Evaluation of Strength of Geopolymer Concrete with different combinations of Pozzolanic Materials

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Abstract - **In this fast-growing world, concrete is one of the predominant building materials in the construction industry due to urbanization and industrialization. The production of concrete uses a lot of cement, which accounts for about 5% of the carbon dioxide in the environment. It is therefore necessary to find a viable alternative to act as cementitious material in concrete mixes. The aim of this study was to develop a geopolymer concrete (GPC) mixes using fly ash (FA), granulated blast furnace slag (GGBFS) and rice husk ash (RHA). For the production of control concrete, FA and GGBFS are used as a base material. Then the rice husk ash was used to replace the FA and GGBFS in the mixture in three different proportions ranging from 10% to 30%. M30 grade GPC samples were subjected to various test methods to determine their performance at different curing periods on strength considerations. Sodium hydroxide and sodium silicate is utilized for the preparation of alkaline solution. It was concluded that the replacement of RHA shows beyond 20% in GPC retards its strength development.**

keywords - **Geopolymer Concrete, Fly Ash, GGBFS, Rice Husk Ash, Alkaline Solution**

I. INTRODUCTION

Concrete, the most widely used building material in the world, has gained popularity due to its many advantages: relatively low production costs, ease of handling, moldability to the desired shape, achieving the desired strength from low to very high, ease of maintenance and durability. The main component of concrete is cement, usually Portland cement (OPC), which acts as a binder and keeps the aggregates intact. Unfortunately, the OPC is associated with some adverse effects on the environment. OPC production uses a lot of energy and releases a significant amount of CO_2 into the atmosphere, which contributes significantly to the greenhouse effect.

At the same time, however, numerous industrial and agricultural wastes with inherent cement properties accumulate in abundance. However, they are mainly disposed of in landfills. The use of by-products as a cement substitute has a number of benefits, including environmental preservation, resource sustainability, and the solution to the problem of byproduct disposal. Especially in India, the environmental impact of the OPC is significant due to the growing demand for cement for rapidly developing construction and infrastructure projects. It is therefore immediately necessary to monitor the use of UCIs by developing potential alternatives.

A. Geopolymer Concrete

In 1978, Joseph Davidovits (1999) proposed that it is possible to produce binders resulting from the polymerization reaction between alkaline liquids and source materials that are rich in silica and aluminium. He coined the term 'geo-polymer' to describe this family of mineral binders that possess a chemical composition similar to zeolites but exhibiting an amorphous microstructure. Pozzolanic materials like blast furnace slag can be activated with the help of alkaline liquids to produce binders which could completely replace OPC in concrete production.

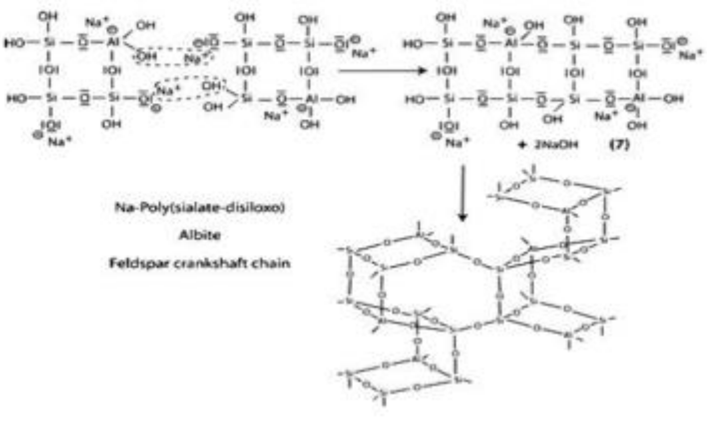

Fig 1. Schematic Diagram of Geopolymer Concrete

B. ROLE OF MINERAL ADMIXTURES IN GPC

Ground Granulated Blast Furnace Slag (GGBS), metakaolin (MK), Fly ash (FA) and silica fumes are used as mineral admixtures is to overcome the adverse effect which is caused during hydration of cement in concrete by calcium hydroxide. These mineral admixtures produce a less percentage of calcium hydroxide when compared to Ordinary Portland Cement (OPC).

During hydration of cement, calcium hydroxide and calcium silicate hydrates are produced when dicalcium silicates (C_2S) and tricalcium silicates (C_3S) reacts with water. The calcium hydroxide may get leached out and makes the concrete porous, weak and undurable. Ca $(OH)_2$ also reacts with sulphates present in water or soil to form calcium sulphates, which further react with Tricalcium Aluminates (C_3A) and cause deterioration of concrete. The effect of calcium hydroxide can be reduced by using pozzolanic materials.

II. LITERATURE SURVEY

Davidovits introduced the term ‘Geopolymer’ in 1978 to represent the mineral polymers resulting from geochemistry. Geopolymer, an inorganic alumina-silicate polymer, is synthesized from predominantly silicon (Si) and aluminium (Al) material of geological origin or by-product material. The chemical composition of Geopolymer materials is similar to zeolite, but they divulge an amorphous microstructure. During the synthesized process, silicon and aluminium atoms are combined to form the building blocks that are chemically and structurally comparable to those binding the natural rocks. Most of the literature available on this material deals with Geopolymer pastes.

Bhosle (2012) carried out an experimental investigation on the processing of geopolymer using fly ash and alkaline activator. Sodium hydroxide and sodium silicate solution were used as an alkaline activator. The ratios of Na_2SiO_3 and NaOH were 0.39 and 2.51. Some geopolymer samples were cured at ambient temperature and some were cured at 60^0C. The compressive strength for 8M to 14M concentration of sodium hydroxide were observed and it was found that, the compressive strength increases with the increase in the molarity and Na_2SiO_3 / NaOH ratio. Also the compressive strength was more for oven drying as compared to specimen left in ambient temperature.

Pavia & Condren (2008) examined the durability properties of GGBS added concrete. Evidently, concrete incorporating GGBS proved more durable than that made with OPC alone in aggressive environments under the action of acids and salts such as those produced by silage. The durability increased with increasing amount of GGBS.

Brooke et al (2005) reported that the behaviour of Geopolymer concrete beam column joints was similar to that of members made of Portland cement concrete. It was found that the application of Geopolymer concrete structural members was correlated well with the OPC concrete.

Kumar S et al (2014) have conducted experimental study on the structural behaviour of reinforced GPC beams of size 100mm x 150mm x 1200mm under two point loading. They have concluded that the flexural capacity of the beam increases with the increase in longitudinal tensile reinforcement ratio, and the tested ultimate moment capacity of beams were found 1.35 times more than theoretical ultimate moment capacity. Stiffness of the beam increases with increase in percentage of tensile reinforcement, which is similar to the reinforced OPC concrete beams.

Vignesh and Vivek (2015) conducted experiments on the concrete specimens for FA based GPC with GGBS and observed that the water absorption for GPC is lesser than the nominal concrete.

Hardjito et al (2004) investigated the influence of the alkali activator solution, curing temperature, curing time, age of curing and water content on the compressive strength of geopolymer concrete. Shrinkage, creep and sulphate resistance in geopolymer concrete were also investigated. They used class F fly ash, Na_2SiO_3 and NaOH solution for making geopolymer. They used 8 molar and 14 molar NaOH solutions and considered the ratio of Na_2SiO_3/NaOH as 0.4 and 2.5. Specimens were cured at 30^0C to 90^0C for 3 hours to 100 hours. They observed that the molarity of NaOH, the ratio of Na_2SiO_3/NaOH, and curing temperature influences the compressive strength of GP concrete. Further, they observed a decrease in compressive strength when water content decreases. They also observed a low drying shrinkage, creep strain and high sulphate resistance for GP concrete at water content corresponding to maximum compressive strength.

Ismail et al (1996) said that even in case of higher burning temperature and having crystalline silica content, favourable results may be obtained by fine grinding RHA. The fine RHA can be used to make good quality concrete with reduced porosity and less $Ca(OH)_2$ content (Zhang & Mohan 1996).

III. MATERIAL PROPERTIES

The following are the materials were utilized in this investigation is given below:

- Fly ash
- Ground granulated blast furnace slag
- Rice Husk Ash
- Coarse aggregate
- Fine aggregate
- Alkaline Solution
- Water

1. Fly Ash

It is the alumino silicate source material used for the synthesis of geopolymeric binder. Class F fly ash obtained from the Mettur Thermal power plant of Tamil Nadu was used in this study.

Table 1 Physical Properties of Fly Ash

Physical parameters	Class F fly ash
Colour	Light grey

Residue retained on 45µ sieve (%)	30.1
Specific surface area (m^2/kg)	430
Specific gravity	2.32
Moisture content (%)	0.54

2. Ground granulated blast furnace slag

GGBS conforming to the specifications of IS 12089-1987 was used as the primary binder to produce GPC. GGBS was obtained from JSW cements limited, Tamilnadu.

3. Rice Husk Ash

It was obtained from a nearby rice mill. It was finely ground in a ball-mill for 30 minutes and passed through 75µ sieve before using in GPC production.

Table 2 Physical Properties of GGBFS and RHA

Physical parameters	**GGBS**	**RHA**
Blaine's Fineness (cm^2/g)	4550	5673
Specific gravity	2.61	2.14

Table 3 Chemical Composition of FA, GGBS, RHA

S. No	**Chemical Composition**	**Fly ash**	**GGBS**	**RHA**
1	SiO_2	55.1	31.25	93.96
2	Al_2O_3	27.8	14.06	0.56
3	Fe_2O_3	7.85	2.80	0.43
4	$SiO_2 + Al_2O_3 + Fe_2O_3$	90.75	48.11	94.95
5	MgO	1.42	7.03	0.50
6	SO_3	1.22	-	-
7	Na_2O	0.89	-	-
8	CaO	0.09	33.75	0.55
9	LOI	2.33	1.52	4.79

4. Alkaline Solution

A combination of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) solutions were used for the activation of fly ash. The laboratory grade sodium hydroxide in pallets form, with 98% purity and three different concentrated laboratory grade sodium hydroxide and sodium silicate were used. Sodium hydroxide solution was prepared by mixing the pellets with Water for the preparation of required molarities of alkaline solution.

5. Fine and Coarse Aggregate

Coarse aggregates comprising of max size 20mm. Fine aggregate (sand) is clean; dry river sand was sieved through 4.75mm sieve to remove pebbles, confirming to grading zone II as per IS 383-2016. Both aggregates were in saturated surface dry condition.

Table 4 Properties of Aggregate

Parameter	**Value**	
	Coarse Aggregate	***Fine Aggregate***
Type	Crushed	Uncrushed (natural)
Fineness modulus	6.50	3.31
Bulk density	1608 kg/m^3	1785 kg/m^3
Specific gravity	2.79	2.61
Grading Zone	-	Zone II
Maximum size	20 mm	4.75mm

6. Water

Locally available ordinary portable drinking water is used in throughout the investigation.

IV. MIX DESIGN

Mix design for M30 grade geopolymer concrete is done based on the guidelines mentioned in IS 10262:2009.

Table 5 Mix Proportioning

Material description	**Fly ash Based GPC**			**GGBS Based GPC**		
	Quantity (kg/m3)		***Proportion***	***Quantity (kg/m3)***		***Proportion***
Flyash	404		1	-		-
GGBS	-		-	394		1
NaOH	101	2.5	0.35	45	2.89	0.40
Na_2SiO_3	40.4			113		
Fine aggregate	658.39		1.63	647.92		1.64
Coarse aggregate	1257.99		3.11	1201.8		3.05
Water	66.22		0.16	59.72		0.15

A. Work Methodology

In this study, RHA was replaces the source material used in the GPC mixes such as FA and GGBFS ranging from 0% to 30% at an interval of 10%. The work methodology is illustrated in Table 6.

Table 6 Work Methodology

Mix ID	Volume of Material (%)		
	FA	*GGBFS*	*RHA*
FA-GPC	100	-	-
FA10RHA	90	-	10
FA20RHA	80	-	20
FA30RHA	70	-	30
GG-GPC	-	100	-
GG10RHA	-	90	10
GG20RHA	-	80	20
GG30RHA	-	70	30

B. Preparation of Alkaline Solution

Following steps are followed to make a 16 M NaOH solution in a 1 liter solution. To prepare a 1 M solution, 40 g of NaOH pellets in solid form are required. Although we mix 40 g granules in a 1 liter solution, we can get a 1 M sodium hydroxide solution. The evaluation of the heat takes place quickly when mixing the pellets in the water. NaOH solution was prepared one day prior to pouring the concrete cubes to avoid contamination when mixing the GPC components. Similarly, we prepare a 16 M solution for GPC by adding 16 x 40 = 640 g sodium beads. Then we get a solution of 16 M per liter of sodium hydroxide.

C. Mixing and Casting

Mixing of all the materials was carried out manually in the laboratory at room temperature. The fly ash and aggregates were initially mixed homogeneously and then the alkaline solutions which have been made one day prior and super plasticiser were added to the mixture of fly ash and aggregates. The mixing of total mass was continued until the binding paste covered all the aggregates and mixture turn out to be homogeneous and uniform in colour.

A Pan type concrete mixer that provides mechanical shearing action can be used for acquiring a uniform mixture with significantly less effort. The specimens were prepared according to the technique followed by Hardjito et.al. Every single cube specimen was cast in three layers by compacting manually as well as by using the vibrating table. Every layer received 25 strokes of compaction by standard compaction rod for concrete, followed by further compaction on the vibrating table.

V. STRENGTH PROPERTIES

In this study, compressive strength, split tensile strength and flexural strength of the geopolymer concrete which were cured in oven drying for 60$_0$C at 3days, 14 days, 28 days and 56 days. The ratio between sodium hydroxide and sodium silicate was kept as 2.5. The tests were carried out accordance with the specifications present in IS 516-1959 and IS 5816-1999.

Table 7 Compressive Strength Test Results

Mix ID	Average Compressive strength (N/mm$_2$)			
	3 days	*14 days*	*28 days*	*56 days*
FA-GPC	16.31	34.25	38.91	45.61
FA10RHA	16.08	35.32	40.04	47.93
FA20RHA	16.89	37.11	42.16	49.88
FA30RHA	11.22	17.81	22.85	25.42
GG-GPC	21.41	32.23	39.44	47.11
GG10RHA	22.85	33.22	43.63	49.55
GG20RHA	23.91	34.74	45.01	50.16
GG30RHA	13.86	18.17	24.39	27.26

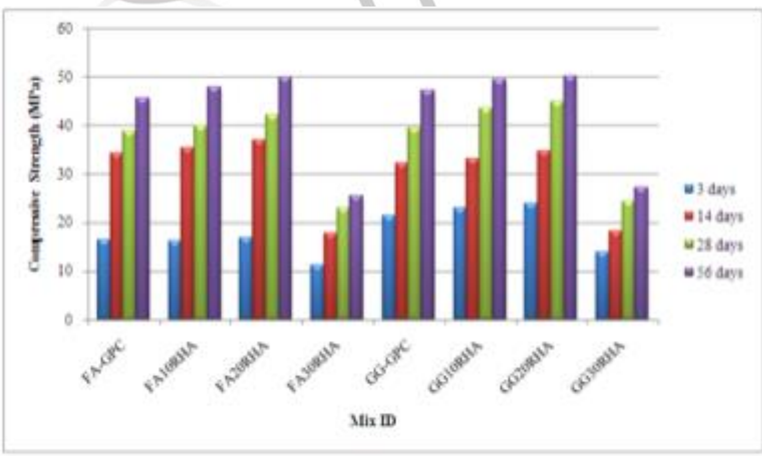

Fig 2. Compressive Strength Test Results

Table 8 Split Tensile Strength Test Results

Mix ID	Average Split Tensile strength (N/mm$_2$)			
	3 days	*14 days*	*28 days*	*56 days*
FA-GPC	2.36	3.38	3.59	3.88
FA10RHA	2.35	3.43	3.64	3.98

FA20RHA	2.40	3.51	3.74	4.06
FA30RHA	1.98	2.46	2.78	2.92
GG-GPC	2.69	3.28	3.63	3.94
GG10RHA	2.78	3.33	3.80	4.04
GG20RHA	2.84	3.40	3.86	4.10
GG30RHA	2.18	2.44	2.83	2.87

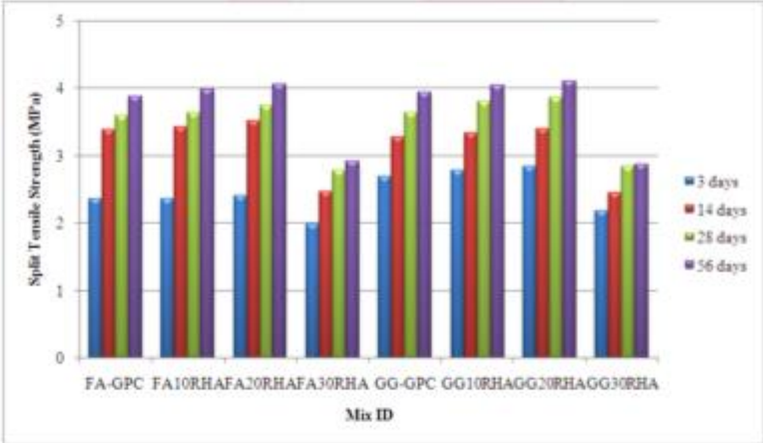

Fig 3. Split Tensile Strength Test Results

Table 9 Flexural Strength Test Results

Mix ID	Average Flexural strength (N/mm^2)			
	3 days	*14 days*	*28 days*	*56 days*
FA-GPC	2.88	4.15	4.42	4.78
FA10RHA	2.86	4.21	4.48	4.90
FA20RHA	2.93	4.31	4.60	4.99
FA30RHA	2.39	3.00	3.40	3.58
GG-GPC	3.29	4.02	4.45	4.85
GG10RHA	3.40	4.08	4.67	4.98
GG20RHA	3.47	4.18	4.75	5.01
GG30RHA	2.66	3.03	3.51	3.70

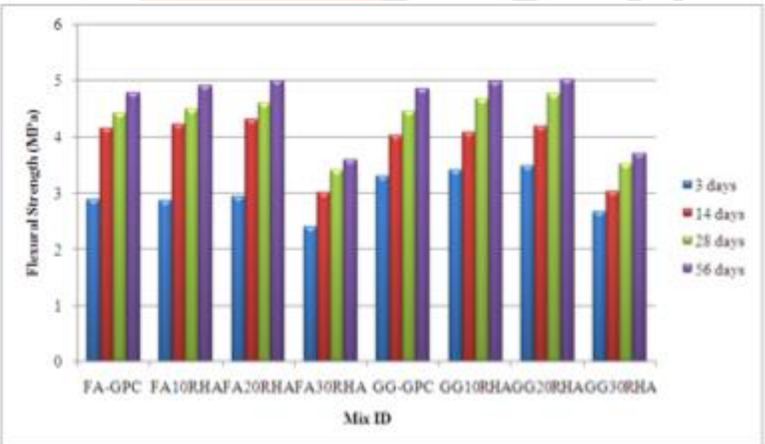

Fig 4. Flexural Strength Test Results

VI. CONCLUSIONS

From the experimental investigations, the following conclusions are drawn:

- Geopolymer concrete made with FA and GGBFS can be efficiently used instead of conventional concrete to minimize the cement consumption without compromising the strength parameters which will reduce numerous environmental pollution issues like CO_2 emission, global warming, landfill issues, etc.,
- Addition of RHA beyond 20% has a retarding effect on the mechanical strength properties and target mean strength was achieved at the end of 28 days curing.
- The strength gain was substantial till 7 days and became moderate till 28th day. As evident from the 56th day compressive strength results, the strength gain beyond 28 days was only marginal for GPC.
- GPC mixes made with GGBFS shows better results than the GPC mixes based with FA.

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