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Experimental Study on Geopolymer Concrete

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Abstract: *The use of Portland cement in concrete construction is under critical review due to high amount of carbon dioxide gas released to the atmosphere during the production of cement. In recent years, attempts to increase the utilization of fly ash to partially replace the use of Portland cement in concrete are gathering momentum. Most of this by-product material is currently dumped in landfills, creating a threat to the environment.*

Geo-polymer concrete is a 'new' material that does not need the presence of Portland cement as a binder. Instead, the source of materials such as fly ash and ggbfs that are rich in Silicon (Si) and Aluminium (Al), are activated by alkaline liquids to produce the binder. Hence concrete with no Portland cement.

This thesis reports the details of development of the process of making fly ash-based geopolymer concrete. Due to the lack of knowledge and know-how of making of fly ash- based geopolymer concrete in the published literature, this study adopted a rigorous trial and error process to develop the technology of making, and to identify the salient parameters affecting the properties of fresh and hardened concrete. As far as possible, the technology that is currently in use to manufacture and testing of ordinary Portland cement concrete were used.

Fly ash was chosen as the basic material to be activated by the geo polymerization process to be the concrete binder, to totally replace the use of Portland cement. The binder is the only difference to the ordinary Portland cement concrete. To activate the Silicon and Aluminium content in fly ash, a combination of sodium hydroxide solution and sodium silicate solution was used.

Manufacturing process comprising material preparation, mixing, placing, and compaction and curing is reported in the thesis. Naphthalene-based super plasticizer was found to be useful to improve the workability of fresh fly ash-based geopolymer concrete, as well as the addition of extra water. The main parameters affecting the compressive strength of hardened fly ash-based geopolymer concrete are the curing temperature and curing time, the molarity of sodium hydroxide to sodium silicate ratio, and mixing time.

Fresh fly ash-based geo-polymer concrete has been able to remain workable up to at least 120minutes without any sign of setting and without any degradation in the compressive strength. Providing a rest period for fresh concrete after casting before the start of curing up to five days increased the compressive strength of hardened concrete.

The elastic properties of hardened fly ash-based geo-polymer concrete,
i.e. the modulus of elasticity, the Poisson's ratio, and the indirect tensile strength, are similar to those of ordinary Portland cement concrete. The stress-strain relations of fly ash-based geo-polymer concrete fit well with the expression developed for ordinary Portland cement concrete.

Keywords *– Alkaline solution, Geo-polymer, GGBSF, Fly ash, NaoH, Na2Sio3*

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I. Introduction

Portland cement is used as binder in production of cement concrete due to its availability of the raw materials over the world, due to its ease for preparing and fabricating in all sorts of conceivable shapes. The usage of Portland cement is found to be satisfactory in most of the civil engineering structures. Each year, the concrete industry produces approximately 12 billion tons of concrete and uses about 1.6 billion tons of Portland cement worldwide. However, Portland cements are highly internal-energy-intensive and cause emission of greenhouse gas, CO_2 during their production. These Portland cement based conventional concretes are found to be less durable in some of the very severe environmental conditions. The contribution of ordinary Portland cement production worldwide to greenhouse gas emission is approximately 7% of the total greenhouse gas emission to the atmosphere. It is reported that the world wide cement industry contributes about 1.65 billion tone's of greenhouse gas emissions annually. Due to the production of Portland cement it is estimated that by the year 2020, the CO_2 emissions will rise by about 50% from the current levels. The production of 1 ton of Portland cement consumes 1GJ energy and produces about 1 ton of carbon dioxide to the atmosphere. About half of the CO_2 emissions from Portland cement production are due to calcination of limestone and other half are due to combustion of fossil fuel.

Geopolymer concrete—an innovative material that is characterized by long chains or networks of inorganic molecules—is a potential alternative to conventional Portland cement concrete for use in transportation infrastructure construction. It relies on minimally processed natural materials or industrial by products to significantly reduce its carbon footprint, while also being very resistant to many of the durability issues that can plague conventional concrete. However, the development of this material is still in its infancy, and a number of advancements are still needed. This Tech Brief briefly describes geopolymer concrete materials and explores some of their strengths, weaknesses, and potential applications.

II. Experimental Investigations

2.1 Materials

The following materials have been used in the experimental study

- Ground Granulated Blast Furnace Slag
- Fly Ash (Class F) collected form Sri Damodara sanjeevaiah Thermal power plant Nellore, having specific gravity 2.8.
- Fine aggregate: Sand confirming to Zone –II of IS: 383-1970 having specific gravity 2.65
- Coarse aggregate: Crushed granite metal confirming to IS:383-1970 having specific gravity 2.70
- Water : Clean Potable water for mixing
- Alkaline liquids: Specific gravity of

Sodium Hydroxide (NaOH) = 1.16
Sodium Silicate (Na2SiO3) = 1.57

2.2 MIX DESIGN OF GEOPOLYMER CONCRETE

In the design of geopolymer concrete mix, coarse and fine aggregates together were taken as 74.7% of entire mixture by mass. This value is similar to that used in OPC concrete in which it will be in the range of 75 to 80% of the entire mixture by mass. Fine aggregate was taken as 30% of the total aggregates. The density of geopolymer concrete is taken similar to that of OPC as 2400 kg/m3. The details of mix design and its proportions for different grades of GPC are given in Table 1.

Table 1: Geopolymer concrete mix design details

Grade of concrete M25	Cement (347 kgs)		Fine aggregate	Coarse aggregate	Water	Alkaline solution (NaoH+Na2Sio3)	Super plasticizer
	Fly Ash	GGBS					
GPC1	277.6	69.4	625.2	915.9	122.5	52.5	0.00033
GPC2	208.2	138.8	625.2	915.9	122.5	52.5	0.00033
GPC3	173.5	173.5	625.2	915.9	122.5	52.5	0.00033
GPC4	138.8	208.2	625.2	915.9	122.5	52.5	0.00033
GPC5	69.4	277.6	625.2	915.9	122.5	52.5	0.00033

2.3 ALKALINE SOLUTION

In geopolymerization, alkaline solution plays an important role. The most common alkaline solution used in geopolymerization is a combination of sodium hydroxide (NaOH) and sodium silicate (Na2SiO3). In this study, a combination of sodium hydroxide and sodium silicate was choosen as the alkaline liquid. Sodium based solutions were choosen because they are cheaper than Potassium based solutions. Generally sodium hydroxide and sodium silicate are readily available in market in the form of pellets and gel (liquid).

2.4 PREPARATION, CASTING AND CURING OF GEOPOLYMER CONCRETE

The alkaline activator solution used in GPC mixes was a combination of sodium hydroxide solution, sodium hydroxide pellets and distilled water. The role of AAS is to dissolve the reactive portion of source materials Si and Al present in fly ash and provide a high alkaline liquid medium for condensation polymerization reaction. To prepare sodium hydroxide solution of 8 molarity (8M), 320 g of sodium hydroxide flakes was dissolved in water. The mass of NaOH solids in a solution will vary depending on the concentration of the solution expressed in terms of molar, M. The pellets of NaOH are dissolved in one litter of water for the required concentration. When sodium hydroxide and sodium silicate solutions mixed together polymerization will take place liberating large amount of heat, which indicates that the alkaline liquid must be used after 24 hours as binding agent.

GPC can be manufactured by adopting the conventional techniques used in the manufacture of Portland cement concrete. In the laboratory, The fly ash and the aggregates were first mixed together dry on pan for about three minutes. The liquid component of the mixture is then added to the dry materials and the mixing continued usually for another four minutes. The addition of sodium silicate is to enhance the process of geopolymerization.

For the present study, concentration of NaOH solution is taken as 8M with varying ratio of Na_2SiO_3 / NaOH as 2, 2.5 for all the grades of GPC mixes. The workability of the fresh concrete was measured by means of conventional slump test. In order to improve the workability, super plasticizer with a dosage of 1.0 % by mass of the fly ash & GGBS was added to the mixture. Extra water (other than the water used for the preparation of alkaline solutions) and dosage of super plasticizer was added to the mix according to the mix design details. The fly ash & GGBS and alkaline activator were mixed together in the mixer until homogeneous pate was obtained. This mixing process can be handled with in 10 to 15 minutes for each mixture with different ratios of alkaline solution. Heat curing (Room temperature) of GPC is generally recommended, both curing time and curing temperature influence the compressive strength of GPC. After casting the specimens, they were kept in rest period for two days and then they were demoulded. The demoulded procedure is similar to that of routine conventional concrete.

Figur1: Preparation of Alkaline solution

Figur2: Mixing of GPC

Table 2: Details of specimen used and tests conducted

Type of test conducted	Size of specimen	No. of specimen cast for different grades
Compressive strength	150x150x150mm	5
Split tensile strength	100x200mm	5
Flexural Strength	150 x150 x750mm	5
Durability	150x150x150mm	3
Permeability	150x150x150mm	3
Capillarity	150x150x150mm	3

III. Results And Discussions

3.1 WORKABILITY

Fresh GPC mixes were found to be highly viscous and cohesive with medium to high slump. The workability of the geopolymer concrete decreases with increase in the grade of the concrete, this is because of the decrease in the ratio of water to geopolymer solids. The ratio of alkaline solution increases the slump value for any grade of GPC, this is due to the fact that there will be more amount of sodium silicate solution and the water present in the fly ash will be released into the mixture during the mixing. An increase in sodium silicate concentration thus reduces the flow of GPC. Hence we can say that as the grade of the concrete increases, the mix becomes stiffer decreasing the workability, which result in strength reduction

COMPRESSIVE STRENGTH

i) At 7 days:

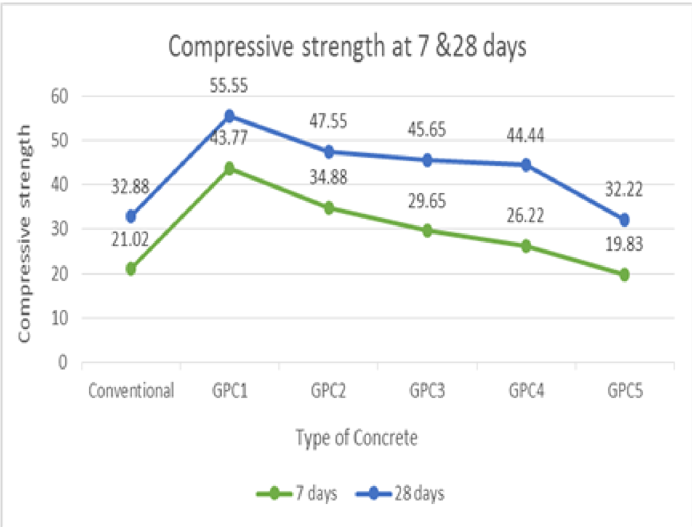
For a blend of 20% fly ash and 80% GGBFS, the compressive strength of geo-polymer concrete 43.77 MPa and for convesional concrete is 21.02 MPa. With this, the resulting incremental change is 42.77%. As given in Table 3.

ii) At 28 days:

For a mixture of 20% fly ash and 80% GGBFS, the compressive strength of geo- polymer concrete reaches to 55.55 MPa and for the nominal mix proportion is 32.8 MPa. Incremental change in the compressive strength at 28 days is 54.55%. As given in Table 3.

Table 3: Compressive strength of concrete at 7 &28 days

Type of Concrete	Mix Design	% of fly ash	% of GGBS	Compressive strength	
				7 Days	28 Days
Conventional	M25	0	0	21.02	32.88
GPC1	M25	20	80	43.77	55.55
GPC2	M25	40	60	34.88	47.55
GPC3	M25	50	50	29.65	45.65
GPC4	M25	60	40	26.22	44.44
GPC5	M25	80	20	19.83	32.22



Figur3: Compressive Strength Test7 & 28 days

3.3 SPLIT TENSILE STRENGTH

i) At 7 days:

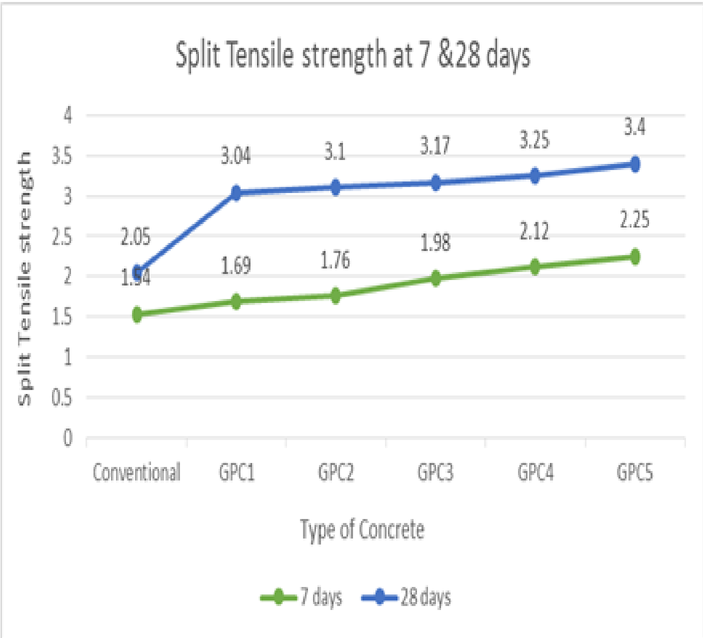
When compared to the Split Tensile strength of nominal cement concrete, the Split Tensile strength of geopolymer concrete with 60% fly ash and 40% GGBFS proportion is increased by 14.29%. As given in Table 4.

ii) At 28 days:

When compared with the Split Tensile strength of nominal cement concrete mix proportion with geo-polymer concrete of blend 80% GGBFS and 20 % fly ash, Split Tensile strength is increased by 65.85% for geo-polymer concrete. As given in Table 4

Table 4: Split Tensile strength of concrete at 7 &28 days

Type of Concrete	Mix Design	% of fly ash	% of GGBS	Split tensile strength	
				7 Days	28 Days
Conventional	M25	0	0	1.54	2.05
GPC1	M25	20	80	1.69	3.04
GPC2	M25	40	60	1.76	3.1
GPC3	M25	50	50	1.98	3.17
GPC4	M25	60	40	2.12	3.25
GPC5	M25	80	20	2.25	3.4



Figur4: Split Tensile strength Test7 & 28 days

3.4 FLEXURAL STRENGTH

i) At 7 days:

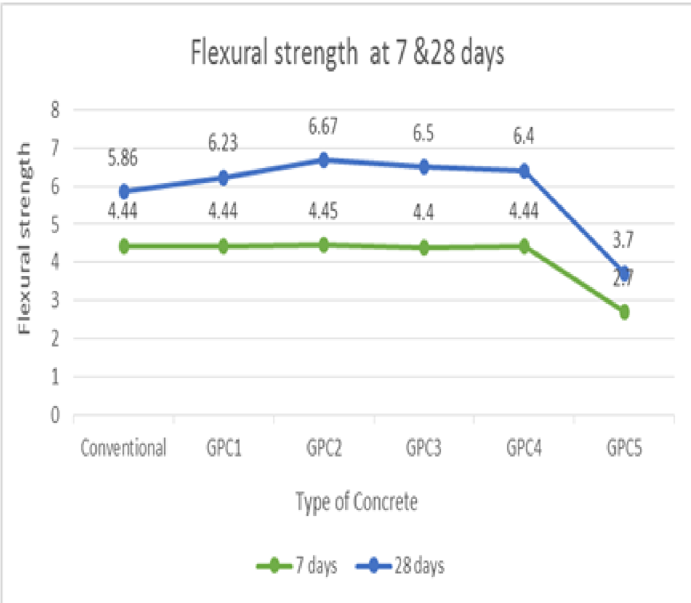
For a mixture of 40% fly ash and 60% GGBFS geo-polymer concrete, the Flexural strength is increased by 0.225% when compared with the nominal mix proportion. As given in Table 5.

ii) At 28 days:

For a blend of 40% fly ash and 60% GGBFS geo-polymer concrete, the Flexure strength is increased up to an extent of 13.82% when compared with the nominal mix proportion of cement concrete. As given in Table 5.

Table 5: Flexural strength of concrete at 7 &28 days

Type of Concrete	Mix Design	% of fly ash	% of GGBS	Flexural strength	
				7 Days	28 Days
Conventional	M25	0	0	4.44	5.86
GPC1	M25	20	80	4.44	6.23
GPC2	M25	40	60	4.45	6.67
GPC3	M25	50	50	4.4	6.5
GPC4	M25	60	40	4.44	6.4
GPC5	M25	80	20	2.7	3.7



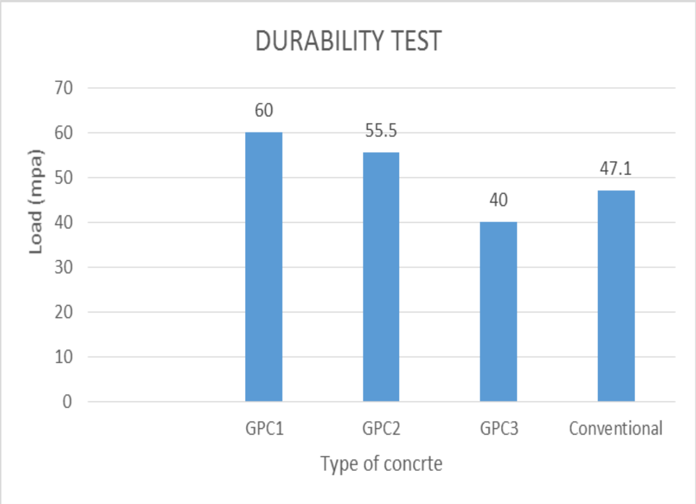
Figur5: Flexural strength Test7 & 28 days

3.5 DURABILITY TEST

These results are obtained by testing the total 12 specimens for 90 days by considering the optimum percentages of fly ash, silica fume and steel slag and by considering the average of the test results and that are tabulated in table 6.

Table 6: Durability of concrete at 90 days

Type of Concrete	Mix Design	Load beared (kn)	Load (mpa)
GPC1	M25	1350	60
GPC2	M25	1250	55.5
GPC4	M25	900	40
Conventional	M25	1060	47.1



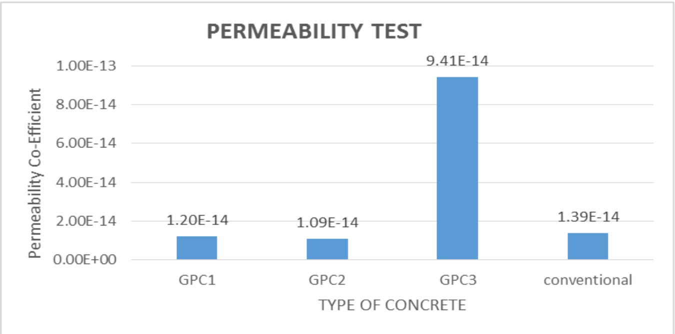
Figur6: Durability at 90 days

PERMEABILITY TEST

These results are obtained by testing the total 12 specimens by varying the pressure differences and the results are tabulated in the table 7.

Table 7: Permeability of concrete at 90 days

.No	Type of Concrete	Mix Design	Permeability Co-Efficient
1	GPC1	M25	**1.20E-14**
2	GPC2	M25	**1.09E-14**
3	GPC4	M25	**9.41E-14**
4	conventional	M25	**1.39E-14**



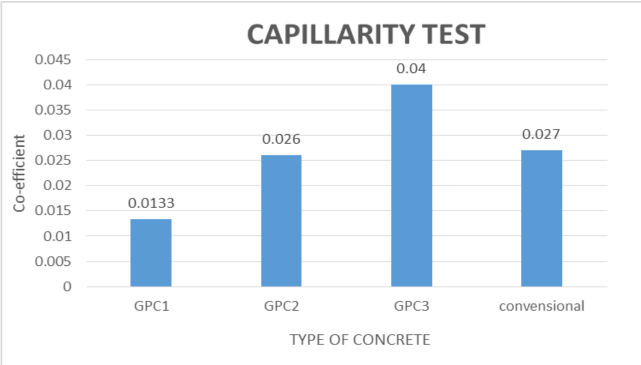
Figur7: Permeability at 90 days

3.6 CAPILLARITY TEST

These results are obtained by testing the total 9 specimens for each proportion and tested for 28 days and by considering the test results that are tabulated in table 8.

Table 8: Capillarity of concrete at 90 days

Type of Concrete	Initial weight	Final weight	Q value	Co-efficient
GPC1	8.35	8.360	.10	.0133
GPC2	8.28	8.300	.20	.026
GPC4	8.060	8.090	.30	.04
conventional				.027



Figur8: Capillarity at 28 days

IV. Stress Strain Results For Geopolymer Concrete:

A Sample of cylinder is placed in compressometer with its ends fixed tightly and then it is placed in the Compression testing machine and load is applied constantly and initially a dial gauge is fixed to the compressometer. With the help of this deflection readings are taken at constant load. For every 10kN load, deflection values are taken until the specimen breaks. Diameter of cylinder = 150mm;Height of the cylinder 300mm , Area = 150 x 150 mm2 ; Gauge Length = 148mm The relationship between stress and strain is important in understanding the basic elastic behavior of concrete in hardened state which is useful in design of concrete Structures. From the values of stresses and strains, average stress-strain curve for each mix is plotted, taking the average values of the results of the three cylinders. The stress-strain curves for Geopolymer concrete at 7 days, 28 days are shown in figures

V. Conclusions

Based on the experimental work reported in this study the following conclusions are drawn:-

- By blending the different compositions of fly ash and GGBFS replaced in place of cement concrete and by getting the geo-polymer concrete, the following points are observed.
- Compressive Strength: For a blend of 20% fly ash and 80% GGBFS geopolymer concrete, the compressive strength is increased by 42.77% at 7 days 54.55% at 28 days.
- Split Tensile strength: For a mixture of 80% fly ash and 20% GGBFS geopolymer concrete, the Split Tensile strength is increased by 65.85% for 28 days.
- Flexure Strength: When compared with nominal cement concrete, strength is increased by 13.82% for 40% fly ash and 60% GGBFS geo-polymer concrete.
- Durability: With the composition of 20% fly ash and 80% GGBFS geopolymer concrete, durability of concrete is increased by 27.39%.
- Permeability: Permeability of 60% fly ash and 40% GGBFS blended geopolymer concrete is decreased by 52.33%.
- Capillarity: For the composition of 20% fly ash and 80% GGBFS geopolymer concrete, the Capillarity coefficient is decreased by 50.83%.
- The waste material like fly ash and GGBFS can effectively be used as construction material.
- By effective utilizations of the waste materials like fly ash and GGBFS the strength and durability aspects can be increased and can reduce the air pollution by converting this pollution causing particulate matter in to useful building materials.
- With the utilization of waste material the Environmental pollution and disposal of waste can effectively be reduced and paves new path for the innovative construction materials & techniques.

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