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A COMPARATIVE STUDY OF GREEN GEOPOLYMER CONCRETE USING FLY ASH

[1]Shri Krishna Gurlhosur*, [2]Abdul Samad M Kamdod
[3]V.M.Patil, [4]Sreekanth B

[1] Department of Chemical Engineering, Rural Engineering College Hulkoti, Gadag, Karnataka, India.
[2] Department of Civil Engineering, Muffakham Jah College of Engineering and Technology, Banjara Hills, Road No:3, Hyderabad-500034, India.
[3] Department of Chemistry, Rural Engineering College Hulkoti, Gadag, Karnataka, India.
[4]Department of Chemical Engineering, SDMCET Dharwad, Karnataka, India

*Corresponding author: kris_hosur@yahoo.co.in
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ABSTRACT
In this work, the long-term properties of low-calcium fly ash-based geopolymer concrete were studied. The long-term properties included in the study were compressive strength, sulfate resistance and sulfuric acid resistance. Fly ash-based geopolymer concrete in this study utilised the low-calcium (ASTM Class F) dry fly ash as the source material. The alkaline liquid comprised a combination of sodium silicate solution and sodium hydroxide solids in flakes or pellets form dissolved in water. The coarse aggregates were crushed granite-type aggregates comprising 16 mm and the fine aggregate was fine sand. High range water reducer super plasticiser was used to improve the workability of fresh geopolymer concrete. The mixture proportions used in this study were developed based on previous study on fly ash-based geopolymer concrete. Two different mixing ratios, M15 and M20, were used for the fly ash concrete, cement concrete and mixture of cement+fly ash concrete specimens. Tests specimens were manufactured in the laboratory using the equipments normally used for Portland cement concrete, such as a pan mixer and steel moulds. For sulfate resistance tests, the test specimens were immersed in 4% sodium sulfate solution for a period of exposure up to one week. The sulfate resistance was evaluated based on the change in mass, change in length and change in compressive strength of the specimens after sulfate exposure. The test specimens were 150x150x150 mm cubes. The sulfuric acid resistance of concrete was also studied. The concentration of sulfuric acid solution was 5% for soaking concrete specimens. The sulfuric acid resistance of concrete was evaluated based on the mass loss and the residual compressive strength of the test specimens after acid exposure up to one week. For each type of test, companion specimens were prepared and tested to determine the 7th day and 28th day compressive strength.

Key words: Geo polymer concrete, Compressive strength, Alkali reasistance, Super alkali based plasticizer.

INTRODUCTION

Fly ash is one of the numerous substances that cause air, water and soil pollution, disrupt ecological cycles and set off environmental hazards.In the last decade geopolymer binders have emrged as one of the possible alternatives to cement binders for applications in concerete industry.Geopolymers can be produced by polymerization of alumino-silicate oxides with alkali silicstes yielding Si-O-Al bonds[1]. The two main ingrediants of geopolymer binders are alkali liquids and source materials.The alkali liquids are usually sodium or potassium based solutions. The source material should be rich in silicon (Si) and aluminium (Al) from geological origin or by product materials auch as clays, metakaolin, flyash, bottom ash , slag and rice husk ash. The use of geopolymer involves a lesser amount of green house gas and is, therefore, a more envronmental- friendly binding material compared to conventional portland cement[2]. In addition, geopolymers possess many excellent properties such as high early strength, excellent mechanical properties, low creep and shrinkage, good resistancein acids and sulfate attacks[3-7]. Fly ash is one of the numerous substances that cause air, water and soil pollution, disrupt ecological cycles and set off environmental hazards. The combustion of powdered coal in thermal power plants produces fly ash. The high temperature of burning coal turns the clay minerals present in the coal powder into fused fine particles mainly comprising aluminum silicate. Fly ash produced thus possesses both ceramic and pozzolanic properties. When pulverized coal is burnt to generate heat, the residue contains 80 per cent fly ash and 20 percent bottom ash. The ash is carried away by flue gas collected at economizer, air pre-heater and ESP hoppers. Clinker type ash collected in the water-impounded hopper below the boilers is called bottom ash. The World Bank has cautioned India that by 2015, disposal of coal ash would require 1000 square kilometers or one square meter of land per person. Since coal currently accounts for 70 per cent of power production in the country, the Bank has highlighted the need for new and innovative methods for reducing impacts on the environment. The process of coal combustion results in fly ash. The problem with fly ash lies in the fact that not only does its disposal require large quantities of land, water, and energy, its fine particles, if not managed well, by virtue of their weightlessness, can become airborne. Currently, 90 million tons of fly ash is being generated annually in India, with 65 000 acres of land being occupied by ash ponds. Such a huge quantity does pose challenging problems, in the form of land usage, health hazards, and environmental dangers. Both in disposal, as well as in utilization of fly ash, utmost care has to be taken, to safeguard the interest of human life, wild life, and environment.

MATERIALS

The material used for making fly ash based geopolymer concrete specimens is Low calcium dry fly ash as the source material, aggregates, alkaline liquids, water, super plasticizer and cement.

a) **Aggregates**

Local aggregates, comprising 16mm coarse aggregates and fine aggregates, in dry condition were used. The coarse aggregates were crushed granite type aggregates and the fine aggregates were fine sand.

b) **Alkaline Liquid**

The alkaline liquid used was a combination of sodium silicate solution and sodium hydroxide solution. The sodium silicate solution (Na_2O = 13.7%, SiO_2 = 29.4%, and water =

55.9% by mass) was purchased from a local supplier in bulk. The NaOH solids were dissolved in water to make the solution.

c) **Super Plasticizer**

In order to improve workability of fresh concrete, high range water reducing naphthalene based crizo primia 721 was added to the mixture.

d) **Cement**

Ordinary Portland Cement of OPC 43- Grade was used in this work.

EXPERIMENTAL METHODS

a) **Mixture Proportions**

Based on the study, two different mixture proportions were formulated for making cement concrete and fly ash specimens. The proportions for M15 (1:2:4, where 1 is cement or fly ash, 2 is fine sand, and 4 is aggregates) and M20 (1:1.5:3, where 1 is cement or fly ash, 1.5 is fine sand and 3 is aggregates) [8].

The concentration of the sodium hydroxide was 8 Molars (M).

b) **Preparation of Alkaline Liquid**

The sodium hydroxide (NaOH) solids were dissolved in water to make the solution. The mass of NaOH solids in a solution varied depending on the concentration of 8M consisted of 8x40 = 320 grams of NaOH solids (in flake or pellet form) per liter of the solution, where 40 is the molecular weight of NaOH.

The sodium silicate solution and the sodium hydroxide solution were mixed together at least one day prior to use to prepare the alkaline liquid. On the day of casting of the specimens, the alkaline liquid was mixed together with the super plasticizer (Crizo Fluid Primia 721) and the extra water (if any) to prepare the liquid component of the mixture.

c) **Preparation of Fresh Concrete and Casting**

The fly ash and the aggregates were first mixed together in the laboratory concrete pan mixer for about 3 minutes. The liquid component of the mixture was then added to the dry materials and the mixing continued for further about 4 minutes to manufacture the fresh concrete. The fresh concrete was cast into the moulds immediately after mixing, in three layers for cubical specimens. For compaction of the specimens each layer was given 60-80 manual stokes using a iron rod. Then the concrete was casted into the moulds and was kept for drying at laboratory temperature.

d) **Curing of Test Specimens**

After casting, the fly ash concrete test specimens were kept for curing at an elevated temperature. Two types of heat curing can be used, i.e. dry curing and steam curing[9]. For dry curing, the test specimens are cured in the oven and for steam curing, they are cured in the steam curing chamber. In this study, specimens were heat-cured at 60◦c for 24 hours.

After the curing period, the test specimens were left in the moulds for at least six hours in order to avoid a drastic change in the environment condition. After remolding, the specimens were left to air-dry in the laboratory until the day of test.

For cement and mixture of cement + fly ash concrete test specimens, water curing was provided. Test specimens were soaked completely under the water for seven days.

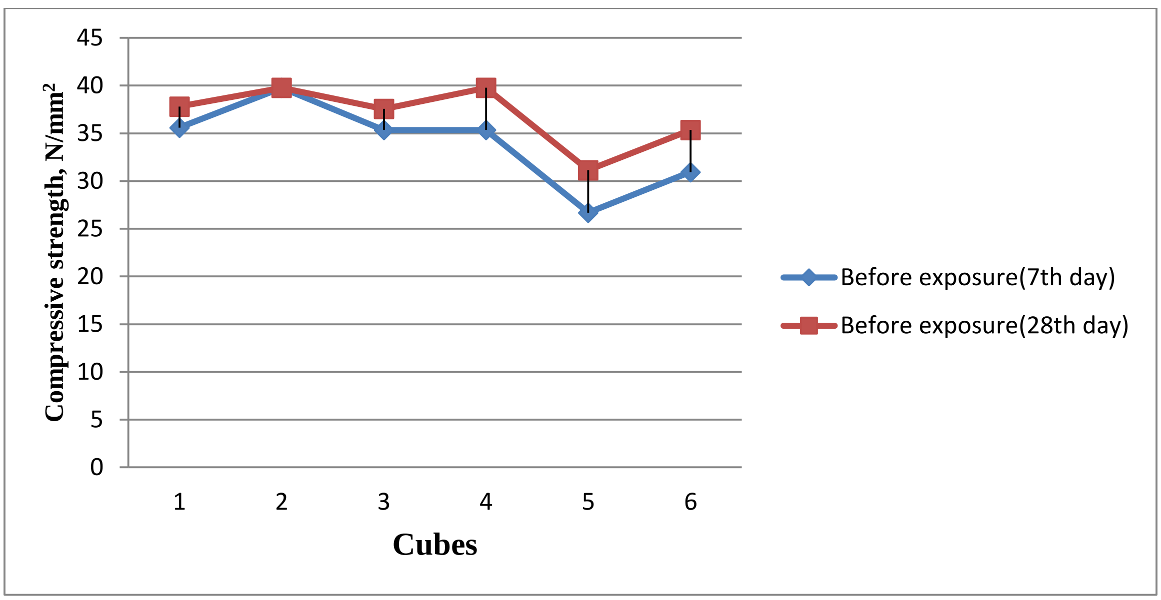
EXPERIMENTAL RESULTS

The test results cover the effect on the age of the compressive strength and unit weight, and the long term properties of concrete. The long term properties include sulphate resistance and resistance to sulphuric acid.

Test specimens were made using fly ash concrete, cement concrete, and mixture of cement + fly ash concrete.

a. **Compressive strength and Unit Weight**

The test data shows that the compressive strength with age in the order of 10 to 15% when compared to the 7th day compressive strength (graph 1). The unit weight of geopolymer concrete decreased slightly in order of about 2% after few days.



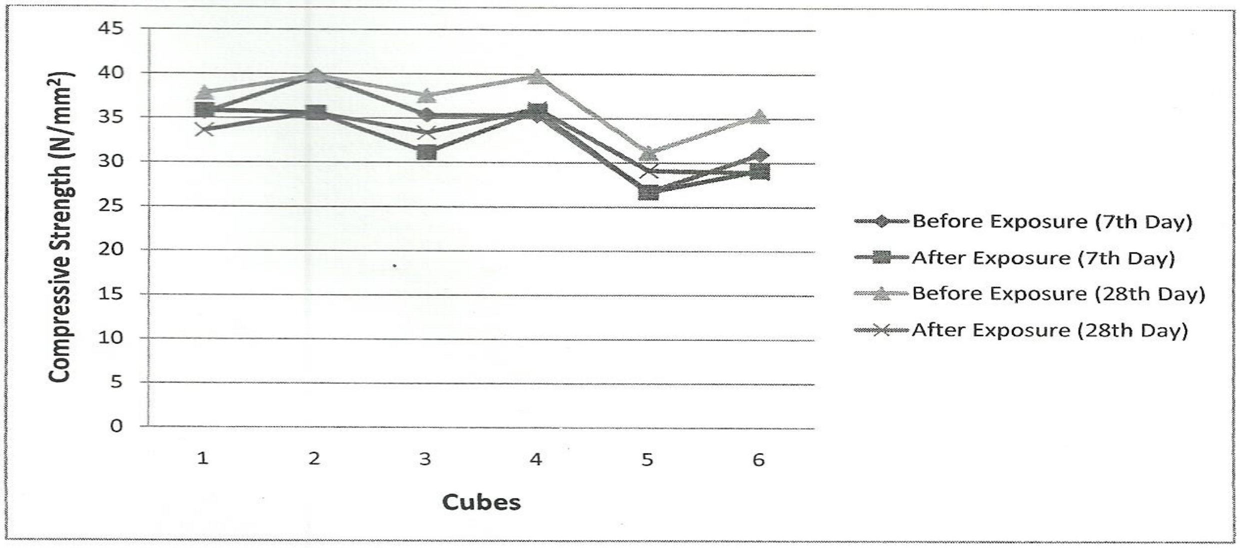
Graph.1-Compressive strength before exposure

b. **Sulphate Resistance**

The sulphate resistance was evaluated based on visual appearance, change in length, change in mass and change in compressive strength after sulphate exposure up to one week period[10-11] The visual appearance of test specimen after exposure. It can be seen that the visual appearance of the test specimens after soaking in sodium sulphate solution up to one week revealed that

there was no change in the appearance of the specimens compared to the condition before they were exposed. There was no sign of surface erosion or cracking of the specimens.
Test results on the change in length of the specimens soaked in sodium sulphate solution up to one week period are presented in graph 2. It was observed that the change in length is extremely small and less than 0.7%. It is stated that concrete specimens that concrete specimens that suffer an expansion in the order of 1.5% must be considered as failed under sulphate attack. The change in the length of 0.7% experienced by heat-cured geopolymer concrete geopolymer concrete is far from this limit of 1.5%. The change in length of geopolymer concrete is also smaller than that of Portland cement concrete.

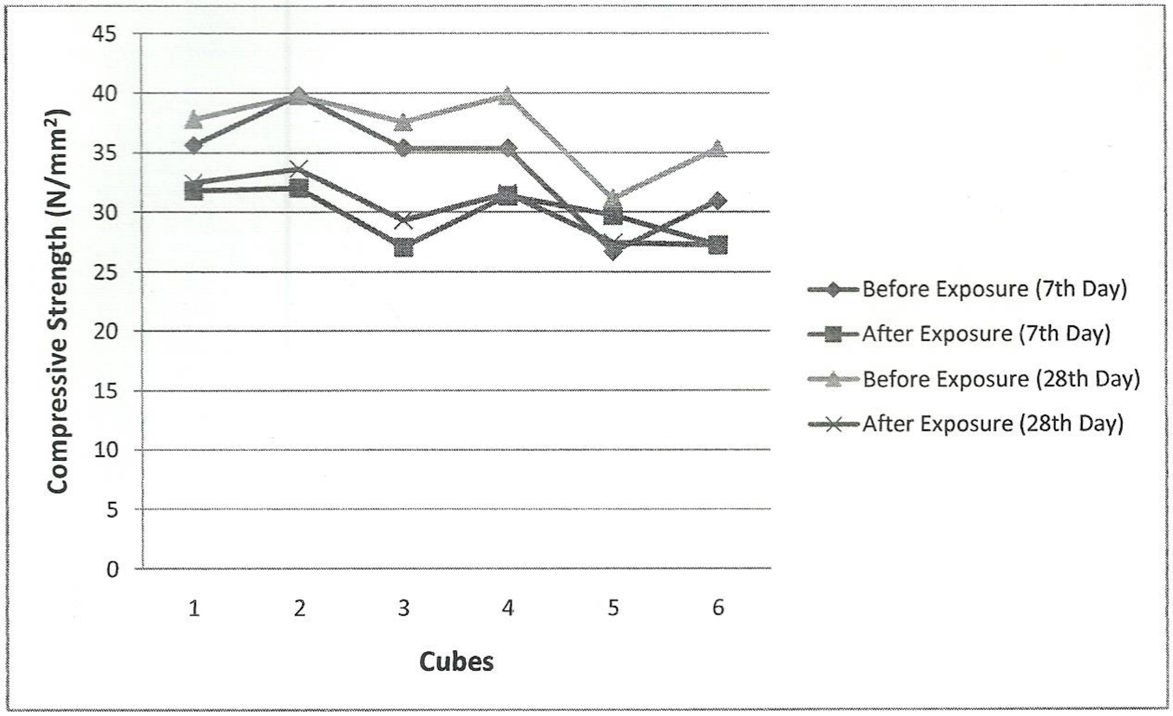
Therefore, the tests results are shown in the graph demonstrate that the heat-cured fly ash based geopolymer concrete has excellent resistance to sulphate attack.



Graph.2-Change in weight of cubes after exposure to sulfatesolution.

c. **Acid Resistance**

Acid resistance was evaluated based on the visual appearance, change in mass and change in compressive strength after exposure for one week. Graph 3 shows the visual appearance of the concrete specimens after soaking in 5% concentration of sulphuric acid solution for a period of one week and left in ambient condition of the laboratory. It can be seen that the specimens exposed to sulphuric acid undergoes erosion of the surface [12]. The damage to the surface of the specimens increased as the concentration of the acid solution increased. The visual inspection of the broken pieces of concrete cubes after the compression test revealed that the acid damage of the specimens, soaked in 5% sulphuric acid solution for one week, seems to have occurred in the outer 20mm shell of the 150mm test cubes. The degradation in compressive strength increases as the concentration of the acid solution and the period of exposure increases (graph 3).



Graph.3- Change in compressive strength of concrete exposed to 5% sulfuric acid solution.

CONCLUSIONS

Based on the test results, the following conclusions are drawn

a. Fly ash-based geopolymer concrete cured in the laboratory ambient conditions gains compressive strength with age. The 7th day compressive strength of ambient-cured specimens depends on the average ambient temperature during the first week after casting; higher the average ambient temperature higher is the compressive strength.

b. The test results demonstrate that heat-cured fly ash-based geopolymer concrete has an excellent resistance to sulfate attack. There is no damage to the surface of test specimens after exposure to sodium sulfate solution up to one week. There are no significant changes in the mass and the compressive strength of test specimens after various periods of exposure up to one week. These test observations indicate that there is no mechanism to form gypsum or ettringite from the main products of polymerization in heat-cured low-calcium fly ash-based geopolymer concrete.

c. Exposure to sulfuric acid solution damages the surface of heat-cured geopolymer concrete test specimens and causes a mass loss of about 3% after one week of exposure. The severity of the damage depends on the acid concentration.

d. The sulfuric acid attack also causes degradation in the compressive strength of heat-cured geopolymer concrete; the extent of degradation depends on the concentration of the acid solution and the period of exposure. However, the sufuric acid resistance of heat-cured geopolymer concrete is significantly better than that of Portland cement concrete as reported in earlier studies.

e. The tests on heat-cured geopolymer mortar specimens indicate that the degradation in the compressive strength due to sulfuric acid attack is mainly due to the degradation in the geopolymer matrix rather than the aggregates. The degradation in compressive strength of mortar specimens is larger than that of concrete specimens due to the larger geopolymer matrix content by mass of mortar specimens.

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