CHARACTERIZATION OF GEOPOLYMER CONCRETE USING GGBS AND FLY ASH WITH C&D WASTE IN DIFFERENT CURING METHODS

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Article History:Received: 03.11.2022 **Revised:**15.12.2022 **Accepted:** 1.01.2023

Abstract: *Concrete is the second most used product in the world after water, however consuming more amount of Cement is not good for our planet, because this Cement itself contributes 7% of the worlwide carbon dioxide emission. Although, Cement cause serious effects to our environment, we can't eliminate Cement completely in construction practise, especiall in India, because in India most of the structures are built using concrete material, wehere cement is the main ingrediant for concrete, however, this is not the similar case in other countries for instance in western countries like United States of America, and Canada, are covered with high rise structures which is built by steel, and individual houses are built using woods. So, to control the carbon emission, geopolymer concrete was introduced into the civil field, in geopolymer concrete Cement can be completely eliminated, instead Cement, other cementitous materials can used for instance Fly ash and GGBS, and Alkaline Activated Content can be used to enhance the polymerization process. So, in this paper, it is mainly discussed about geopolymer concrete with Fly Ash and GGBS with differement mix ratio: 100% Fly Ash 0% GGBS, 100% GGBS and 0% Fly Ash, 50% GGBS and 50% Fly Ash, 75% GGBS and 25% Fly Ash, finally 75% Fly Ash and 25% GGBS. For different mix proportions mechanical properties of Geopolymer Concrete were determined such as Compressive Strength, Split Tensile Strenght, and flexural strength*

Keywords: ***Geopolymer concrete, Fly Ash, GGBS, Compressive Strength***

DOI: 10.31838/ecb/2023.12.1.006

1. INTRODUCTION

Ordinary Portland Cement (OPC) is the most commonly used building material on the planet, and it is the main ingredient in concrete. Furthermore, cement manufacturing emits a considerable volume of carbon dioxide (CO2) into the atmosphere, which adds directly to greenhouse gas emissions. For every ton of OPC made, one ton of CO2 is expected to be emitted into the atmosphere. As a result, there is a need to find viable alternatives to traditional cement. However, there are several alternatives that are industrial by-products, such as Fly Ash, GGBS, and copper slag, which have cementitious properties[3].

Davidovits coined the word "geopolymer" in 1978 to describe a group of mineral binders with a chemical composition comparable to zeolites but an amorphous microstructure. Unlike ordinary Portland cements, geopolymers depend on the polycondensation of silica and alumina precursors to achieve structural strength rather than calcium silicate hydrates for matrix forming and strength[7]. Two main constituents of geopolymers are source materials and alkaline liquids. Cement can be entirely substituted by marginals such as Fly Ash and GGBS, which reacts with alkaline solutions to form a cementitious substance that does not release carbon dioxide into the atmosphere and improves the mechanical properties of geo – polymer concrete. [GPC].

Davidovits proposed that binders could be produced by polymeric reaction of alkaline liquids with the silicon and the aluminium in source materials or by – product materials such as fly ash and rice husk ash. Portland cement is still the main binder in concrete construction prompting a search for more environmentally friendly materials[12].

2. MATERIALS USED

To determine the mechanical properties of geopolymer concrete and find the most optimum design of concrete, the materials used are ground granulated blast furnace slag, fly ash, sodium hydroxide pellets, sodium silicate solution, tap water, M-Sand, and coarse aggregate[1,2]

2.1. Ground granulated blast furnace slag [GGBS]

GGBS (Ground Granulated Blast-furnace Slag) is a cementitious substance that is mostly used in concrete and is a by-product of iron blast furnaces. Blast furnaces run at about 1,500°C and are supplied with a finely balanced combination of iron ore, coke, and limestone. The iron ore is converted to iron, and the remaining materials float on top of the iron, forming slag.

Table 1 Properties of GGBS

Description	Value
Calcium Oxide	40%
Silica	35%
Alumina	13%
Magnesia	8%
Color	Off-white
Specific Gravity	2.85
Bulk Density	1000-1100 kg/m3
Fineness	>350 m2/kg

2.2. Fly Ash

Fly ash is a coal burning substance that is made up of particulates and flue gases that are ejected from coal-fired boilers. The ash that accumulates at the bottom of the boilers is gathered. Electrostatic precipitators are often used to trap fly ash. Class F fly ash was used for the GPC

Table 2 Properties of Fly Ash

Sl. No	Properties	Test Results
1	Specific gravity of Fly ash	2.2
2	Fineness, percentage passing on 150 µm sieve	99.6%
3	Fineness, Percentage passing on µm sieve	98.1%
4	Class of Fly Ash	Class F

2.3 Sodium Hydroxide Solution [NaOH]

Sodium hydroxide pellets were used and were mixed with water to form sodium hydroxide solution. When sodium hydroxide pellets and water are mixed, it causes an exothermic reaction and hence the solution should be used the next day.

2.4 Sodium Silicate Gel [Na2SiO3]

Sodium silicate gel is used for the polymerisation process to occur. Here we have used it in the ratio of 1:1.5 where 1 denotes the quantity of sodium hydroxide and 1.5 gives the quantity of silicate gel with respect to sodium hydroxide solution.

2.5 Fine aggregate

A good quality M-sand was used which was single washed to attain finer particles according to IS - 383: 1970. The specific gravity was 2.65.

2.6 Coarse aggregate

A combination of 12mm and 20mm coarse aggregate were used in the combination of 65% - 20mm and 35% - 12mm as per IS – 2386-1: 1963. The specific gravity was 2.65

3. MIX DESIGN

We used the density method approach for our mix design, but now we'll set our concrete's target density first, and then we'll do the GPC mix design. The density of concrete is often thought to be 2400 kg/m3, which is unrealistic since concrete density varies based on the number of additives in the mix. We used an 8-molarity solution, which equaled 320g (40 x 8) of Sodium Hydroxide, and a 1-to-1.5 ratio of Sodium Hydroxide Solution to Sodium Silicate Gel. **Table 2** displays the mix proportion for one cubic meter of concrete.

Table 3 Mix proportion for one cubic meter of concrete.

Description	Value
Weight of Sodium Hydroxide	80 kg/m^3
Weight of Sodium Silicate gel	120 kg/m^3
Weight of Binder content	500 kg/m^3
Weight of Fine aggregate	628.7 kg/m^3
Weight of Coarse aggregate	1220 kg/m^3

4. TEST RESULTS AND DISCUSSION

The tests were conducted on five different mix proportions which are,

1. GPC 1 - 100% Fly Ash
2. GPC 2 - 100% GGBS
3. GPC 3 - 50% GGBS – 50% Fly Ash
4. GPC 4 - 25% GGBS – 75% Fly Ash
5. GPC 5 - 75% GGBS – 25% Fly Ash

4.1. Slump Cone Test

Slump cone test was conducted to determine the workability of fresh concrete. Slump as per IS 1199-1959 was followed.

Table 4 Slump Cone test of Mix Proportions

Mix Proportion	Slump [mm]
GPC 1	True Slump
GPC 2	True Slump
GPC 3	90 mm
GPC 4	70 mm
GPC 5	110 mm

4.2. Compressive strength

The average compressive strength values for 3days and 7 days respectively for the 5 trial mixes - 100% GGBS, 100% Fly ash, 50% GGBS-50% Fly ash, 75% GGBS-25% Fly Ash, 25% GGBS-75% Fly ash respectively are shown in **Table 5, Table 6**, **Table 8, Table 9** and **Fig 1**, **Fig 2, Fig 3, Fig 4** gives the graphical representation of the compressive strength.

4.3. Split tensile strength

*The average split tensile strength results of 50% GGBS – 50% Fly Ash is given in **Table 7** and **Fig 5** gives the graphical representation.*

4.4. Flexural strength

*The average flexural strength results of the different specimen sets are given in **Table 10** and **Fig 6** shows the strength changes for different curing periods respectively.*

Table 5 *Three-day Compressive Strength test results*

		Compressive Strength [MPa]

S.No	Trial Mix	3 Days	
		Ambient Curing	Hot Air oven Curing @ 60C
1	GPC 1	1.67	2.58
2	GPC 2	25.39	27.28
3	GPC 3	23.125	28.93
4	GPC 4	6.95	10.22
5	GPC 5	25	28.79

Table 5 gives us the data for the compressive strength of geopolymer concrete for 3 days for the cube specimens kept for both ambient curing and hot air oven curing. Here we can observe that initially 100% ggbs gives us the highest strength of 25.39 MPa under ambient curing and 31.28 MPa under hot air oven curing and 50% GGBS – 50% Fly ash cube specimens are comparatively closer but still has lesser strength.

Table 6 *7-day Compressive Strength test results*

S.No	Trial Mix	Compressive Strength [MPa]	
		7 Days	
		Ambient Curing	Hot Air oven Curing @ 60C
1	GPC 1	5	16.2
2	GPC 2	27.55	28.29
3	GPC 3	36.8	42.36
4	GPC 4	14.35	17.25
5	GPC 5	33.27	36.54

Table 6 gives us the data for the compressive strength of geopolymer concrete for 7 days for the cube specimens kept for both ambient curing and hot air oven curing. Here we can observe that 50% GGBS - 50% Fly Ash gives us more strength than anyother mix

proportion, be it in ambient curing or hot air oven giving us values as 36.8Mpa in ambient curing and 42.36MPa in hot air oven curing.

Table 7 Split Tensile Strength Results

	Curing Age	Split Tensile Strength [MPa]
GPC 3	7 Day	2.104
	14 Day	3.48
	28 Day	4.18

Table 7 shows the split tensile strength results for 50% GGBS – 50% Fly ash cylinder specimens. Here we can observe the average load that each specimen withstood for the 7day specimen, 14day specimen and 28 day specimen. And the split tensile strength for 7 day is 2.104 MPa and 28 day is 4.18 MPa.The values are depicted as a graphical representation in fig.4

Fig 1 Accelerated Curing Correction Factor

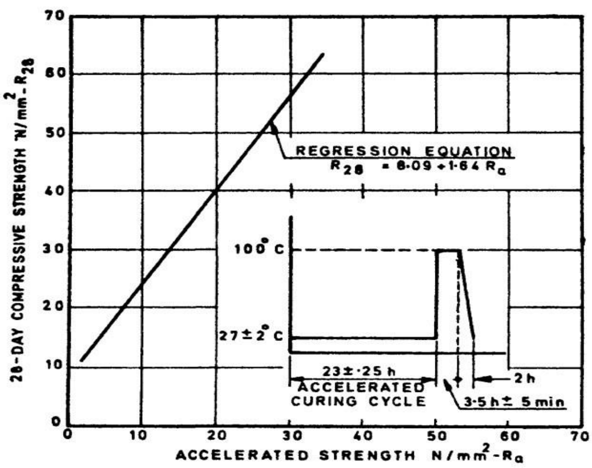


Table 8 28-day Compressive Strength test results

S.No	Trial Mix	Compressive Strength [MPa]	
		28 Days	
		Achieved through Accelerated Curing	Corrected Value using correction factor R28
1	GPC 1	-	-
2	GPC 2	36.33	67.7
3	GPC 3	42.6	77.954
4	GPC 4	16.62	35.34
5	GPC 5	39.51	72.88

Table 8 displays the data on compressive strength of geopolymer concrete for 28 days which was achieved through accelerated curing. In this we can observe that GPC 3 cube specimens gives us the highest strength of 42.6MPa which is 77.954 MPa after the correction factor is applied to it.

Table 9 - 28-day Compressive strength test of specimens subjected to ambient curing and hot air oven curing at 60^{o}C

S.No	Trial Mix	Compressive Strength [MPa]	
		28 Days	
		Ambient Curing	Hot air overn curing @ 60C
1	GPC 1	16.3	21.5
2	GPC 2	59.67	61.25
3	GPC 3	66.27	75.81
4	GPC 4	32.87	36.54
5	GPC 5	62.4	65..91

Table 9 shows the value of compressive strength of cube specimens after 28 days in which specimens from all the five trial mixes were subjected to ambient curing and hot air oven curing and a comparison was drawn from them which is depicted in fig.3.

Table 10 - Fluxural Strength test Results

	Curing Age	Flexural Strength [MPa]
GPC 3	7 Day	4.03
	14 Day	4.21
	28 Day	5.85

Table 10 shows the flexural strength values obtained at 7day, 14day and 28day curing period subjected to ambient curing. The values are depic ted in graaphical representation in fig.6. The value obtained at 28day is 5.85 MPa.

Fig 1 - Compressive Strength of Specimens at 3rd Day for the Ambient Curing

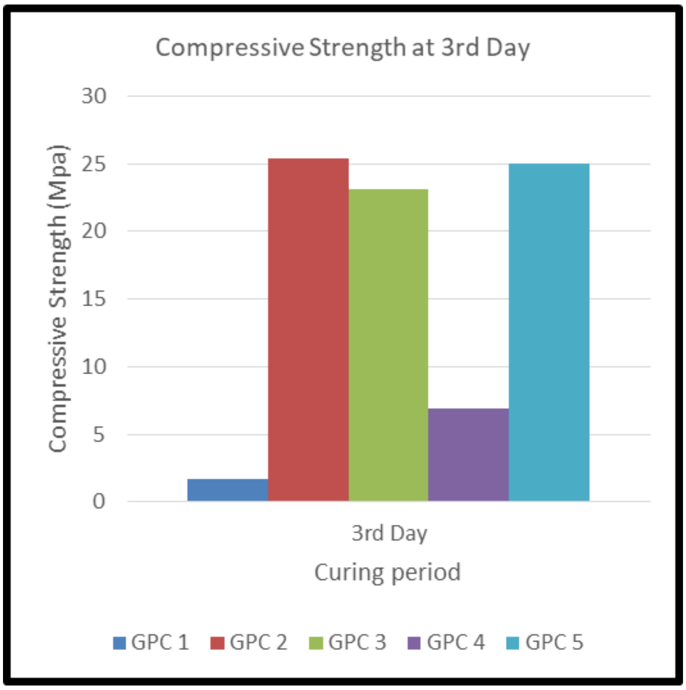


Fig 2 - Compressive Strength of Specimens at 3rd Day for the Hot Air Oven Curing

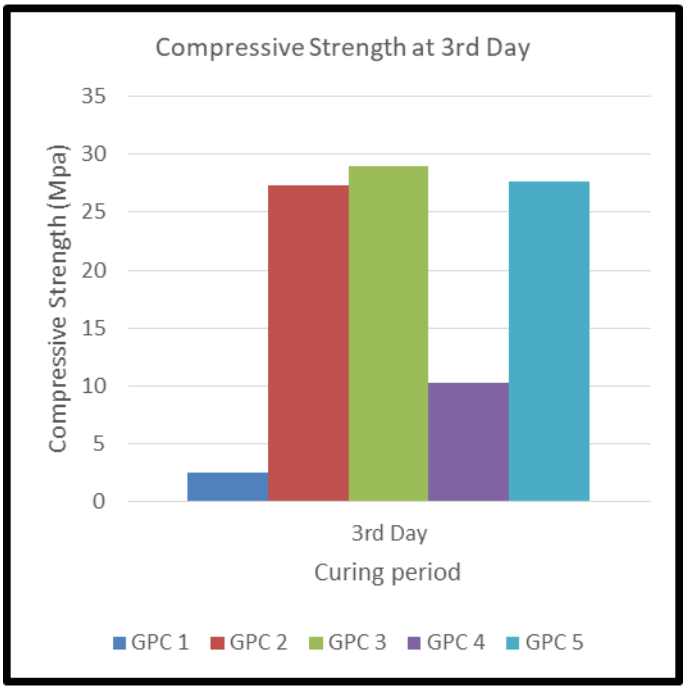


Fig 3 - **Compressive Strength of the Specimens at 7th Day for the Ambient Curing**

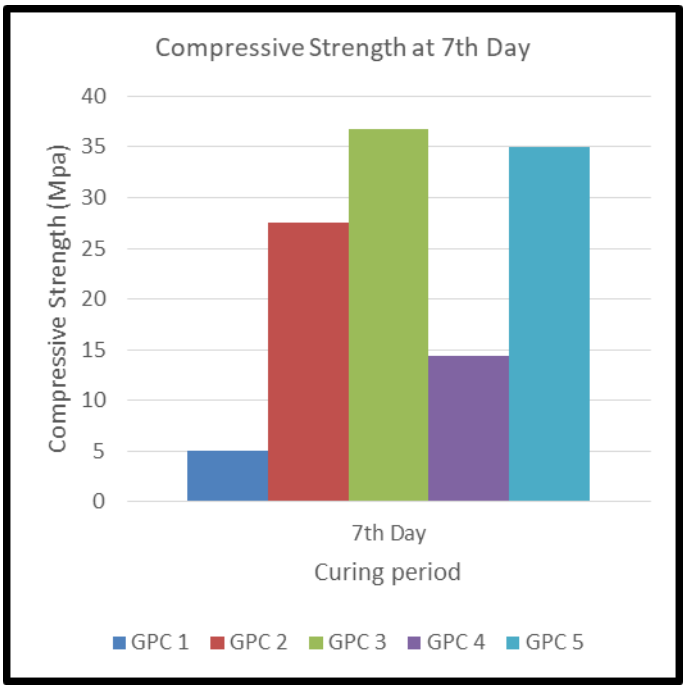
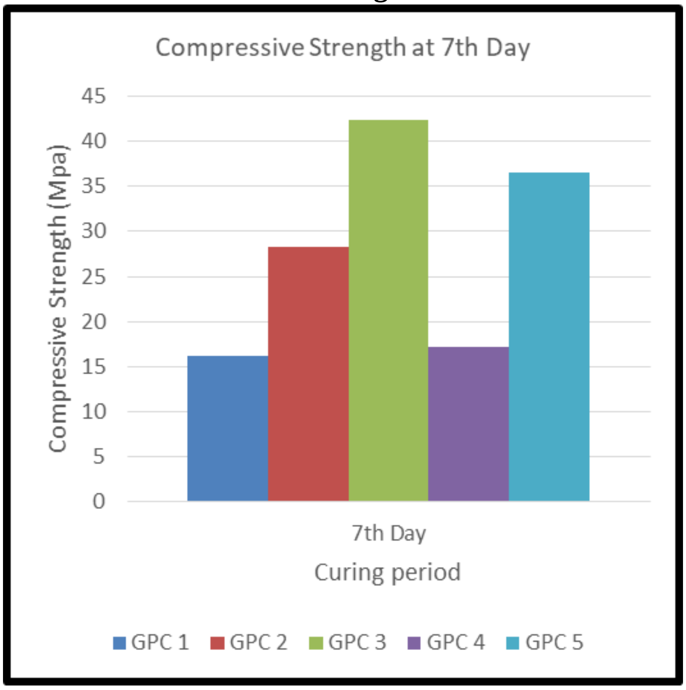
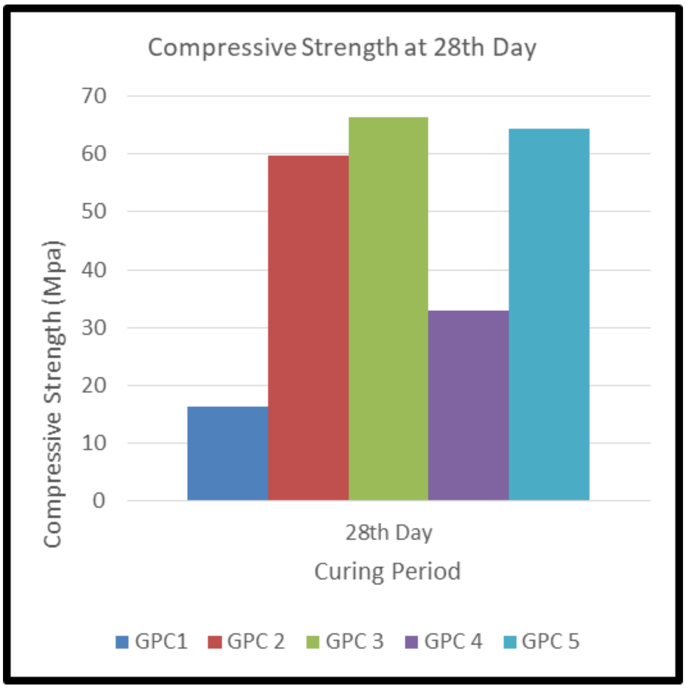


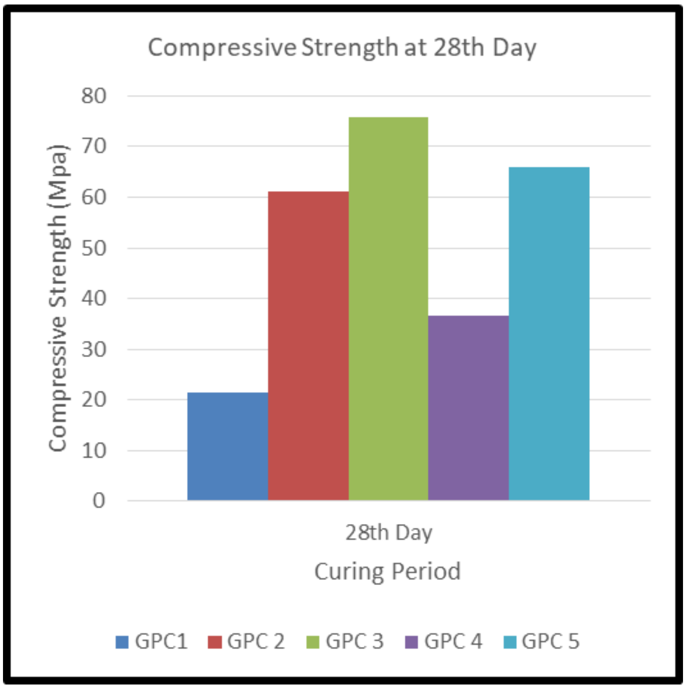
Fig 4 - **Compressive Strength of the Specimens at 7th Day for the Hot Air Oven Curing**



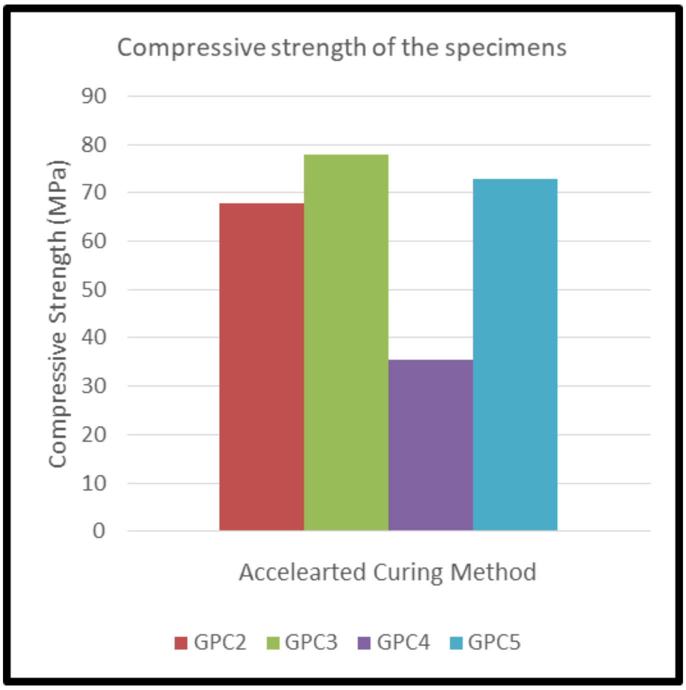
<u>Fig 5</u> - Compressive Strength of the Specimens at 28th Day for the Ambient Curing



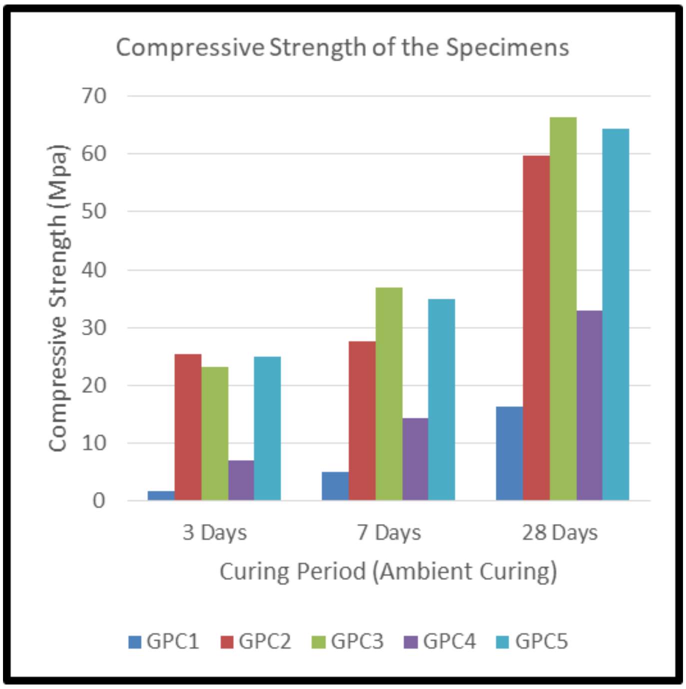
<u>Fig 6</u> - Compressive Strength of the Specimens at 28th Day for the Hot Air Oven Curing



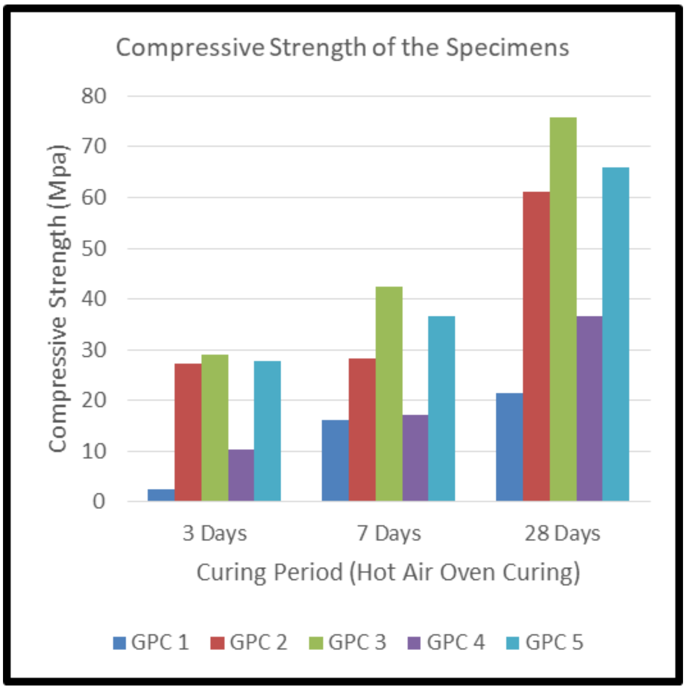
<u>Fig 7</u> - Compressive Strength of the Specimens Kept for Accelerated Curing



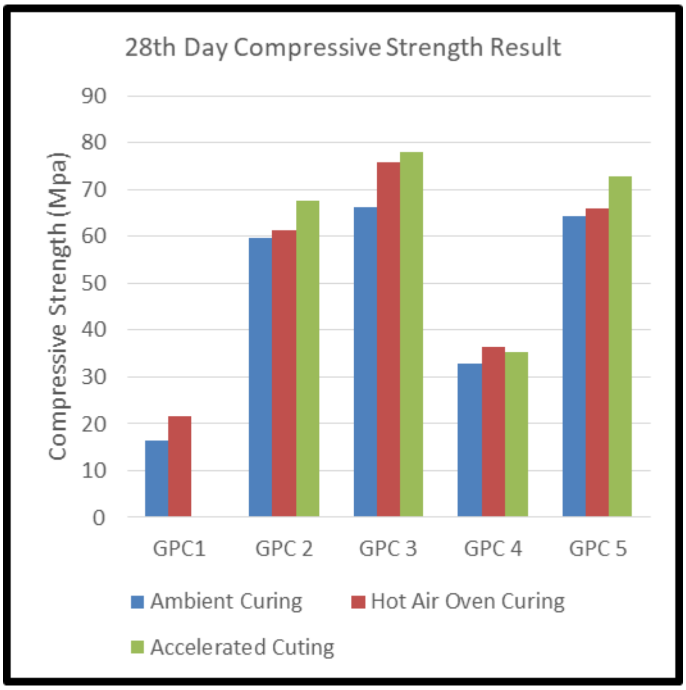
<u>Fig 8</u> - Compressive Strength of the Specimens Kept for Ambient Curing



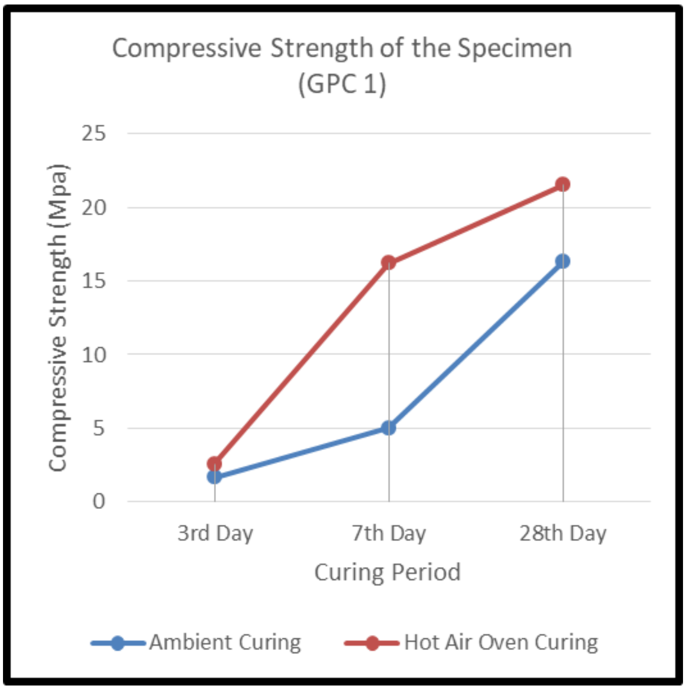
<u>Fig 9</u> - Compressive Strength of the Specimens Kept for Hot Air Oven Curing



<u>Fig 10</u> – 28 Days Compressive Strength of the Specimens Kept for Different Curing Method



<u>Fig 11</u> – Comparison Compressive Strength of GPC 1 with Different Curing Methods



<u>Fig 12</u> – Comparison Compressive Strength of GPC 2 with Different Curing Methods

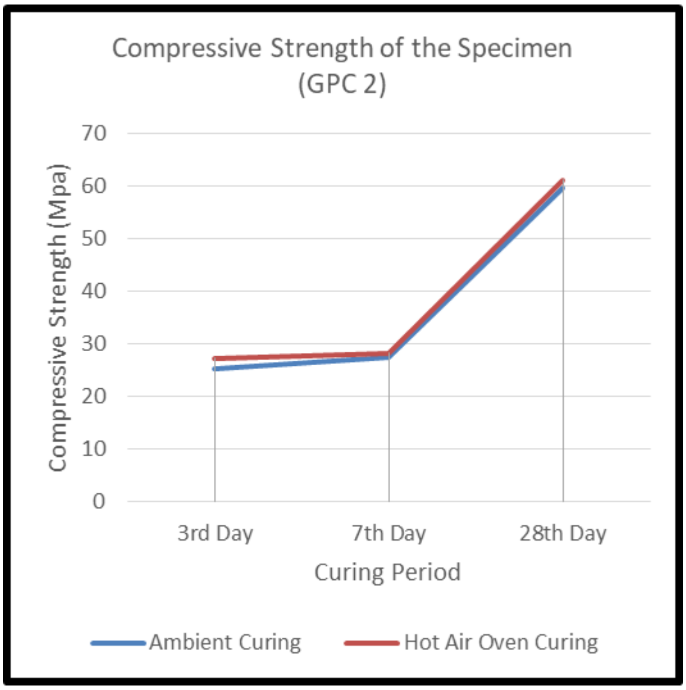


Fig 13 – Comparison Compressive Strength of GPC 3 with Different Curing Methods

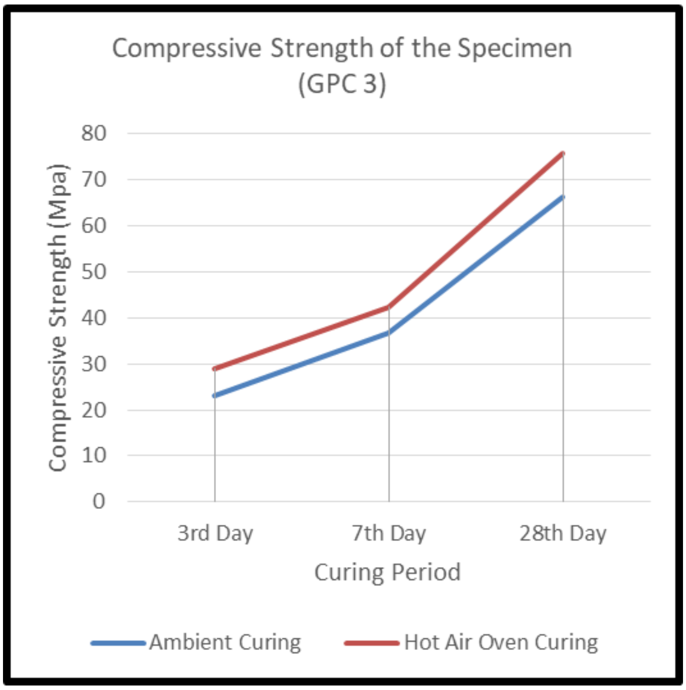


Fig 14 – Comparison Compressive Strength of GPC 4 with Different Curing

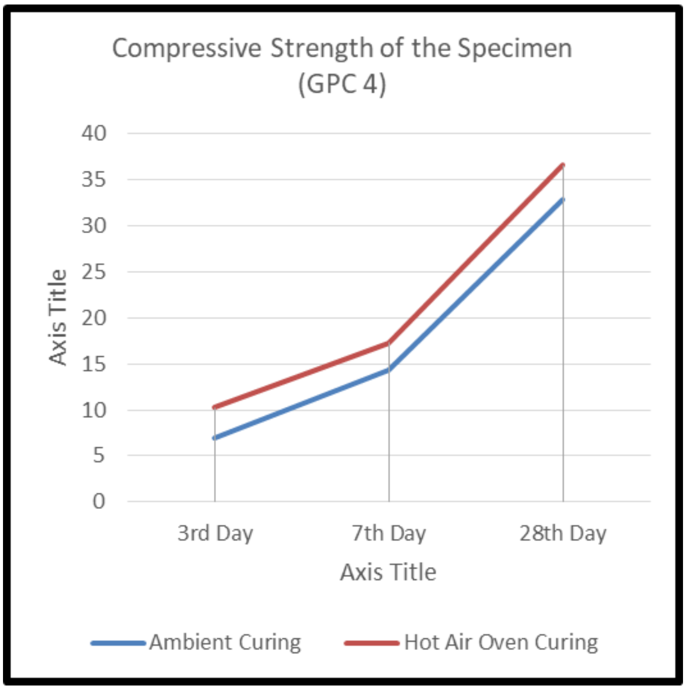


Fig 15 – **Comparison Compressive Strength of GPC 5 with Different Curing**

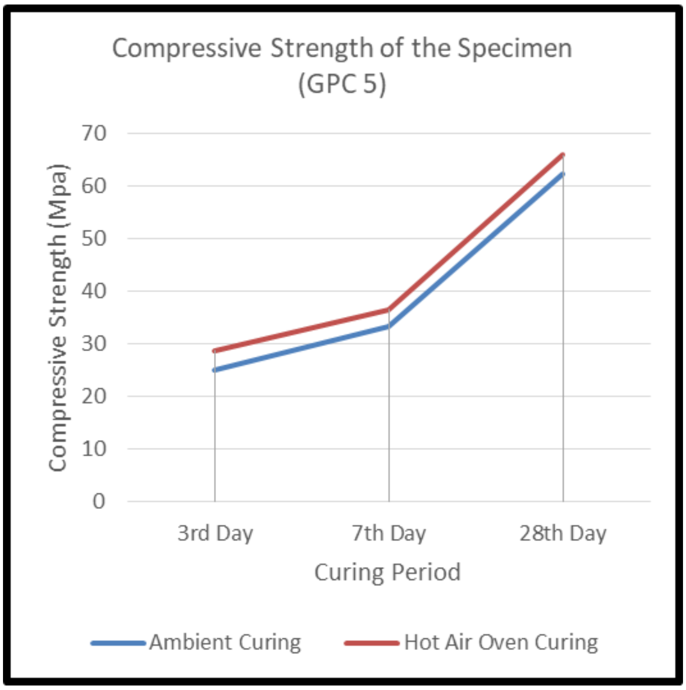


Fig 16 – **Split Tensile Strength of GPC 3**

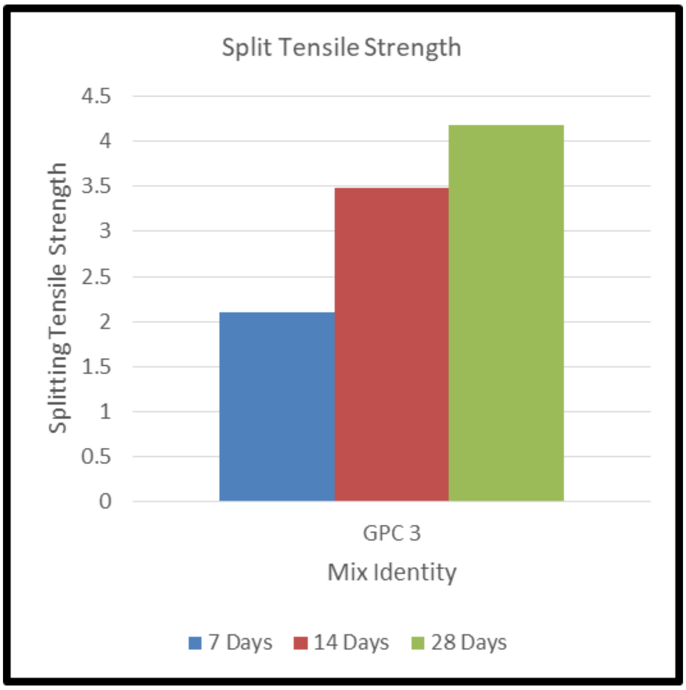


Fig 17 – Flexural Strength of GPC

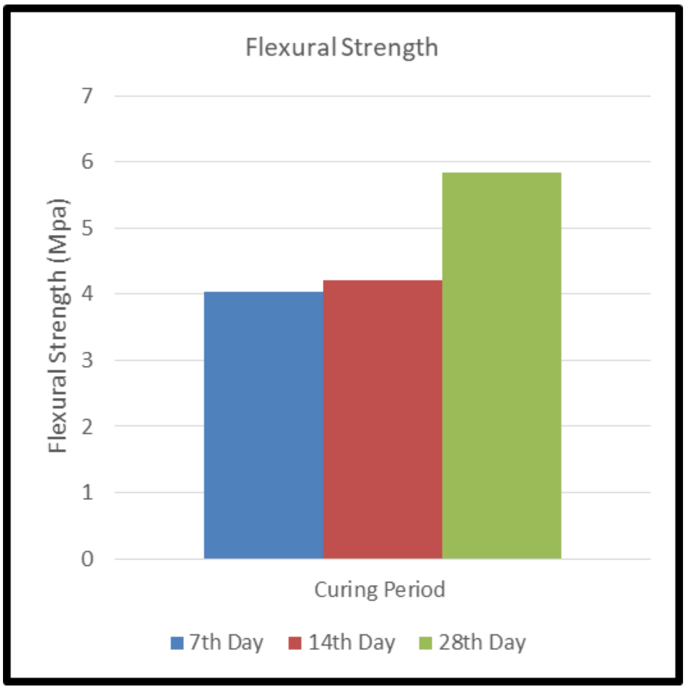


Fig 18 - Concrete Cubes

Fig 19- Compression Test on Concrete Cubes

Fig 20 – Specimens Kept for Accelerated Curing

Fig 21 – Specimens Kept for Hot Air Oven Curing

Fig 22 – Split Tensile Test

Fig 23 – Flexural Strength Test

Table 11 – Loss of Weight Due to Hot Air Oven Curing

SL.NO	MIX ID	INITIAL WEIGHT	FINAL WEIGHT	LOSS IN WEIGHT
1	GPC 1	8.14	7.98	1.96
2	GPC 2	7.784	7.73	2.1
3	GPC 3	8.23	7.81	1.63
4	GPC 4	7.94	7.81	1.63
5	GPC 5	8.29	8.09	2.41

Fig 24 – Loss of Weight Due to Hot Air Oven Curing

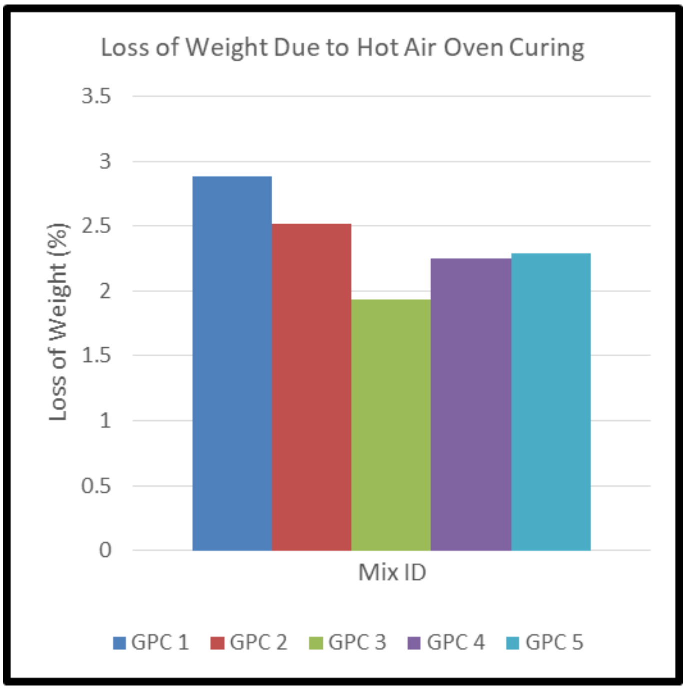


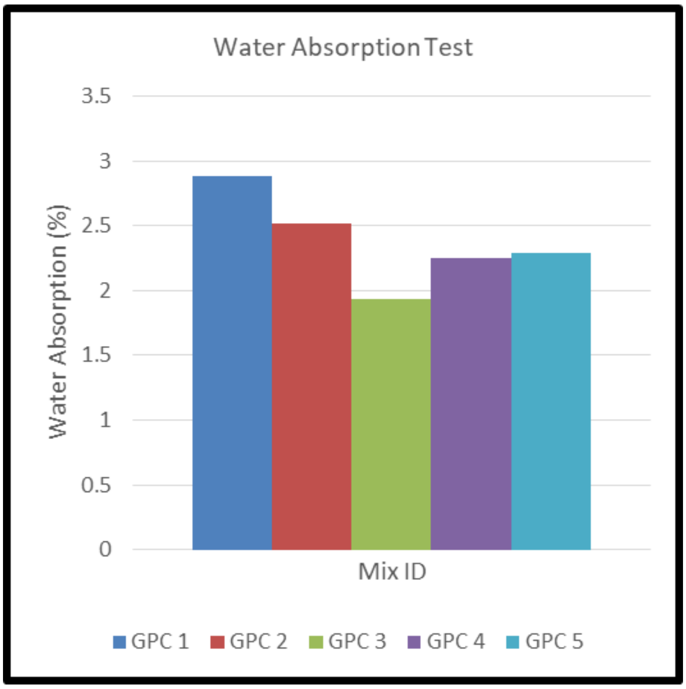
Table 12 – Water Absorption Test on Cubes

MIX ID	OVEN DRY WEIGHT	WEIGHT AFTER IMMERISON	WATER ABSORPTION
GPC 1	7.98	8.21	2.88
GPC 2	7.73	7.93	2.52
GPC 3	8.09	8.25	1.93
GPC 4	7.81	7.99	2.25
GPC 5	8.09	8.28	2.29

Table 12 Represents the water absortption test on concrete cubes, water absorption characterestic of the concrete plays an important role for the durabilty of the concrete.

Ingress of water detoriates concrete and in in reinforced concrete structure, corrosion of the bars took place which results it no cracking and spalling of the concrete and ultimately the life span of the structure

Fig 25 – Water Absorption Test on Cubes



5. CONCLUSION

- The compressive strength of oven cured concrete was more than that of ambient cured concrete irrespective of age, and mix ratio.
- From graph inferred that there is considerable amount of increase in compressive strength of the oven cured specimens with high constituent of Fly ash content.
- It is observed that, GPC 1 completely made of Fly ash doesn't gave good strength at the initial period, then on the 7th day, the strength of this specimens was increased adequately, and also, GPC 1 with hot air oven gave better result than the ambient curing, almost there was 35% increase in compressive strength of the concrete on 7th day of oven cured specimens at 60o C, however, on 28th day it doesn't reach the required compressive strength. Therefore, it doesn't full fill the expectation of mix design. Since, GPC 1 took more time to set, it is not possible to subject for accelerated curing method.
- GPC 2 with 100% GGBS gave good strength at the initial curing period itself, it was noted that only GPC 2 and GPC 5 (25% Fly ash & 75% GGBS) gave good strength at

3rd day, however, on 7th day the increase in strength on upcoming curing period was not more, comparatively. 28 days compressive strength of accelerated curing and oven cured specimens at 60o C was 1.1 times and 1.15 times more than that of ambient cured specimen, for GPC 2.

- GPC 3 with 50% GGBS & 50% Fly ash is the optimum mix design. Even though, initially its compressive strength was less while comparing with other mix ratios, finally it gave highest compressive strength while comparing with other mix proportions. 28 days compressive strength of accelerated curing and oven cured specimens at 60o C was 1.05 times and 1.18 times more than that of ambient cured specimen, for GPC 3. GPC 3 was decided as optimum mix ratio, and also, for GPC 3 cylinders and beams were casted to study the split tensile and flexural behavior, respectively.
- Although, GPC 4 gave lesser strength, it was almost fulfilled the mix design expectation, we designed for M30 concrete, on 28th day its compressive strength was more than 30KN/m2, therefore it was safe mix proportion, and for GPC 4, compressive strength of accelerated cured specimens was lesser than 28th day compressive strength of hot air oven cured specimen. 28 days compressive strength of accelerated curing and oven cured specimens at 60o C was 1.07 times and 1.11 times more than that of ambient cured specimen, for GPC 4.

- For GPC 5, initially it gave good strength similar to GPC 2. However, the increase of compressive strength was stable. 28 days compressive strength of accelerated curing and oven cured specimens at 60o C was 1.07 times and 1.17 times more than that of ambient cured specimen, for GPC 5.

- After finding out the optimum mix (optimum mix design obtained by based on maximum compressive strength), with the aid of accelerated curing, we found GPC 3 gave maximum compressive strength. So, we casted beams and columns for GPC 3 and observed the split tensile strength and flexural strength of columns and beams, respectively.

- Water absorption test was conducted, from that test we observed that GPC 1 observed more amount of water, in contrast, GPC 3 observed less quantity of water, we are very much aware that, Geopolymer concretes are best in water repellent, however, GPC 3 acts much better in water absorption.

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