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Mechanical Properties of High Calcium Flyash Geopolymer Concrete

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Abstract: The present study deals with the mechanical properties of High Calcium Fly Ash Geopolymer Concrete (HCFA GPC). A preliminary study was made on high calcium fly ash geopolymer mortar by varying sodium based alkaline activator to binder ratio to find an ideal composition. Alkaline activators were the mixture of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3. Based on the compressive strength of high calcium fly ash geopolymer mortar, the optimum mix combination was arrived for the further study on concrete. Upon the optimum mix combination, mechanical properties such as compressive strength, split tensile strength and modulus of elasticity were further determined. Test results depict that strength properties of HCFA GPC were marginally higher under steam curing than ambient curing.

Keywords: *Geopolymer, High Calcium fly ash, Alkaline activator, Steam Curing, Strength Properties*

1. Introduction

Manufacturing of Portland cement is an energy intensive process and releases a large amount of greenhouse gases to the atmosphere. Recently, another form of cementations materials using silicon and aluminum activated in a high alkali solution was developed. It is referred as geopolymer or alkali-activated binder. Geopolymers was first developed by Davidovits, which consists of SiO_4 and AlO_4 tetrahedral networks [1-3]. Alumina silicate reactive materials dissolve in strong alkaline solutions and free SiO_4 and AlO_4 tetrahedral structure forms. It is also well known that geopolymers possess excellent mechanical properties [4].

Several factors such as curing mode, curing temperature, alkaline liquid to binder ratio, molarity of sodium hydroxide, ratio of sodium hydroxide to sodium silicate solution are the key factors in developing geopolymeric reaction [5-8]. The geopolymer mixtures may be subjected to curing either at room temperature or at a given temperature. It is mentioned that the reaction of the fly ash in the production of geopolymers is low at ambient temperatures [9]. The geopolymer concrete achieves high compressive strength at given temperatures between 40 to 95°C [10]. Yunfen et al. [11] demonstrated the influence of concentration and modulus (SiO_2: N_2O) of sodium silicate solutions and curing mode in geopolymers prepared. It can be seen that the compressive strength increased with increase in modulus of sodium silicate solution. However, when the modulus exceeds 1.4, compressive strength decreased [12]. Also, elevated temperatures can increase the early strength buildup of the samples. However, the later strength after 7 days was the same at irrespective of different temperature [13, 14].

Among various source materials, low calcium fly ash (LCFA) is extensively used for geopolymer owing to its easy availability and enhanced properties. [15].As well, abundant work on geopolymer has been reported with the use of low calcium fly ash. Despite, a quite reasonable work is carried out with the use of high calcium fly ash for geopolymer. High calcium fly ash (HCFA) also contains a considerable amount of silica and alumina. [16]. High calcium fly ash has few drawbacks compared to low calcium fly ash in geopolymer. The early age compressive strength of high calcium fly ash geopolymers attains under high pressure and high temperatures of curing to get the similar strength of ordinary Portland cement binder [17-19]. While molarity of NaOH as 8M is found suitable for LCFA, HCFA needs 10M for the geopolymer synthesis [20-22].

Turkish construction industry promoted HCFA geopolymer for both cast-in-place and precast concrete products. Steam curing was applied to develop adequate compressive strength for form removal at age 1-day [23].Compressive strength and microstructure of HCFA geopolymer depend upon mass of water to fly ash ratio and [19-21]. The annual output of lignite fly ash from Neyveli Lignite Corporation station 28.5 million tons per annum at Neyveli and one open cast lignite mine of capacity 2.1 million tonnes per annum. This fly ash contains a high percentage of calcium and is being used quite extensively for construction in Tamilnadu. The knowledge of the use of high calcium lignite fly ash in producing geopolymer would be beneficial to increase the scope of HCFA.

In the above background, the present study made an attempt to determine the mechanical properties of HCFA geopolymer concrete under ambient curing and steam curing. In this respect, a preliminary study was proposed on HCFA geopolymer mortar by varying sodium alkaline activator to binder ratio to find the ideal composition for the study in concrete. Accordingly, the mechanical properties include compressive strength, split tensile strength and modulus of elasticity to substantiate the development of HCFA geopolymer concrete.

2. Experimental Details

2.1 Materials

Fly ash used in this work was collected from Neyveli Lignite Corporation in Cuddalore district of Tamilnadu. The chemical composition of high calcium fly ash is shown in Table 1. The CaO content of fly ash used reveals that it is categorized as high calcium fly ash. Alkaline solution comprises of sodium silicate and sodium hydroxide. Coarse aggregate of size 12 mm and 6 mm and fine aggregate were used. The physical properties of fine and coarse aggregate are shown in Table 2.

***Table 1** Chemical Composition of High Calcium Fly Ash*

S.NO	Chemical composition	Observed
1.	Silica (SiO_2)	63.11%
2.	Calcium Oxide (CaO)	17.13%
3.	Magnesium Oxide (MgO)	0.24%
4.	Iron Oxide (Fe_2O_3)	5.03%
5.	Aluminium Oxide (Al_2O_3)	19.58%
6.	Sodium Oxide (Na_2O)	0.29%
7.	Potassium Oxide (K_2O)	0.84%
8.	Loss of Ignition (LOI)	1.55 %

***Table 2** Physical Properties of fine and coarse aggregate*

Description	Fine aggregate	Coarse aggregate
Specific gravity	2.55	2.70
Bulk density	1791.1kg/m^3	1689.32 kg/m^3
Fineness modules	2.6	6.50

2.2 Mix Design of HCFA Geopolymer Mortar

Primarily HCFA geopolymer mortar was studied for finding the optimum composition of the mix. Trial mixes were made by considering the various factors. The ratio of fly ash to sand ratio was 1:3. The concentration of NaOH was kept as 10M. Alkaline liquid to binder ratio was considered as 0.35, 0.40, 0.45 and 0.5. The sodium silicate to NaOH ratio by mass was 2.5. The mixing was done at room temperature. The mixing procedure started with mixing of NaOH solution and sodium silicate solution. This was followed by the addition of fly ash for 5 min in a pan mixer. Sand was then added and mixed for 5 min.

2.2.1 Curing of HCFA Geopolymer Mortar

Two types of curing were attempted for the mixes. Ambient and steam curing were selected. In ambient curing the casted specimens were demoulded on the next day and kept in room temperature until the day of testing. In case of steam curing the casted specimens were kept in steam curing chamber at 60ºC for 24 hours to activate the geopolymerisation of geopolymer specimens were demoulded and kept in room temperature until the day of testing.

2.3 Experimental Work

2.3.1 Compressive strength of HCFA Geopolymer Mortar

Mortar cube of size 70.6 mm x 70.6 mm x 70.6 mm were casted. Compressive strength of HCFA geopolymer mortar was measured using 200 tons capacity compressive testing machine at the age of 3, 7, 28, 56 and 91 days. In case of HCFA geopolymer mortar specimens were cured under steam at 60°C for one day and kept in room temperature up to the date of testing. The specimens curing in steam curing chamber is presented in fig 1.

***Fig.1** Specimens in steam curing chamber*

2.3.2 Strength properties of HCFA geopolymer concrete

On arriving, the ideal mix composition of HCFA geopolymer from compressive strength of mortar, strength properties was evaluated. Cubes of size 100 mm for compressive strength and cylinder of size 150 mm dia x 300 mm height for split tensile strength were used. Strength of HCFA geopolymer was determined under both ambient and steam curing. Fig 2 & 3 shows the testing of compression and split tensile strength testing of the concrete specimens.

***Fig.2** Compression test*

***Fig.3** Split tensile strength test*

2.3.3 Modulus of Elasticity

Cylinder of size 150 mm diameter and 300 mm height was cast for modulus of elasticity of HCFA geopolymer concrete. It was evaluated at the age of 28 days and testing is shown in Fig. 4. Compressometer is attached over the specimen and the gauge length is noted. The specimen is then placed in the compression testing machine and carefully aligned for concentric loading. The load was applied gradually and the compressometer reading was noted at every 5 division deflection. After reaching about 80% of the ultimate load the compressometer grip was released and the load continued until failure. Stress – strain graph was plotted for every specimen and the elastic modulus was calculated.

***Fig. 4** Compressive modulus of elasticity Test on HCFA GPC*

3. Results and Discussion

3.1 Compressive strength of HCFA geopolymer mortar

The compressive strength test results of HCFA geopolymer mortar is displayed in Fig.5. The compressive strength of HCFA geopolymer mortar increases with increase in liquid to binder ratio. It was found 0.5 as ideal liquid to binder ratio. It is quite obvious that compressive strength increased with increase in age.

Besides, the rate of strength development is slow at early age. It is surprising to note that substantial geopolymeric reaction developed at the age of 7 days. However beyond 7 days, the progress in strength is moderate up to 91 days. The maximum compressive strength was noted as 37 MPa for liquid to binder ratio 0.5 at the age of 28 days. Therefore, liquid to binder ratio 0.5 is chosen as optimum combination. This combination was selected for further study with High Calcium Fly Ash GeoPolymer Concrete.

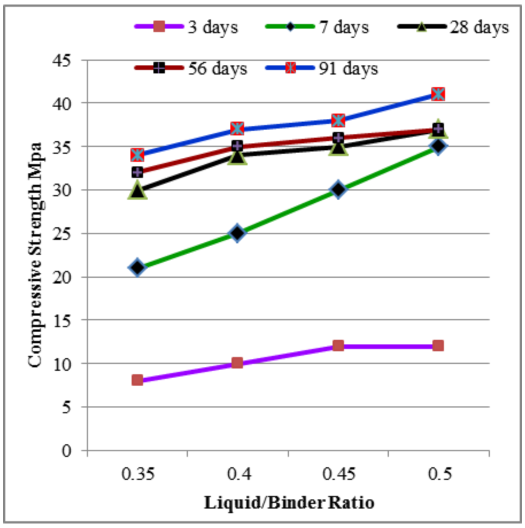

***Fig 5:** Compressive strength of High Calcium Fly Ash GeoPolymer Mortar*

3.2 Compressive strength of HCFA GPC

The compressive strength of HCFA GPC was determined at the age of 7, 28, 56 days in both ambient and steam curing. The results indicates that specimens cured under steam curing provided has the compressive strength of 33.8N/mm^2 which was 15% higher compressive strength than specimens cured in ambient curing at the age of 28 days. Fig. 6 depicts the compressive strength of HCFA GPC.

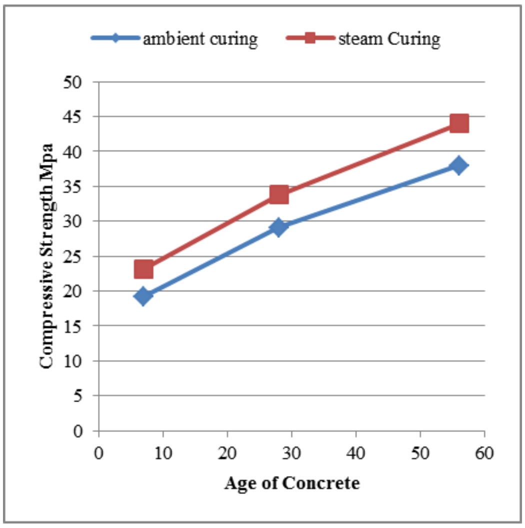

Fig. 6 *Compressive strength of HCFA GPC*

3.3 Split tensile Strength of HCFA GPC

The split tensile strength of HCFA GPC determined at the age of 7, 28, 56 days in both ambient and steam curing. Similar to compressive strength, the specimens cured at steam curing provided better results than specimens cured at ambient curing. The steam curing specimens was attained 3.34N/mm^2 which was 18% of higher strength than the ambient curing specimens at the age of 28 days. Fig. 7 represents the split tensile strength of HCFA GPC.

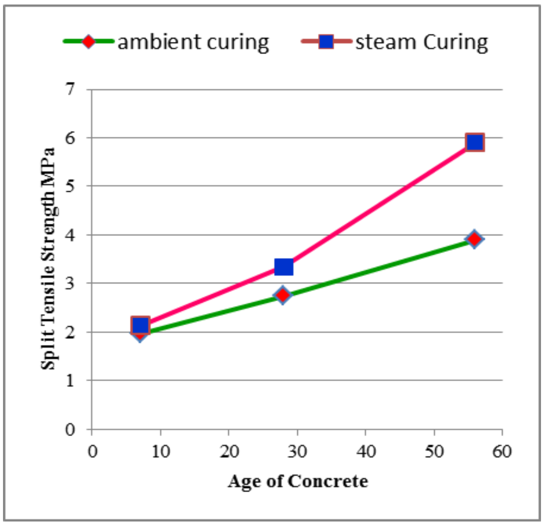

Fig.7 *Split Tensile strength of HCFA GPC*

3.4 Modulus of Elasticity of HCFA GPC

Modulus of elasticity of HCFA GPC of steam cured specimens attained 47% high load carrying capacity than the ambient curing specimens at the same stress level. The modulus of elasticity was found as 24556.45 N/mm^2 and 25685.80N/mm^2 in ambient and steam curing respectively. The stress strain relationship of HCFA GPC is displayed in Fig.8.

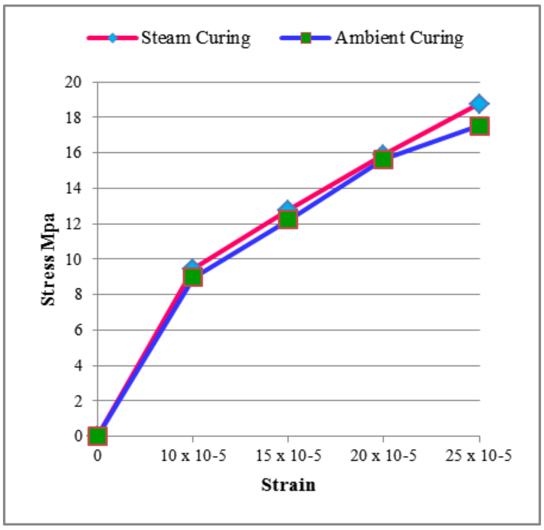

Fig.8 *Modulus of Elasticity of HCFA GPC*

4. Conclusion

The following conclusion is drawn from the study on high calcium fly ash geopolymer.

1) The maximum compressive strength of high calcium fly ash geopolymer mortar was attained when liquid to binder ratio was kept as 0.5
2) Steam cured HCFA geopolymer concrete specimens achieved 16% higher compressive strength than ambient cured specimens.
3) Split tensile strength of steam cured HCFA geopolymer concrete had 18% higher value than the ambient cured specimens.
4) Modulus of elasticity HCFA geopolymer concrete showcased only small variations among steam cured and ambient cured condition
5) Hence, it is concluded that the steam curing is better than ambient curing for HCFA GPC.

5. Acknowledgements

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