Strength and Behaviour of Geopolymer Concrete using Low-Calcium Flyash and Calcium Hydroxide Cured at Ambient Temperature

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Abstract - *The present study reports the mechanical and durability properties of Geopolymer concrete (GPC) using calcium hydroxide as fly ash replacement. Calcium hydroxide because of its fineness and size it can be effectively used as a replacement of fly ash. Fly ash is abundantly available in the form of industrial waste. In this study, calcium hydroxide was replaced at different replacement levels (0%, 0.5%, 1.0%, 1.5%, 2.0% and 2.5%). Class F Fly ash is used as geopolymer binder. Sodium silicate (Na_2SiO_3) and sodium hydroxide (8M, 10M, 12M) has been used as a alkali activator. Specimens for compressive strength, Split tensile strength and flexural strength were cast and tested at 28 and 60days maintain an ambient curing. From the result it is revealed that studied mechanical properties were increased with the increasing replacement level of calcium hydroxide up to 2.0% and there is strength decrements were observed after 2.5% replacement level. It is concluded that the optimum percentage replacement for fly ash with calcium hydroxide is 2.0%.*

***Key Words*: Geopolymer concrete, calcium hydroxide, Fly ash, alkali activator, ambient curing.**

1. INTRODUCTION

The consumption of concrete stands second globally after water. As the demand for concrete increases it also increases the demand for Portland cement. On the other hand, the climate change due to global warming has become a major concern. Global warming is caused by the emission of greenhouse gases, such as carbon dioxide (CO2) to the atmosphere by human activities. The cement industries are held responsible for some of the CO2 emissions, because the production of one ton of Portland cement emits approximately one ton of CO2 into the atmosphere.

Several efforts are in progress to supplement the use of Portland cement in concrete in order to address the global warming issues. These include the utilization of supplementary cementing materials such as fly ash, silica fume, granulated blast furnace slag, rice-husk ash and metakaolin as the alternative binders to Portland cement.

In this respect, the geopolymer technology shows considerable promise for application in concrete industry as an alternative binder to the Portland cement. In terms of global warming, the geopolymer technology could significantly reduce the CO2 emission to the atmosphere caused by cement industries.

This "Geopolymer" was developed in the mid 1970 by Davidovits and it had geopolymeric alumino-silicate gel performing the role of binder. Recently, Ragan and Hardjito (2005) also exploited silica (SiO2) and alumina (Al2O3) of fly ash to synthesize geopolymeric binder which was found to be useful to prepare structural grade concretes.

Wastes can be used to produce new products or can be used as admixtures so that natural resources are used more efficiently and the environment is protected from waste efficiently.

2. OBJECTIVES

The major objective of this project stand the use of calcium hydroxide as fly ash in different variations in low calcium fly ash based geopolymer concrete to evaluate its mechanical properties and also studying the durability properties of it.

3. MATERIALS USED

3.1 Cement

In present studies, Zuari cement of 53 grade confirming to grade IS 12269-2013 was used and cement sample was tested as per IS 4031-1988 part 4 and IS 4031-1988 part 5. Physical properties like specific gravity, standard consistency, initial setting time and final setting time of cement were determined by using the codes (IS: 4031-1988).

Table – 1: Properties of cement

Property	Test Results
Normal Consistency	
Specific Gravity	Font
Initial Setting Time	Heading
Final Setting Time	Spacing

3.2 Coarse aggregate

Crushed granite stones of size 20mm down aggregates were used as the coarse aggregates in the concrete mixtures. Properties of coarse aggregates were determined as per IS 2386-1997 part III guidelines.

Table – 2: Properties of Coarse aggregate

Property	Test Results
Specific Gravity	2.67
Water absorption	0.2%
Bulk density	1450 kg/m^3

3.3 Fine aggregate

In the present Work crushed stone aggregates was used as fine aggregate and test were conducted as per IS: 2386-1997 Part-III and IS:383-1970.

Table – 3: Properties of Fine aggregate

Property	Test Results
Specific Gravity	2.66
Water absorption	2.1%
Fineness modulus	2.9
Bulk density	1670 kg/m^3
Grading Zone	II

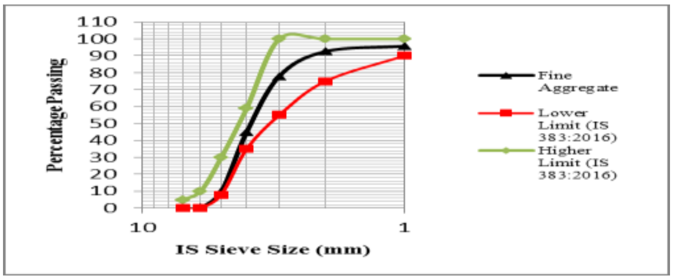

Fig-1: Sieve analysis of Fine aggregate

3.4 Fly ash

Fly ash of Class F grade collected from Raichur thermal power plant (RTPS) was used in the present work. From test Specific gravity of the fly ash was found to be 2.33.

3.5 ALAKALIA ACTIVATOR

Fly ash of Class F grade collected from Raichur thermal power plant (RTPS) was used in the present work. From test Specific gravity of the fly ash was found to be 2.33.

4. EXPERIMENTAL PROCEDURE

Six mixes casted were fly ash was replaced with 0%, 0.5%, 1.0%, 1.5%, 2.0% and 2.5% calcium hydroxide by weight respectively and are given below.

Table – 4: Mix proportions of concrete

Table 3.4 Geopolymer concrete mix proportions

Materials		Mass (Kg/m3)					
		CH0	CH0.5	CH1.0	CH1.5	CH2.0	CH2.5
Coarse aggregate		1294	1294	1294	1294	1294	1294
Fine aggregate	Sand	554.4	554.4	554.4	554.4	554.4	554.4
Flyash (ClassF)		409	406.95	404.91	402.87	400.82	398.8
Calcium hydroxide $Ca(OH_2)$		0	2.045	4.09	6.13	8.18	10.23
Sodium hydroxide solution		72	72	72	72	72	72
Sodium silicate solution		72	72	72	72	72	72
Extra water		90	90	90	90	90	90
Alkaline solution/Flyash		0.35	0.35	0.35	0.35	0.35	0.35
Water/Geopolymer solids		0.17	0.17	0.17	0.17	0.17	0.17
$NaOH/Na_2Sio_3$		1.0	1.0	1.0	1.0	1.0	1.0

4.1 Preparation of Alkaline Liquid

Sodium hydroxide flakes were dissolved in distilled water to make a solution of 10M. Sodium silicate solution and sodium hydroxide solution of 10M were mixed together at room temperature. When both solutions were mixed together it starts to react i.e. "polymerization" takes place this liberates large amount of heat. So, it is recommended to leave it for about 24 hours.

Fig-3: Prepared alkaline liquid before casting

4.2Preparation of Geopolymer Concrete Mixtures

Preparation of geopolymer concrete is similar to that of cement concrete. Coarse aggregates, two types of fine aggregate like sand and granite powder and fly ash were mixed in dry state. Then alkaline solution which is prepared 24hrs prior to mixing were added along with extra water based on water to geopolymer binder ratio and mixed thoroughly for 3 to 4 mins so as to obtain homogeneous mix.

4.3 Specimen Casting and Curing

For each concrete mixture, 150mm cubes, 150mm X 300mm cylinders, 100mm X 100mm X 500mm prisms, 100mm X 50mm cylinders were cast. 150mm cubes were used to determine the compressive strength, 150mm X 300mm cylinders were used to evaluate the split tensile strength, 100mm X 100mm X 500mm prisms were used to evaluate flexural strength and 100 mm X 50 mm cylinders were used to evaluate the water absorption, chloride ion permeability and sorptivity value of the concrete specimen.

The specimens were compacted using vibration table.

After 24hrs of casting all moulds were demoulded and then placed in room temperature for ambient curing till the time of testing.

Fig-4: Casting of the concrete specimen

Fig-5: Curing of the concrete specimen

4.4 Specimen testing

After the curing period of 28 days and 60days, specimens are taken out for testing. Test will be conducted for compression test for cubes (150x150x150mm), split tensile test for cylinders (150mm diax300mm height) and flexural test for beams (100x100x500mm) as per IS:516-1959.Sorptivity test for durability using cylinders (150mm dia and 50mm height).

Fig-6: Compressive strength test setup

Fig-7: Split tensile strength test setup

Fig-8: Flexural strength test setup

5. TEST RESULTS

5.1 Workability of concrete

Workability was measured using slump cone test. Results show that geopolymer concrete has given below and the degree of workability is medium.

Table – 5: Slump values

Concrete Type	Slump values(mm)
GPC (8M)	40
GPC (10M)	50
GPC (12M)	65

5.2 Mechanical Properties of Concrete

Table 5 shows the compressive strength, split tensile strength and flexural strength of GPC mixes as well as normal concrete mix at different curing periods.

Table – 6: Mechanical properties of GPC for (8M)

	AGE	CH0	CH0.5	CH1.0	CH1.5	CH2.0	CH2.5
Compressive strength (MPa)	28	30.07	32.4	34.73	36.87	39.21	36.12
	60	35.03	38.1	41.27	44.27	46.00	41.27
Split tensile strength (MPa)	28	1.05	1.32	1.43	1.58	1.65	1.49
	60	1.31	1.48	1.56	1.67	1.75	1.56
Flexural strength (MPa)	28	1.24	1.32	1.40	1.49	1.61	1.47
	60	1.38	1.52	1.62	1.69	1.78	1.58

Table – 7: Mechanical properties of GPC for (10M)

	AGE	CH0	CH0.5	CH1.0	CH1.5	CH2.0	CH2.5
Compressive strength (MPa)	28	32.59	34.33	35.71	37.87	39.67	33.89
	60	36.83	39.35	43.04	46.23	47.81	39.56
Split tensile strength (MPa)	28	1.26	1.51	1.58	1.66	1.83	1.57
	60	1.54	1.59	1.61	1.75	1.89	1.64
Flexural strength (MPa)	28	1.57	1.68	1.81	1.92	2.03	1.85
	60	1.82	1.96	2.08	2.26	2.43	2.12

Table – 8: Mechanical properties of GPC for (12M)

	AGE	CH0	CH0.5	CH1.0	CH1.5	CH2.0	CH2.5
Compressive strength (MPa)	28	34.54	36.80	38.40	39.77	41.84	37.93
	60	39.63	42.56	44.69	48.64	49.37	41.29
Split tensile strength (MPa)	28	1.47	1.86	1.99	2.15	2.37	2.10
	60	1.75	2.11	2.29	2.59	3.05	2.46
Flexural strength (MPa)	28	1.84	1.96	2.14	2.45	2.78	2.51
	60	2.19	2.28	2.48	2.75	3.13	2.8

5.2.1 Compressive strength test

In the present study, 6 cubes for each mix proportion were tested and average of 3 cubes was taken as compressive strength of concrete. The compressive strength of concrete can be seen in Fig. Above results shows that there will be increase in compressive strength of geopolymer concrete when it is replaced with calcium hydroxide up to 2.0%. As the calcium hydroxide variation increases after that the compressive strength gets decreased.

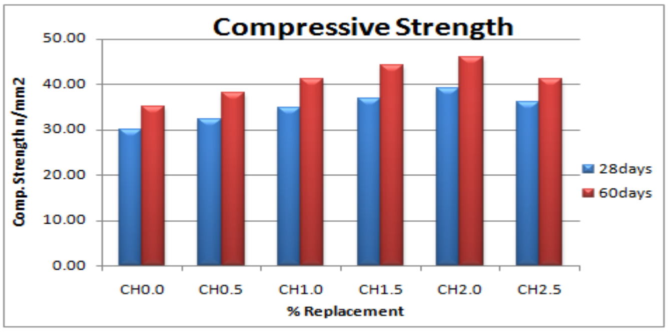

Fig-9: 28 & 60days compressive strength (8M)

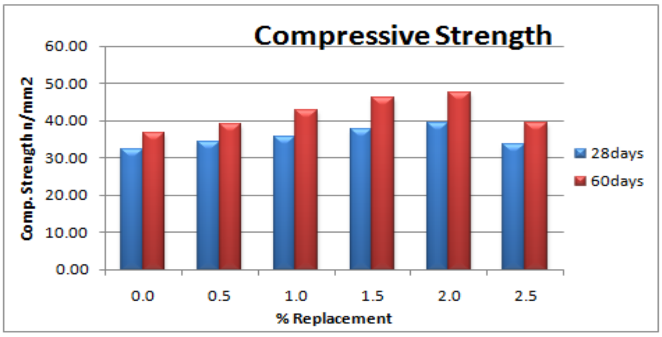

Fig-10: 28 & 60days compressive strength (10M)

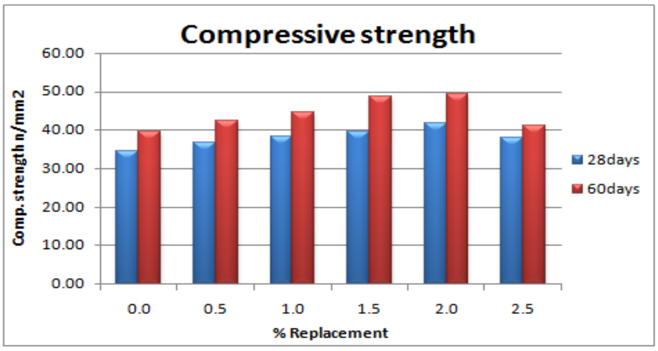

Fig-10: 28 & 60days compressive strength (12M)

5.2.2 Split tensile strength test

Split tensile strength of concrete was tested on 150mm X 300mm cylinder at the age of 28 and 60 days. Test results are shown in the Fig. Splitting tensile strength of GPC mixes with calcium hydroxide increases up to 40%. But at CH2.5% mix the splitting tensile strength decreases.

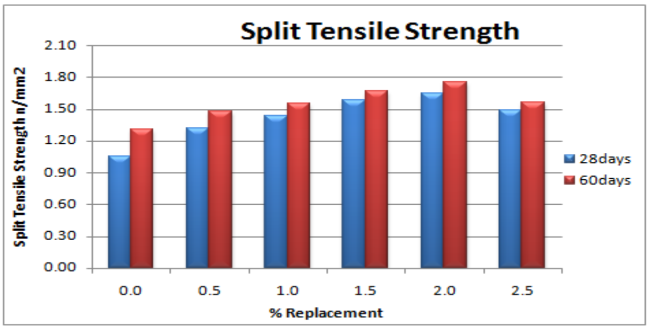

Fig-11: 28 & 60days Split tensile strength (8M)

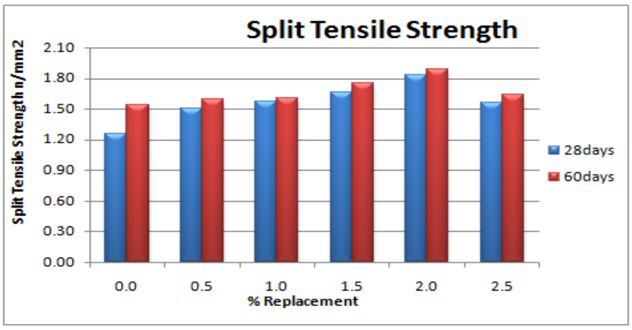

Fig-12: 28 & 60days Split tensile strength (10M)

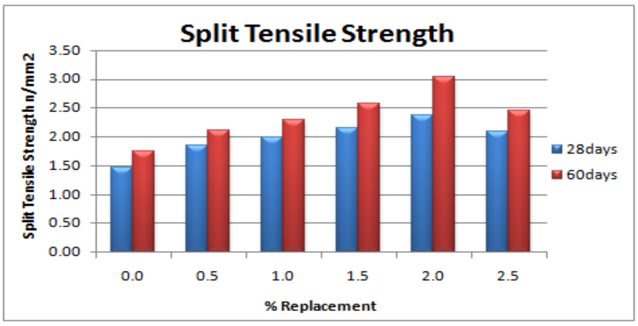

Fig-13: 28 & 60days Split tensile strength (12M)

5.2.3 Flexural strength test

Flexural strength of concrete was tested on 100mm X 100mm X 500mm prisms at the age of 28 and 60 days. Test results are shown in the Fig. The test results show that there will be increase in the flexural strength as the percentage of calcium hydroxide increases.

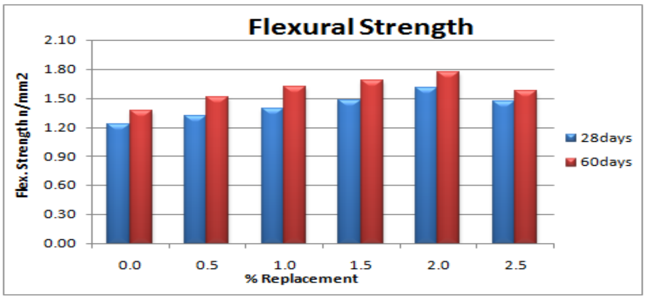

Fig-14: 28 & 60days Flexural strength (8M)

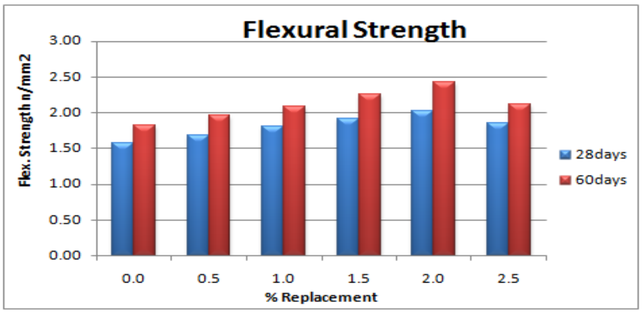

Fig-15: 28 & 60days Flexural strength (10M)

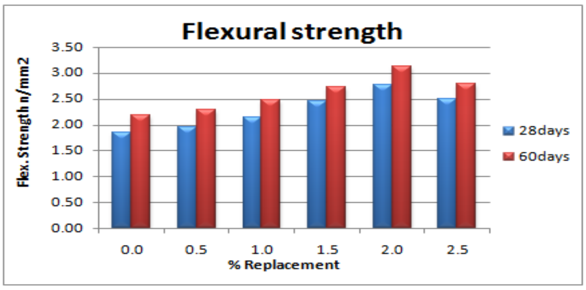

Fig-16: 28 & 60days Flexural strength (12M)

5.3 Durability properties of concrete

5.3.1 Sorptivity

Sorptivity has been tested on both geopolymer concrete with replacement of calcium hydroxide. This test was conducted on 100mm X 50mm size specimen after 28 days of curing. The dry weights of the specimen are noted and its wet weights are noted at 30 min interval. Table 9 gives Sorptivity values of geopolymer concrete with different percentage of calcium hydroxide. The result shows that, in geopolymer concrete the Sorptivity will goes on decreasing when the percentage of calcium hydroxide increases.

Table – 9: Sorptivity test values

For 8M					
Type of concrete	**No. of specimen**	**Dry weight W1 (kg)**	**Wet weight W2 (kg)**	**Sorptivity values in 10-6**	**Avg. Sorptivity value**
CH0	1	0.862	0.912	1.163	1.202
	2	1.01	1.064	1.256	
	3	0.936	0.987	1.186	
CH0.5	1	0.962	1.01	1.116	1.295
	2	1.023	1.075	1.209	
	3	0.989	1.056	1.558	
CH1.0	1	0.862	0.912	1.163	1.349
	2	1.062	1.136	1.721	
	3	0.965	1.015	1.163	
CH1.5	1	0.915	0.995	1.860	1.488
	2	1.015	1.064	1.140	
	3	0.987	1.05	1.465	
CH2.0	1	0.865	0.899	0.791	1.109
	2	0.789	0.85	1.419	
	3	0.801	0.849	1.116	
CH2.5	1	0.802	0.895	2.163	1.008
	2	0.801	0.831	0.698	
	3	0.798	0.805	0.163	

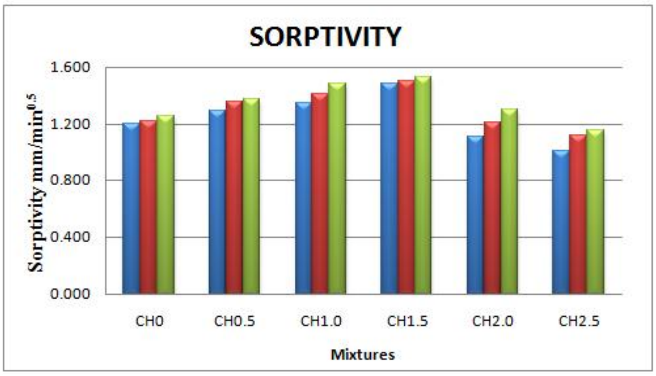

Fig-17: Sorptivity values of GPC

3. CONCLUSIONS

Study was given on GPC's mechanical features and durability features when partially replaced with calcium hydroxide. Maj or conclusions could be drawn from this study as follows,

- The usage of waste materials like fly ash can reduce the environmental pollution and also disposal problem.
- Addition of super plasticizer increases the workability of geopolymer concrete.
- Geopolymer concrete attains its maximum strength in 60 days. This is because polymerization process will attain slowly at ambient temperature.
- Compressive strength and divided tensile strength of GPC mixes up to 2.0 percent replacement level of calcium hy droxide were observed as a increasing trend. And both characteristics had a downward trend at 2.5 percent of calc ium hydroxide replacement rate.
- Flexural strength improves as the proportion of calcium hydroxide replacement rises as fly ash in geopolymer concrete rises.
- It is concluded that a 2.0 percent replacement of calcium hydroxide is considered to be the optimum amount of replacement. And it seems that calcium hydroxide act as filling material and makes the concrete thick.
- Sorptivity of GPC is less. That means the rate of absorption of geopolymer concrete is unsubstantial.
- The effect of curing hours on the geopolymer concrete when it is replaced with optimum percentage of calcium hydroxide increase as there is increase in curing hours.

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