Experimental Study on Durability Properties of Ambient Cured Fly Ash and GGBFS Based Geopolymer Concrete with Addition of Lime

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Abstract: As the tremendous use of cement for construction, the Ordinary Portland Cement (OPC) production increases day by day. The cement production is held responsible for CO_2 emissions, which polluted the atmosphere. Hence, it is inevitable to find an alternative material to OPC. The geopolymer concrete is a best alternative which shall be produced by the chemical action of inorganic molecules. This paper focuses on fly-ash based Geopolymer concrete with addition of hydrated lime. In the geopolymer concrete, cement is completely replaced by fly ash, ground granulated blast furnace slag (GGBFS) and hydrated lime. A solution of Sodium Hydroxide (NaOH) and Sodium Silicate (Na_2SiO_3) was used as an alkaline solution with Na_2SiO_3: NaOH ratio 2.0. The hydrated lime is used with variation in GGBFS replacement with percentiles as 5%, 10%, 15% and 20%. The GPC samples were cured at ambient temperature (27± 2°C) for 7 days and 28 days and then tested for compressive strength. Slump cone test on fresh mixes were also performed. The optimized geopolymer concrete with the best workability and compressive strength, was chosen, and the specimens of standard sizes were casted and tested for acid attack of H_2SO_4, HCl and NaCl. Also, the sorptivity test and the abrasion value test were performed to compare the density of concrete.

Key words: Sorptivity, Acid Attack, Hydrated Lime, Abrasion Value.

1. INTRODUCTION

The demand of cement is increasing drastically with increment in the urbanization. According to the reports cement production is responsible for 4% to 7% of total carbon dioxide emission into the atmosphere leading to global warming. The production, Usage and the need for cement will increases at higher rate which will have a severe impact on the environment. So, another material is required which is same as the cement and the alternative of the cement which provide safety and durability to the structures as complete replacement for cement in concrete. As a result, our geopolymer concrete cuts CO_2 emissions by 80%. Geopolymer is gaining popularity and acceptability as a means of ensuring sustainability. Fly ash and GGBS are rich in silicon and aluminum, which are polymerized by an alkali activating solution to form molecular chains and networks, resulting in a rigid binder. So, alumino-silicate based materials are the best alternatives of the cement. So, use of these alumino-silicate materials with the alkali activators are known as the geopolymer concrete (GPC).

Manufacturing of Geopolymer concrete necessitates considerable caution and material selection. GPC mix construction entails a series of extensive tests. Geopolymer concrete is made from fly ash, GGBS, fine and coarse aggregate, and an alkaline activator solution.
Silicon (Si) and aluminium (Al)-rich source materials such as Fly Ash, Rice Husk, Silica Fume, GGBS, and others, and alkaline liquids are the two basic components of binder in geopolymer concrete. The curing time and temperature have an effect on properties of GPC.

As an alkaline activator solution, catalytic liquid is utilized. It is composed of sodium or potassium silicates and hydroxides dissolved in water. The function of alkaline solution is to activate Fly and GGBS. The alkaline solution should be handled with caution to guarantee the user's safety.

2. MATERIALS AND METHODS

Because of the numerous parameters involved, developing a mix design for geopolymer concrete is more challenging than for OPC concrete. A higher compressive strength is obtained by increasing the mass ratio of Na_2SiO_3/NaOH. Workability can be increased by adding superplasticizer upto 4 percent of fly ash content by mass. The concentration of NaOH solution can range between 8 and 16 molar. Higher concentration of NaOH produces higher strength (Wallah et al, 2005).

The geopolymer paste is produced by the reaction of the alkali activator with the Al_2O_3 and SiO_2 of fly ash. The performance of geopolymer concrete is dependent on the chemistry that occurs between the two major ingredients. For example, Sodium Silicate solution activates GGBS better than other activators, but Sodium Hydroxide activates fly ash better (Fareed et al., 2011). (Fareed et al., 2011). Experiments demonstrated that a Sodium Silicate solution with a mass ratio of 0.75 SiO_2 / Na_2O can attain high early age strength. (Bakharev and colleagues (1999).

Experimental work that carried out to find the optimum calcium content for the standard fly ash and GGBFS based geopolymer concrete which is cured at ambient temperature. Firstly, some parameters for the GPC mix design are fixed, like the alkaline to binder ratio (Al/Bi) is taken as 0.35, water to binder ratio (W/Bi) is considered as 0.25 and sodium silicate to sodium hydroxide (SS/SH) ratio is taken as 2 with Sodium Hydroxide solution of 14M, so that the effects of another parameter like Lime to GGBFS ratio (Ca/GB) can be checked. After calculating proportions for GPC Mix Designs with varying Ca/Bi ratio, the specimens are casted for the pilot study to select a GPC Mix Design and further properties to be checked with considering mix proportions of higher compressive strength out of all GPC mix designs. Standard mix design approach (IS 10262:2009) was used for mix proportion of M30 grade normal cement concrete (NC). A sand passing through 4.75 mm sieve conforming to grading zone II of IS 383:1970 (BIS, 1970, reaffirmed 2002), and having a fineness modulus of 2.64 and specific gravity of 2.62 was used. The maximum size of the coarse aggregate used was 20 mm with a fineness modulus of 7.03 and specific gravity of 2.82. The water absorption values for sand and coarse aggregate were 1.05% and 0.68% respectively. Fly ash, GGBFS and Hydrated Lime were used as precursors and solution of sodium silicate and sodium hydroxide was used as an activator. The values of specific gravity for cement, fly ash, GGBFS and hydrated lime are evaluated as 3.12, 2.1, 2.88 and 2.25 respectively.

After adopting a geopolymer mix which shows higher compressive strength among all, the various durability tests carried out like Sorptivity Test, Abrasion Value Test and Acid Attack Tests on GPC Concrete and results were compared with normal cement concrete of same grade M30. The trial mix of 1:2.06:3.79 is adopted with water to binder ratio (W/Bi) as 0.25 for GPC and water to cement ratio (W/C) as 0.45 for normal cement concrete (NC) as per mix design calculation. Then casted the cube specimens with varying parameter Lime to GGBFS ratio (Ca/GB) by keeping 0%, 5%, 10% and 15% and tested them. An ambient curing method is adopted for GPC and water curing for NC.

2.1 Workability Test: In the fresh state of casting normal cement concrete and geopolymer concrete, the workability of concrete is to be checked using Slump Test according to IS 1199 (Part-2): 2018.

Compressive Strength Test: The compressive strength test was conducted according to IS: 516-1959. After the curing period of 7 days and 28 days, the cube specimens of Geopolymer concrete (GPC) and normal cement concrete (NC) were tested using compression strength testing machine (CTM).

2.2 Sorptivity Test (ASTM C1585-13): Hall (1981) created this test, which is based on Darcy's law of unsaturated flow. This is the simplest and fastest test to detect the concrete's ability to absorb water in a single path through homogeneous material capillary action. The standard test sample is a disc with a diameter of 100±6 mm and a length of 50±3 mm. The specimens are either drilled cores in accordance with Test Method C42/C42M or casted cylinders in accordance with practices C31/C31M or C192/C192M. A specimen's cross-sectional area cannot vary from the top to the bottom of the specimen by more than 1%.

2.3 Abrasion Value Test: The testing apparatus according to IS: 1237- 2018 shall be a grinding device consisting essentially of a horizontally fixed smooth grinding disc of about 750 mm diameter, rotating about a vertical axis and furnished with a replaceable grinding path. The square specimens measuring 71 x 71 x 50 mm are taken for testing and the abrasive wear of the specimen after 16 cycles of testing shall be calculated as the mean loss in specimen volume.

2.4 Acid Attack Test: Test specimens in cubical shape of 15cm x 15cm x 5cm were casted and cured with acid solutions of H_2SO_4, HCl and NaCl using 5% concentration. Calculate the percentage weight loss and percentage strength loss by comparing the initial and final readings of weight and strength of the specimens.

3. RESULTS AND DISCUSSIONS

3.1 Workability Test: The slump test is carried out on all mixes of geopolymer concrete and normal cement concrete in the fresh state and found the results as mentioned in table-1 and concluded that the addition of hydrated lime can reduce workability of geopolymer concrete.

Table-1 Results of Slump Test

Concrete Mix	NC	GCG-0	GCG-5	GCG-10	GCG-15
Slump Value (mm)	75	65	55	50	40

3.2 Compressive Strength Test: The results showed that the compressive strength of trial mix Ca/GB-10 is maximum compared to other GPC mixes. The compressive strength has increased by 9% by replacing lime up to 10% with GGBFS when compared with no addition of lime. So we can say that the replacement of 10% of Lime gives the satisfactory results and the same mix is adopted for further durability tests on GPC.

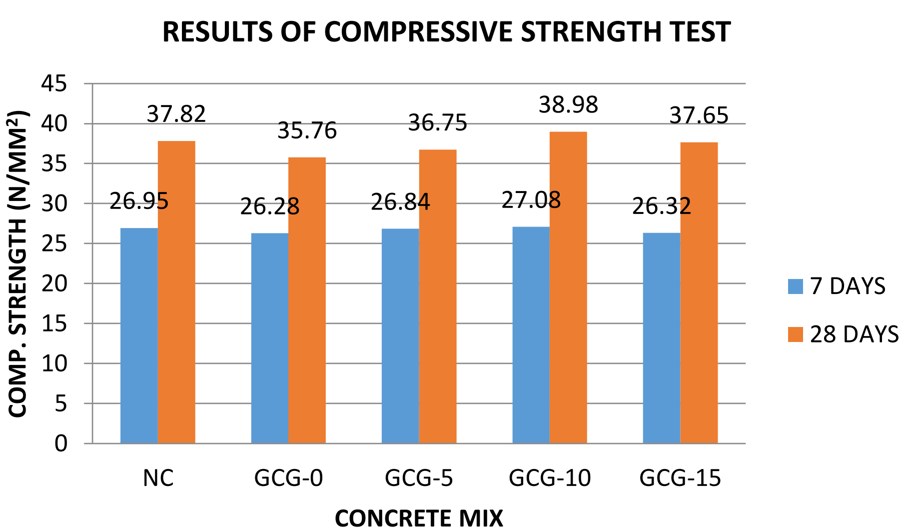

Fig.1 Comparison of results of compressive strength test

3.3 Sorptivity Test: This test is preformed over three specimens i.e. discs of GPC mix which made with 10% lime replacement (GCG-10) and another three specimens of normal cement concrete (NC).

Table-2: Weight of discs at regular time interval in Sorptivity Test

TIME in MIN	NC D1	NC D2	NC D3	GCG-10 D1	GCG-10 D2	GCG-10 D3
0	115.5	113.5	118	103	104.5	105.5
30	116	114	118.5	103.5	105	105.5
60	116.5	114	118.5	103.5	105	105.5
90	116.5	114.5	118.5	103.5	105	106
120	116.5	114.5	119119	103.5	105.5	106
150	117	114.5	119.5	104	105.5	106
180	117	114.5	119.5	104	105.5	106.5
210	117	114.5	119.5	104	105.5	106.5
240	117	114.5	119.5	104	105.5	106.5
Weight Difference in %	**1.29**	**1.05**	**1.27**	**0.97**	**0.94**	**0.94**
Sorptivity Co-efficient(i) in mm/(min)$^{0.5}$	**0.1**	**0.095**	**0.105**	**0.0625**	**0.05**	**0.05**

From the above table, it can be concluded that the Average Sorptivity co-efficient of GPC concrete GCG-10 is 0.054 $mm/(min)^{0.5}$ which is lesser than the normal concrete which is 0.1 $mm/(min)^{0.5}$. So the absorption of water in GPC concrete would be lesser than the normal concrete.

3.4 Abrasion Value Test: The abrasive wear of the specimen after 16 cycles of testing shall be calculated as the mean loss in specimen volume AV from the equation:

AV = $\Delta m / \rho R$

Where, AV = loss in volume after 16 cycle in mm^3;

Δm = loss in mass after 16 cycles, in g; and

ρR = density of the specimen or in the case of two-layer specimens the density of the wearing layer, in gm/mm^3.

Table-3 Results of Abrasion Value Test

Specimen No.	NC 1	NC 2	NC 3	GPG-10 1	GPG-10 2	GPG-10 3
Average Length (mm)	68.4	69.3	67.5	69.3	67.8	68.6
Average Width (mm)	67.6	68.5	67.3	69.4	68.3	68.5
Average Thickness (mm)	48.5	49.0	49.1	49	47.2	48.1
Initial Volume = V (mm^3)	224850.92	232991.48	223653.14	235661.58	218570.9	226026.71
Initial Weight (gm)	561.9	582.24	558.9	535.65	496.81	513.75
Weight after 16 cycles (gm)	538.58	569.72	545.15	521.72	484.38	502.45
Area of Abrasion = A in (mm^2)	4631.33	4753.95	4549.49	4809.42	4630.74	4699.1
AV= Loss in Volume after 16 cycles (mm^3)	9331.73	5010	5502.2	6128.46	5468.5	4971.4
% Loss in Volume	**4.15**	**2.15**	**2.46**	**2.60**	**2.50**	**2.20**

After performing Abrasion Value Test, the average loss in volume after 16 cycles resulted as 2.92% and 2.43% for normal cement concrete (NC) and geopolymer concrete (GPG-10) respectively.

3.5 Acid Attack Test: This test is performed on the specimens of GPC Concrete (GCG-10) and Normal Concrete (NC). The results shows that the exposure of H_2SO_4, HCl and NaCl leads to weight loss and strength loss in GPC and NC, but resistance to acid is more in GPC compared to NC.

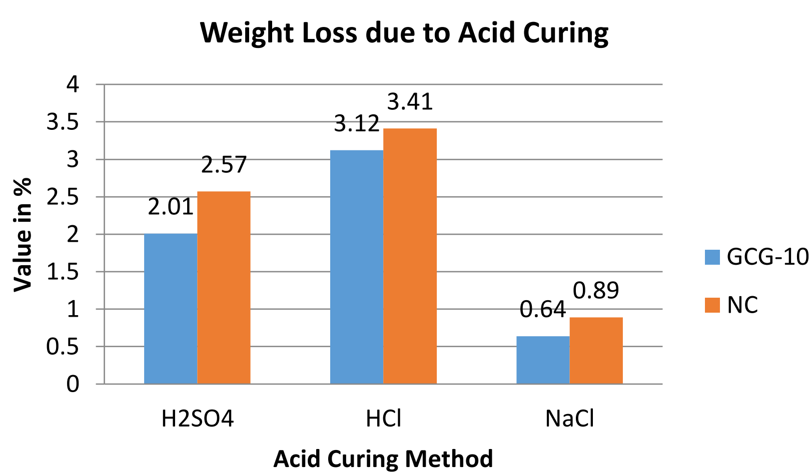

Fig.2 Comparison of results of Weight Loss due to Acid Curing

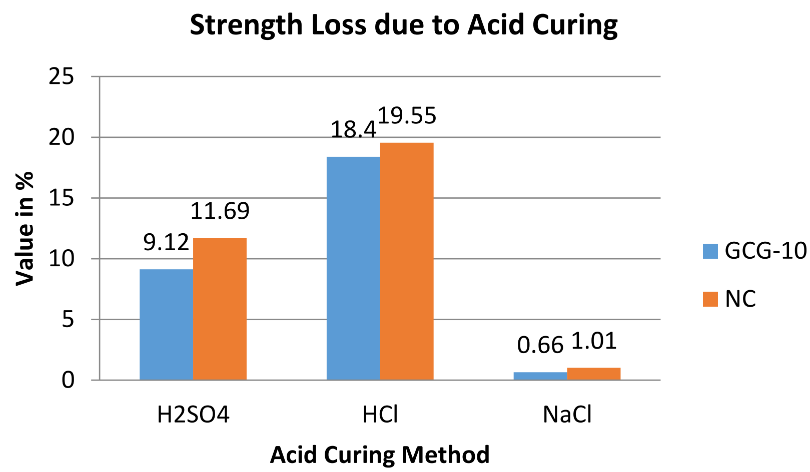

Fig.3 Comparison of results of Strength Loss due to Acid Curing

CONCLUSION

The workability of the concrete is decreased due to addition of hydrated lime to Geopolymer concrete as a partial replacement of GGBFS, but the compressive strength is dramatically boosted as a result. The compressive strength has increased by 9% when GGBFS is replaced by 10% with hydrated lime and found decrement in compressive strength by addition of more hydrated lime content. However, it is noted that a lime-based Geopolymer concrete has the potential to build strength at an early age. Because of availibility of pozzolonic materials in geopolymer concrete, the loss in weight and strength marked less for geopolymer concrete compared to normal cement concrete in H_2SO_4, HCl and NaCl acidic exposure condition. In Sorptivity test, the value of Sorptivity Co-efficient is less for geopolymer concrete by 0.046mm/$\sqrt{T}$ and in Abrasion Value Test, the Loss in Average Volume Loss in geopolymer concrete is 16% lower as compared to Average Volume Loss in normal cement concrete which indicates the higher density of geopolymer concrete than normal concrete.

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