional concretes.

II. LITERATURE SURVEY

1. GPC an eco-friendly construction material by L. Krishnan, S. Karthikeyan, S Nathiya, K. Suganyaat IJRET2019. The Alkaline liquids used in this study for the polymerization process are the solutions of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3). A 12 Molarity solution was taken to prepare the mix. The cube compressive strength was calculated for 12M solution for different mix Id i.e. F90 G10, F80 G20, F70 G30, and F60 G40 (Where F and G are, respectively, Fly Ash and GGBS and the numerical value indicates the percentage of replacement of cement by fly ash and GGBS). The cube specimens are taken of size 100 mm x 100 mm x 100 mm. Ambient curing of concrete at room temperature was adopted. In total 36 cubes were cast for different mix Id and the cube specimens are tested for their compressive strength at age of 1 day, 7 days and 28 days respectively. The result shows that geopolymer concrete cubes gains strength within 24 hours without water curing at ambient temperature. Also the strength of geopolymer concrete was increased with increase in percentage of GGBS in a mix. It was observed that the mix Id F60G40 gave maximum compressive strength of 80.50 N/mm². The geopolymer concrete gained strength within 24 hours at ambient temperature without water curing. The necessity of heat curing of concrete was eliminated by incorporating GGBS and fly ash in a concrete mix. The strength of geopolymer concrete was increased with increase in percentage of GGBS in a mix.

2. A Review on Strength and Durability Studies on Geopolymer Concrete by Shriram Marathe, Mithanthaya I R, N Bhavani Shankar Rao at Department of Civil Engineering, NMAMIT, Nitte, India 2018. This paper briefly reviews the constituents of geopolymer concrete, its strength and potential applications. The production of OPC requires large amount of energy consumption, also leading to an enormous emission of carbon di- oxide to the atmosphere, which is being a great challenge to the sustainable development. Efforts are needed to develop a environmental friendly civil engineering construction material for minimizing emission of green-house gases to the atmosphere. A review summary of the extensive literature survey conducted to know about one such environmental friendly concrete namely geopolymer concrete is presented in this paper. And conclusions were as followed. The load capacity and behavior of geopolymer columns are similar to the

conventional concrete. The bond strength of GGBS is observed to be significantly higher than that of conventional OPC concrete.

3. Rashida A jhumarwala et.al 2013. conducted an experimental investigation on Self compacting geopolymer concrete (SCGC). SCGC were synthesized from low calcium fly ash and it is activated by combination of sodium hydroxide and sodium silicate solution. Incorporation of super plasticizer is done for self-compatibility. In this study it is observed that maximum compressive strength of SCGC is achieved at higher temperature cured concrete. It is also observed that, as molarity increases the strength goes on decreasing.

4. Sashidhar C et.al 2015. conducted study on Fresh and Strength Properties of Self compacting Geopolymer Concrete Using Manufactured Sand. In this study, SCGC mixes were manufactured using class F fly ash and ground granulated blast furnace slag (GGBS) with proportion of 50:50 and with 100% manufactured sand (MS). This investigation is mainly focused on the fresh and compressive strength properties of SCGC. It is done by varying the molarity of sodium hydroxide. During all curing periods at ambient temperature, the contribution of GGBS helps the SCGC mixes to attain significant compressive strength development.

5. Ushaa T G et.al 2015. investigated the performance of self compacting geopolymer concrete containing different mineral admixtures. In this study, fly ash was replaced by different mineral admixtures. The use of such materials reduces the cost of self compacting geopolymer concrete. It occurs especially if the mineral admixtures used are waste or industrial by-product. From the study it was found that all the self compacting geopolymer concrete mixes had a satisfactory performance in the fresh state. Good workability is found for blast furnace slag series compared to silica fume series among the mineral admixtures considered.

III. OBJECTIVES

- To study the compressive strength of geopolymer concrete with 50% fly ash & 50% GGBS as replacement of cement.
- To study the split tensile strength of geopolymer concrete with 50% fly ash & 50% GGBS as fully replacement of cement.
- To compare the mechanical properties of geopolymer concrete with the conventional concrete.

IV. MATERIAL USED

4.1 MATERIAL AND ITS PROPERTIES

- Fly Ash.
- Ground Granulated Blast Furnace Slag (GGBS).
- Cement.
- Sodium hydroxide & Sodium silicate.
- Fine aggregate.
- Coarse aggregate.
- Water.

4.1.1 Fly Ash

Class F fly ash is a pozzolanic material produced as a by-product from the combustion of bituminous or anthracite coal in thermal power plants. It is characterized by low calcium content ($\text{CaO} < 10\%$) and high amounts of silica (SiO_2), alumina (Al_2O_3), and Iron oxide (Fe_2O_3). Light grey to dark grey colour depends on carbon and iron content Specific Gravity 2.1 – 2.8 Lower than cement.

4.1.2 Ground Granulated Blast Furnace Slag(GGBS)

Ground Granulated Blast Furnace Slag (GGBS) is a by-product obtained from the manufacture of iron in a blast furnace. It is formed when molten slag (a mixture of lime, silica, and alumina) is rapidly quenched with water or steam, resulting in a glassy granular material. Colour Off-white to light grey Depends on iron content Specific Gravity 2.7 - 2.95

4.1.3 Sodium hydroxide

Sodium hydroxide (NaOH), commonly known as caustic soda or lye, is a strong inorganic base with key physical and chemical properties that make it widely used in industry. It is highly soluble in water, with the dissolution process being highly exothermic (releases significant heat). NaOH melts at approximately 318°C and boils at 1,388°C. Sodium hydroxide is a white, odorless, crystalline solid in its pure form

4.1.4 Sodium silicate

Sodium silicate, commonly known as water glass or liquid glass, is a water-soluble alkaline compound composed of sodium oxide (NaO) and silica (SiO₂). It is one of the most important alkaline activators in geopolymer concrete, used in combination with sodium hydroxide (NaOH) to initiate polymerization reactions between silica and alumina present in source materials like fly ash and GGBS.

Cement
Cement is a binding material that, when mixed with water, sets and hardens through chemical reaction known as hydration. Its properties can be classified into physical, chemical, and mechanical properties.

4.1.5 Fine Aggregate

- Particle Size: Fine aggregates pass through a 4.75 mm sieve and are retained above a 75- micron sieve. This size distribution influences the workability and strength of concrete mixes.
- Specific Gravity: Ranges between 2.5 and 2.9, impacting the weight and overall calculations for concrete design.

4.1.6 Coarse Aggregate

- Size and Grading: Coarse aggregates typically range in size from 4.75 mm up to about 63 mm, with the maximum size selected as per structural requirements and spacing of reinforcements. Consistent grading is important for uniform concrete strength and workability.
- Specific Gravity: Usually range between 2.4 and 2.9, indicating that aggregate is 2.4-2.9 times denser than water.

4.2 Preliminary Test on Materials

Specific gravity

Specific gravity is said to be signify the ratio of the density of a substance. That is to be density of a reference substance. specific density is also known as relative density. We are conducted specific gravity test on materials for knowing the obtained values of specific gravity

- Fly Ash and GGBS

Table 4.2.1: Physical Properties of Fly Ash & GGBS

S.No	Material	Name Of The Test	Result
1	Fly Ash	Specific Gravity	2.76
2	GGBS	Specific Gravity	2.92

- Fine Aggregates

Table 4.2.2: Specific Gravity of Fine Aggregate

S.No	Observations	Result
1	Weight of empty Bottle, W1 =	610 gms
2.	Weight of (Bottle + F.A), W2 =	1160 gms

3	Weight of (Bottle + F.A+ water), W3 =	1784 gms
4.	Weight of (Bottle + Water), W4 =	1440 gms
5.	Specific Gravity of Fine Aggregate= $(w_2-w_1)/((w_2-w_1)-(w_3-w_4))=$	2.67

Coarse Aggregate

Table 4.2.3: Specific Gravity of Coarse Aggregate

S.No	Observations	Result
1.	Weight of empty Bottle, W1 =	610 gms
2.	Weight of (Bottle + F.A), W2 =	1606 gms
3	Weight of (Bottle + F.A+ water), W3 =	2056 gms
4	Weight of (Bottle + Water), W4 =	1440 gms
5	Specific Gravity Coarse Aggregate= $(w_2-w_1)/((w_2-w_1)-(w_3-w_4)) =$	2.7

4.1.7 Analysis Of Fine Aggregate

The sieve analysis is conducted to determine the particle size distribution in a sample of aggregate, which we call gradation. Many a times, fine aggregates are designated as coarse sand, medium sand and fine sand. These classifications do not give any precise meaning. What the supplier terms as fine sand may be really medium or even coarse sand and also find the zone classification by using sieve analysis.

Table 4.2.4 Sieve Analysis Test Results for Fine Aggregate

Sieve size	Mass retained in grams	Cumulative weight retained in each sieve	Weight passed in grams	%age Passing	Permissible Range For Zone-II as per IS:383-2016		
					Zone-I	Zone-II	Zone-III
10 mm	0	0	2000	100	100	100	100
4.75 mm	135	135	1865	93.25	90-100	90-100	90-100
2.36 mm	343	478	1522	76.10	60-95	75-100	85-100
1.18 mm	385	863	1137	56.85	30-70	55-90	75-100
600 μm	335	1198	802	40.10	15-34	35-59	60-79
300 μm	455	1653	347	17.35	5-20	8-30	12-40
150 μm	290	1943	57	2.85	0-20	0-20	0-20

The Grading Zone of fine aggregate =Zone – II

Table 4.2.5: Coarse Aggregate Sieve Analysis Test Results. :

Sieve size	Percentage passing	Requirements as per IS:383-2016 %passing Graded aggregates
20 mm	100	100
12.5 mm	100	85-100
10 mm	42	0- 45
Pan	08	0- 10

V. METHODOLOGY

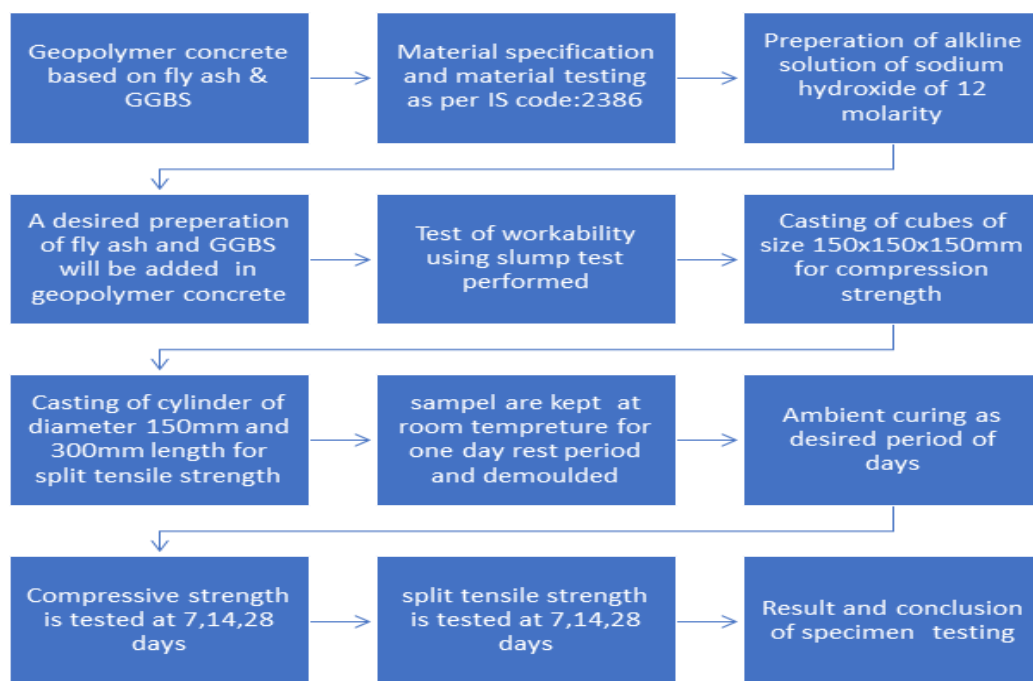


Fig 5.1: Flow chart of methodology

5.1 Preparation of Alkaline Solution

The characteristics of geo polymer concrete is assessed for mixes of 12 Molarity of NaOH. The nuclear load of NaOH is 40. To prepare of 12 molarity of arrangement, 480 grams of sodium hydroxide chips are gauged and broke down in 1 liter refined water. NaOH chips are added bit by bit to refined water to prepare arrangement. The weight of sodium hydroxide pieces considered to get ready NaOH arrangement is appeared in table below.



Fig 5.1.1: Alkaline Solution

5.2 Mix of Geopolymer Concrete

Cover is the significant distinction among GPC and PPC. Alkaline activator arrangement is utilized to respond with silicon and aluminum oxides to shape a geopolymer paste. The thickness of GPC is 2400 Kg for every meter cube. In this fly ash and GGBS are taking diverse replacements. The proportion is 2.5 for sodium silicate to sodium hydroxide and the proportion of soluble activator to the fly ash is taken as 0.35 percent consistent.



Fig 5.2: Mixing of Concrete

5.3 Casting of specimens

The arrangement of anti acid activator is to be set up before 24 hours of casting. Properly blended geopolymer concrete is emptied promptly into the moulds. Concrete is put in 3 layers and packing is accomplished for each layer by giving in excess of 25 blows, so as to get completely compacted geopolymer concrete specimens. Then top surface is very much wrapped up. Following 24 hours the molds were demoulded and were kept in a room temperature for curing. The sizes of molds utilized are 3D shape (150mmx150mmx150mm); chamber (150mm dia and 300 mm stature).



Fig 5.3: Casting of Specimen

5.4 Curing of Specimens:

- **Water curing**

The test specimens are stored in moist air for 24 hours and after this period the specimens are marked and removed from the moulds and kept submerged in clear fresh water until taken out prior to test.

Curing is the process where the concrete surfaces are kept wet for a certain period after placing of concrete so as to promote the hardening of cement. It consists of a control of temperature and of the moisture movement from and into the concrete.



Fig 5.4.1: Curing of Cubes in Water

- **Ambient Curing**

Ambient curing of geopolymer concrete (GPC) means letting it harden at normal room temperatures (around 20-35°C) instead of using ovens, making it more practical for construction, though strength gain is slower than with heat curing. Achieving good strength involves optimizing mix designs with materials like Flyash/GGBS, activators (NaOH/Na₂SiO₃), and sometimes fibers or silica fume, allowing for structural use, but longer curing times (up to 28+ days) are needed to reach design strength.



Fig 5.4.2: Ambient Curing

VI. TEST ON EXPERIMENTAL SPECIMENS

6.1 COMPRESSIVE STRENGTH TEST

As per IS Code for each mix 3 cubes should be casted for checking the compressive strength of concrete so after the desired curing period, the compressive strength of the specimen is determined.

So in total 18 cubes each of size 15cm X 15cm X 15cm were tested by compressive testing machine out of which 3 cubes were tested after 7 days and 3 cubes were tested after 14 days and 3 cubes were tested after 28 days.

Compressive strength= Load/Cross sectional area.



Figure 6.1.1: Compressive Strength

6.2 SPLIT TENSILE STRENGTH

As per IS Code for each mix 3 cylinder should be casted for checking the split tensile strength of concrete so after the desired curing period, the compressive strength of the specimen is determined.

So in total 6 cylinder each of size 15 cm dia 30cm hight were tested by compressive testing machine out of which 3 cylinder were tested after 7 days and 3 cylinder were tested after 28 days.

Split Tensile strength was calculated as follows as split tensile strength: Split Tensile strength (MPa) = $2P / \pi DL$,

Where, P= failure load D

= diameter of cylinder L

= length of cylinder



Figure 6.2.1: Split Tensile Strength

VII. RESULTS

CONVENTIONAL CONCRETE COMPRESSION TEST RESULTS.

Table No 7.1: Conventional Concrete compressive strength 7 days

Sample No.	Weight (Kg)	Load (KN)	Compressive Strength (N/mm ²)
1	8.25	450	20.00
2	8.23	430	19.10
3	8.34	450	20.00
Mean			19.70

Table No 7.2: Conventional Concrete compressive strength 14 days

Sample No.	Weight (Kg)	Load (KN)	Compressive Strength (N/mm ²)
1	8.28	550	24.44
2	8.40	535	23.77
3	8.35	580	25.70
Mean			24.63

Table No 7.3: Conventional Concrete Compressive Strength 28 days

Sample No.	Weight (Kg)	Load (KN)	Compressive Strength (N/mm ²)
1	8.01	820	36.40
2	8.53	700	32.00
3	8.65	780	34.60
Mean			34.33

GEOPOLYMER CONCRETE COMPRESSION TEST RESULTS

Table 7.4: Geopolymer Concrete Compression Test 7 Days

Sample No.	Weight (Kg)	Load (KN)	Compressive Strength (N/mm ²)
1	8.54	455	20.22
2	8.43	400	17.77
3	8.52	420	18.66
Mean			18.88

Table 7.5: Geopolymer Concrete Compression Test 14 Days

Sample No.	Weight (Kg)	Load (KN)	Compressive Strength (N/mm ²)
1	8.64	560	24.88
2	8.41	545	24.22
3	8.31	530	23.55
Mean			24.21

Table 7.6: Geopolymer Concrete Compression Test 28 Days

Sample No.	Weight (Kg)	Load (KN)	Compressive Strength (N/mm ²)
1	8.53	850	37.77
2	8.41	820	36.44
3	8.48	790	35.11
Mean			36.44

CONVENTIONAL CONCRETE SPLIT TENSILE TEST RESULTS

Table 7.7: Conventional Concrete Split Test Results 7 days

Sample No.	Weight (Kg)	Load (KN)	Split Tensile Strength (N/mm ²)
1	16.85	150	2.12
2	16.55	100	1.41
3	16.25	180	2.54
Mean			2.05

Table 7.8: Conventional Concrete Split Tensile Test Results 28 days

Sample No.	Weight (Kg)	Load (KN)	Split Tensile Strength (N/mm ²)
1	15.67	200	2.82
2	15.46	260	3.67
3	16.50	325	4.59
Mean			3.69

GEOPOLYMER CONCRETE SPLIT TENSILE TEST RESULTS

Table 7.9: Geopolymer Concrete Split tensile Test Results 7 days

Sample No.	Weight (Kg)	Load (KN)	Split Tensile Strength (N/mm ²)
1	16.55	160	2.26
2	15.98	140	1.98
3	15.84	210	2.97
Mean			2.04

Table 7.10: Geopolymer Concrete Split Tensile Test Results 28 days

Sample No.	Weight (Kg)	Load (KN)	Split Tensile Strength (N/mm ²)
1	16.95	210	2.97
2	16.74	300	4.24
3	15.89	350	4.95
Mean			4.05

Final Resultw

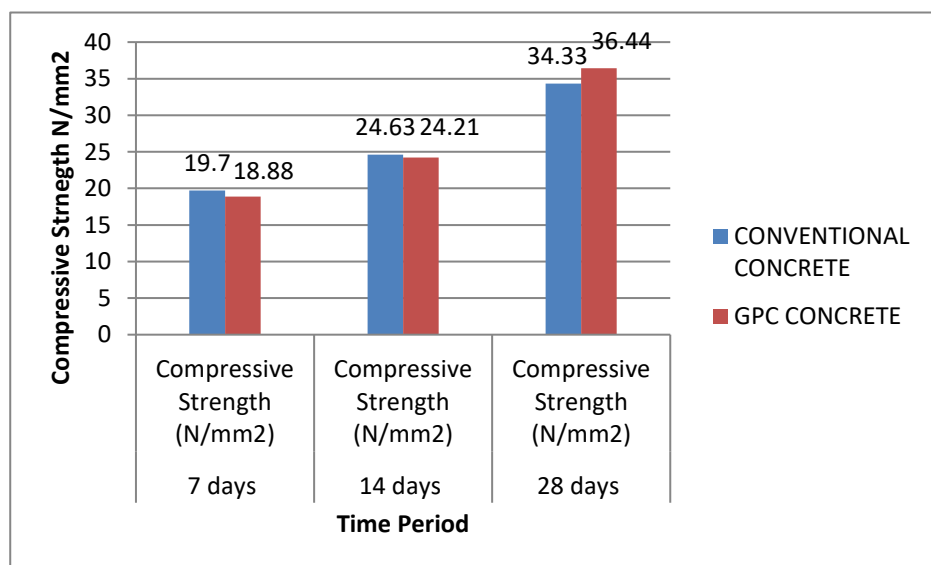


Fig 7.1: Result of Compressive Test

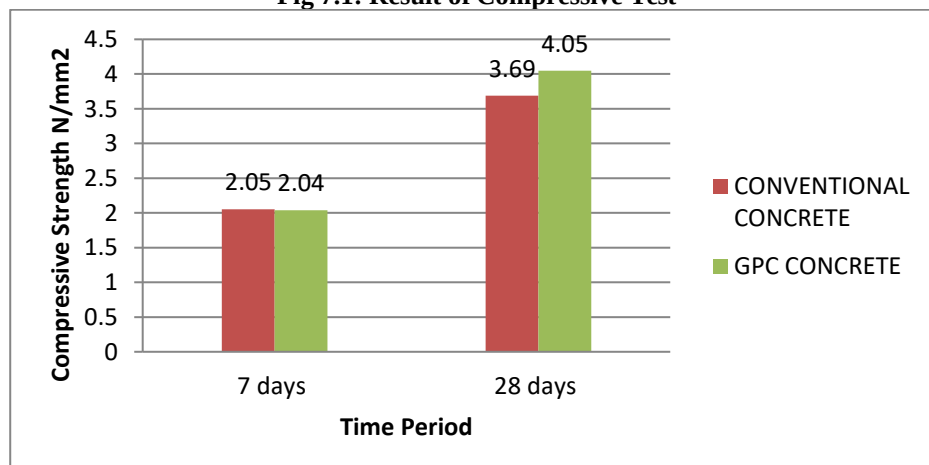


Fig 7.2: Result of Split Tensile Test

VIII. CONCLUSION

- 12M Geopolymer concrete has maximum compressive strength of 36.44N/mm² which is 7.37% greater than conventional concrete.
- 12M Geopolymer concrete has maximum split tensile strength of 4.05N/mm² which is 9.30% greater than conventional concrete.
- Combining Fly Ash (rich in silica/alumina) and GGBS (high in calcium) creates a more reactive binder system, improving mechanical properties
- As our aim was: cement can be completely replaced with 50% Fly Ash and 50% GGBS, to give the better strength compare to the conventional concrete. The aim is achieved based on studies conducted.

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