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Experimental Investigation of Geopolymer Concrete Performance Using Mineral Admixtures

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ABSTRACT-One of the creative construction materials and emerging trends is Geopolymer Concrete.The chemical action of inorganic molecules is known as the polymerization process. This process is used to produce Geopolymer Concrete. The alkaline solution from alumino silicate gel, a product of the polymerization process, is used as a binder when it reacts with mineral admixtures rich in silica and alumina. The innovation of Geopolymer Concrete has reduced cement usage by partial or full replacement by mineral admixtures. It helps to reduce CO_2emissions from the cement industry. We can consider this construction material as an excellent alternative to cement. Here this paper summarizes the strength and the constituents of Geopolymer Concrete and also compares results with conventional concrete of M30 Grade.

Keywords: GPC, Hot air oven curing, Compressive Strength Test, Spilt Tensile Strength Test, Flexural Strength Test

I. INTRODUCTION

French Professor Davidovits in 1978 formed the name Geopolymer. He formed to represent a broad range of materials characterized by networks of inorganic molecules. Mineral admixtures or industrial – products (like silica fume, fly ash, rice husk, etc.,) are a source of silicon and aluminium. It is the best source of thermally active materials used for the production of Geopolymers. The alkaline activating solution (like sodium silicate and sodium hydroxide) is used to dissolve silicon and aluminium in thermally active materials. This process is known as the polymerisation process which polymerizes into alumino silicate gel to form a binder.

II. LITERATURE REVIEW

The environmental aspects of sustainable development in the construction industry consist of the utilization of secondary raw materials and materials which can be recycled in the design and construction of new structures. The preliminary and inevitable interest in the use of full or partial replacements of by-products as complementary pozzolanic materials was mostly induced by the enforcement of the reduction/elimination of greenhouse gas emissions from the production of Portland cement. With the significant evolution of Geopolymer concrete as an alternative to Portland cement in the past decade, it is necessary to explore possible construction applications in which Geopolymer concrete can be utilized. Hence, this review paper was carried out to explore various elements such as the precursors used in Geopolymers concrete and their corresponding applications. The environmental impacts of various Geopolymer concrete are also discussed. This paper also presents an overview of the real applications of Geopolymer concrete for the construction of various infrastructures. Recommendations and prospects for geopolymer concrete are also provided - Ahmad L Almutairi, Bassam A Tayeh, Adeyemi Adesina, Haytham F Isleem, Abdullah M Zeyad (2021), Potential applications of Geopolymer concrete in construction: A review.

Extensive studies conducted on fly ash-based Geopolymer concrete are presented. Salient factors that influence the properties of the Geopolymer concrete in the fresh and hardened states are identified. Test data of various short-term and long-term properties of the Geopolymer concrete are then presented. The paper describes the results of the tests conducted on large-scale reinforced Geo polymer concrete members and illustrates the application of Geopolymer concrete in the construction industry. Some recent applications of Geopolymer concrete in precast construction and the economic merits of Geopolymer concrete are also included - B Vijaya Rangan (2014), Geopolymer concrete for environmental protection.

Geopolymer is a type of amorphous alumina silicate cementitious material. Geopolymer can be synthesized by polycondensation reaction of Geo polymeric precursor, and alkali polysilicates. Compared to Portland cement, the production of Geopolymers has relatively higher strength, excellent volume stability, and better durability. Geopolymer concrete based on pozzolana is a new material that does not need the presence of Portland cement as a binder. This paper presents the results of studying materials, mixture composite, microstructure of Geopolymer, and parameters affecting properties of Geopolymer concrete - Nguyen Van Chanh, Bui Dang Trung, Dang Van Tuan (2008), Recent research Geo polymer concrete.

III. MATERIALS USED

A. Fly Ash

Here, industrial by-productFly ash - Class F is a thermally active material to form a binder which is thewaste by-productof a combination of coal. Based on the type of coal burnt class of fly ash varies. For this experiment we use low calcium Fly ash (Class F) from the local area conforming to IS 3812 – part I (2013): Pulverized Fuel ash

Table -1: Specifications are used. The physical properties of Fly ash are specified below:

Test	Apparatus used	Result
Specific Gravity	Le Chatelier Flask	2.52
Fineness	45µ sieve	24%
Consistency	Vicat Apparatus	34%

B. Coarse Aggregate

Here, we use Coarse Aggregate of maximum nominal size 20mm, crushed, angular. Coarse Aggregate is known as when it almost passes through a 4.75 mm sieveConforming to IS 383 (1970): Specifications for Coarse and Fine aggregate from Natural sources for Concrete.

Table -2: Specifications for Coarse aggregate are given below,

Test	Result	As per IS 3812
Specific Gravity	2.88	2.6-2.9
Fineness modulus	1	<10
Water Absorption	0.3%	Max. 3%
Crushing value	23%	< 30%
Impact value	13.8%	Max. 35%

C. Fine Aggregate

Aggregatepasses through a 4.75 mm sieve known as Fine aggregate. Manufactured sand (M-Sand)is used as a Fine aggregate Conforming to IS 383 (1970).

Table -3: Specifications for Fine aggregate are given below

Test	Result	As per IS 3812
Specific Gravity	2.8	2.6-2.9
Fineness modulus	Zone III	Zone I to IV
Water Absorption	1.1%	Max. 2%

D. Alkaline Materials

Sodium hydroxide (NaOH) or potassium hydroxide (KOH) and sodium silicate or potassium silicate are used most commonly used alkaline materials for polymerization to form geopolymers. Here, The alkaline materials used are Sodium hydroxide and Sodium Silicate. Since Al-Si minerals are more soluble in Sodium-based compounds.

➢ **Sodium Hydroxide (NaOH) [SH]**

For experimental investigation,a pellet form of Sodium Hydroxide is used which is colourless and soluble in water. It is used to enhance the polymerization process and is a key alkaline activator. The chemical indication of sodium hydroxide is NaOH and its molecular weight is 40 g/ mole.

Table -4: Specifications of NaOH are given below:

Chemical Compounds	
Purity	97%
Na_2CO_3	2.0%
Cl	0.01%

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SO_4	0.01%
SiO_2	0.02%

➢ **Sodium Silicate (Na2SiO3) [SS]**

Sodium Silicate is a colourless viscous gel is used as an alkaline activator to create durable and strong material. It is normally available in the market. There isno specifications are available about the gel.

Table -5: Specifications of NaOH are given below:

Chemical Compounds	
Purity	98%
Na_2CO_3	7.5%
SiO_2	25%
Molecular formula	Na_2SiO_3
Molecular weight	242.2 g/mole

Density	1720 kg/m^3
Ph	11.2

E. Water

Ordinary water is used in concrete which is free of impurities. Water is essential for workability and hydration process of concrete. Based on the workability test after mixing of concrete, the slump value in the range of 80-100mm.

F. Super Plasticizer

Super-plasticizers are soluble macromolecules. The use of super-plasticizer permits the reduction of water to the extent of up to 30 per cent without reducing the workability. Coloplast SP-430 (Sulphonated naphthalene-formaldehyde based) is used here.

°IV. MIX PROPORTIONS

A. Conventional Concrete

Table -6: Mix proportion of M 30 Grade conventional Concrete

MATERIALS	MASS in kg/m3	PROPORTION
Cement	332	1
Coarse aggregate	1250	3.7
Fine aggregate	800	2.6
Water	149	0.45

B. Geopolymer concrete

Mix proportion of geopolymer concrete can be prepared by only Trial mix method. There is no proper procedure in Indian Standards. Right now, there is no Indian Standard method for the mixed design of geopolymer concrete. Based on investigation,Lloyd and Rangan was adopted a procedure of mixed design. The density of Geopolymer concrete is assumed as 2400 Kg/m3.

- ➢ The mass of the combined aggregate = 70-80%.
- ➢ The alkaline Liquid binder ratio = between 0.30 and 0.40.
- ➢ The ratio of Sodium silicate to Sodium hydroxide = 2 to 3.
- ➢ The molarity of NaOH = 10M and 8M.
- ➢ To assist workability, a superplasticizer is added a range of 5% by weight of binder material.
- ➢ **Mixing Process**: The solid constituents of Geopolymer concrete are dry-mixed for nearly three minutes. Subsequently,an alkaline solution and superplasticizerare added. Then mix it thoroughly for four minutes to make it homogeneous. Extra wateris added to the mix to maintain a workability range of 75- 100mm if needed.

Table -7: Mix Proportion for M30 grade of Geopolymer Concrete

MATERIAL S	Mass of materials in kg/m3	
	Trial A-10M SS/SH = 2	**Trial B- 8M SS/SH = 2**
Coarse aggregate	1266	1213
Fine aggregate	725	666
Binder	438	395
Alkaline Solution	198	158
Binder and Alkaline	636	553
NaOH Solution	66	53
Na_2SiO_2 Solution	132	105
Proportion	1:2.89:1.66: 0.45	1:3.07:1.69:0. 4

V. GEOPOLYMER CONCRETE PREPARATION

A. Preparation of Alkaline Solution

- ➢ Sodium/Potassium Hydroxide and soluble Sodium/Potassium silicates are mixed to prepare the chemical activators, at room temperature.

- Sodium hydroxide pellets of 400g and 320g were dissolved in water to make the solution into one litre for preparation of 10M and 8M.
- The mass of NaOH solids was measured as 40%. The solution temperature rises to 800°C while dissolving sodium hydroxide pellets in water.
- So, it is necessary to prepare the solution 24 hours before concrete preparation. It changes to a semi-solid liquid state when exceeds 36 hours.
- Thus, the Alkaline Liquid is ready to use as a binding agent. Before usage, it is essential to cool at room temperature.
- The Sodium hydroxide solution thus prepared was mixed well with Sodium silicate solution to get the desired alkaline solution.
- Sodium hydroxide is better than potassium hydroxide, economically.

B. Mixing
- Geopolymer manufacturing is more or less the same procedure as the conventional Mixing method used for Conventional OPC.
- There are two stages ofthe mixing process.
- Firstly, Dry mix for about 2 minutes (Fly ash, M-sand and Coarse Aggregate).
- Secondly, add an Alkaline Solutionto the dry materials and mix for about 4 minutes as wet mixing.
- Add 2% superplasticizer and 15% extra water will be added to the mix if needed.

C. Casting
- Casting is the process of pouring a prepared mixture intomoulds for the preparation of specimens.
- It allows for the hardening of the specimen.
- Casting Procedures are based on that specified in IS 516-1959 and Methods of Tests for the Strength of Concrete are based on the following 6.2.4

D. Curing
- Curing is a process of maintainingmoisture in concrete to facilitate the process of hydration and hardening.
- There are various methods of curing (like heat curing, and ambient curing).
- Here, we use hot oven curing. Geopolymer concrete specimen is cured at the temperature of 60°Cfor 24 hours in a hot air oven.
- They are then de-moulded and kept at room temperature till the required age is reached.
- The strength properties are determined, after the prescribed days.

Figure 1: Preparation of geopolymer concrete

VI. RESULT AND DISCUSSION

A. Compressive Strength (fck)

The Compressive strength (fck) results were taken on the Compression testing machine (CTM) on 7, 14 and 28 days. The grade of Conventional Concrete is M30. The molarity of NaOH is 10M and 8.

Table -6: describes the Optimum Compression Strength of Conventional Concrete and GPC in 7, 14 and 28 days.

Days	**Compression Strength of Specimen**		
	Conventional concrete	**SS/SH=2**	
		GPC – A (NaOH = 10M)	**GPC – B (NaOH = 8M)**
7	17.37	27.82	27.08
14	26.98	32.67	31.38
28	29.4	37.51	31.78

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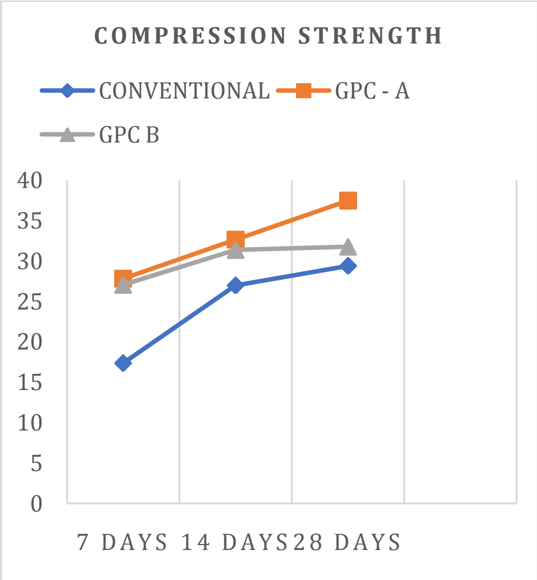

Chart -1: describes the Optimum Compression Strength of Conventional Concrete and GPC in 7, 14 and 28 days as graphical representation.

11. Split Tensile Strength (T)

The Split Tensile Strength results were taken on the Compression testing machine (CTM) on 7, 14 and 28 days. The grade of Conventional Concrete is M30. The molarity of NaOH is 10 M and 8 M.

Table -7: describes the Optimum Spilt Tensile Strength of Conventional Concrete and GPC in 7, 14 and 28 days.

Days	Spilt Tensile Strength of Specimen		
	Conventional concrete	SS/SH=2	
		GPC – A (NaOH = 10M)	GPC – B (NaOH = 8M)
7	1.9	2.88	2.8
14	2.26	3.42	3.19
28	2.64	4	3.93

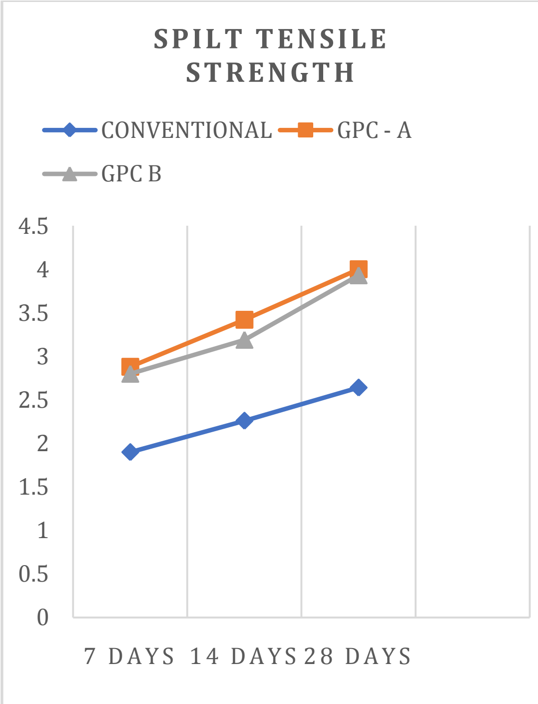

Chart -2: describes the Optimum Split Tensile Strength of Conventional Concrete and GPC in 7, 14 and 28 days as a graphical representation.

C. Flexural Strength (Σ)

The Flexural Strength results were taken on the Universal testing machine (UTM) on 7, 14 and 28 days. The grade of Conventional Concrete is M30. The molarity of NaOH is 10M and 8.

Table -8: describes the Optimum Flexural Strength of Conventional Concrete and GPC in 7, 14 and 28 days.

Days	Flexural Strength of Specimen		
	Conventional concrete	SS/SH=2	
		GPC – A (NaOH = 10M)	GPC – B (NaOH = 8M)
7	2.43	3.68	3.41
14	3.15	4.78	4.4
28	3.52	5.33	5.2

Chart -3: describes the Optimum Spilt Tensile Strength of Conventional Concrete and GPC in 7, 14 and 28 Days.

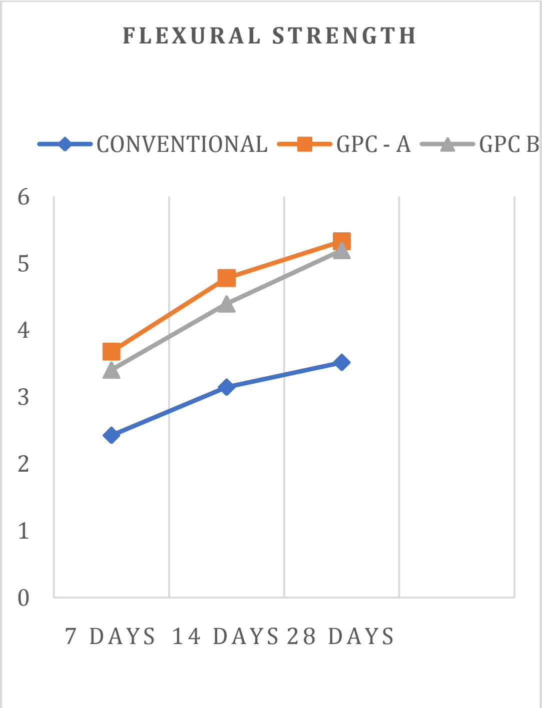

Figure 2: Testing of geopolymer concrete

VII. CONCLUSION

Experimental report based on Cube, Cylinder and Prism Specimens (Conventional Concrete and Geopolymer Concrete):

When compared to Conventional concrete,

- The Compression Strength of GPC (Trial A and Trial B) Cube specimens is increased by 20%.
- The Split Tensile Strength of GPC (Trial A and Trial B) Cylinder specimens is increased by 34%.
- The Flexural Strength of GPC (Trial A and Trial B) Prism specimens is increased by 35%.
- When the molarity of NaOH is increased, the strength of the concrete also increases.

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