

Assessment of Study on Geopolymer Concrete Block

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Abstract— The increasing emphasis on energy conservation and environmental protection has led to investigation of alternatives to customary building material. Effort are urgently underway all over the world to develop environment friendly construction materials which makes minimum utility of natural resources and helps to reduce green house gas emission. The contribution of green house gas emission due to ordinary Portland cement production worldwide is approximately 7%. For each ton of Portland cement manufactures, it is estimated that one ton of CO₂ is released into the environment. Compared to Portland cement, fly ash based geopolymer concrete can reduce carbon emissions by 80% which has the potential to reduce global emissions by approximately 2.1 billion tons a year. In this connection, Geopolymers are showing great potential and does not need the presence of Portland cement as a binder.

Geopolymer Concrete (GPC) is the name given to concrete where the binder is entirely replaced by an inorganic polymer formed between a strong alkaline solution and an aluminosilicate source. The source material such as fly ash that are rich in silicon (Si) and aluminium (Al) are activated by alkaline liquid to produce the binder. On the other hand the abundant availability of fly ash worldwide creates opportunity to utilise as substitute for OPC to manufacture concrete. This research report presents the study on the development of strength for various grades of geopolymer concrete for different curing conditions (ambient and oven curing). Trial mix was chosen for low calcium fly ash based. The alkaline solution used in the study is a combination of sodium silicate and sodium hydroxide solution with the ratio of 2.5. The effect of change in concentration and curing condition on mechanical property such as compressive strength, tensile strength, flexural strength for GPC solid block and GPC hollow block are studied. Result indicates that heat cured GPC block performed better than specimen cured at room temperature. The result also shows that as the molarity increases the strength of GPC also increases.

Index Terms— Geopolymer Concrete (GPC), GPC solid block, concrete, GPC hollow block.

I. INTRODUCTION

The cement industry is a major source of carbon emissions and deserves attention in the assessment of carbon emission-reduction options. It is responsible for about 6% of all CO₂ emissions, because the production of one ton of Portland cement emits approximately one ton of CO₂ into the atmosphere (Davidovits, 1994c and Mc Caffrey, 2002). The contribution of Ordinary Portland Cement (OPC) production worldwide to greenhouse gas emissions is estimated to be approximately 1.35 billion tons annually or approximately

7% of the total green house gas emission to the earth's atmosphere (Malhotra, 2002).

Recent research has shown that it is possible to use 100% of fly ash as the binder in mortar by activating it with an alkali component, such as silicate salts and non silicate salts of weak acids (Bakharev et al (1999a), Talling et al (1989)).

In 1978, Davidovits (1999) proposed that binders could be produced by a polymeric reaction of alkaline liquids with the silicon and the aluminium in source materials of geological origin or by-product materials such as fly ash. This research work covers an extensive study on fly ash based geopolymer concrete block which aims at a 100% replacement of cement with fly ash as an alternative binding material..

A. Problem Statement

The world is facing the challenge of global warming and climate changes due to carbon dioxide (CO₂) greenhouse gases and increment of CO₂ concentration. According to current trends and development the industrial sector has a big challenge to maintain high quality of life while ensuring low energy consumptions and CO₂ emissions. Introducing Geopolymer Materials not only for environmental issue but also for reduction of carbon dioxide emission caused by 80% to 90% of Ordinary Portland Cement (OPC) in building construction.

B. Low Calcium Fly Ash Based Geopolymer Concrete

In this research work, low calcium fly ash based geopolymer concrete is obtained from Ennore Power Station, Tamil Nadu, India was used as the base material. The source material such as fly ash, that is rich in silicon (Si) and aluminium (Al) are activated by alkaline liquid to produce the binder. The fly ash-based geopolymer paste binds the loose coarse aggregates, fine aggregates and other un-reacted materials with alkaline liquid that is a combination of sodium silicate and sodium hydroxide solutions to form the geopolymer paste that binds the aggregates and other non-reacted materials together to form the geopolymer concrete.

C. Research Significance

The study on the properties of geopolymer concrete is of supreme importance for instilling confidence in engineers and builders. The literature indicates that some studies are available on geopolymer concrete using fly ash and other materials as a substitute for cement. The utilisation of fly ash in geopolymer concrete could turn this waste material into a valuable resource with the added benefit of preserving environment

D. Motivation for Research

Fly ash is one of the materials used in geopolymer concrete that could be considered otherwise as a waste material with a

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promising future in the construction industry as a partial or a full substitute of cement. Geopolymer concrete shows significant potential to be a material for the future because it is not only environment friendly but also possesses excellent mechanical properties. Practical recommendations on the use of geopolymer concrete technology such as precast concrete products and waste encapsulation needs to be developed in Indian context. Due to lower CO₂ emission contents of ingredients of geopolymer based composites compared to those of conventional portland cement concretes, the new composites can be considered to be more eco-friendly

E. Objective of the Research

The main objective of the research is to conduct an extensive study on geopolymer concrete block. Also To study the physical, mechanical and chemical property of geopolymer concreteblock.

II. EXPERIMENT

A. General

This chapter presents the details of the developments in the process of making fly ash based geopolymer concrete. The materials used for making geopolymer concrete, mix proportions, manufacturing and curing of the test specimens are explained. This is followed by a description of number and types of specimens used, parameters tested and the various test procedures adopted.

B. Materials

Flyash

Fly ash is a fine powder recovered from the gases of burning coal during the generation of electricity. These micron-sized earth elements consist primarily of silica, alumina and iron. Fly ash particles are almost totally spherical in shape, allowing them to flow and blend freely in mixtures. Fly ash

improves considerably the performance of binder paste and increases the bonding action with aggregate and reinforcement. The properties of fly ash may vary considerably according to several factors such as the geographical origin of the source coal, conditions during combustion and sampling position within the power plant. The major elemental constituents of fly ash are Si, Al, Fe, Ca, C, Mg, K, Na, S, Ti, P and Mn. Nearly all naturally occurring elements can be found in fly ash in trace quantities. Certain trace elements, including As, Mo, Se, Cd and Zn, are primarily associated with particle surfaces. The most abundant species in fly ash extracts are inorganic ions derived from Ca, Na, Mg, K, Fe, S andC. Fly ash has been widely used as a partial replacement of cement in concrete for over half a century. The benefits include saving of cement and lowering of the heat of hydration in mass concrete (Baoju et al 2005). The use of fly ash in concrete is economical and modifies the properties of concrete in both the fresh and hardened states with improvements to workability, strength, abrasion, heat evolution, shrinkage and reduces water reducing admixture demands. In addition, the storage and disposal problem of fly ash, which is an industrial waste or by-product is also solved by the use of fly ash in concrete; otherwise, the fly ash has to be disposed of in landfills at a considerable cost. It reduces cracking due to autogenous and plastic shrinkage. It increases the packing density of the cementitious system, thus creating a less permeable structure (Malek et al2005).

Geopolymer concrete in this study was made fromlow calcium fly ash with a combination of sodium hydroxide (NaOH) and sodium silicate solution (Na₂SiO₃). Fly ash used in this study was low-calcium (ASTM Class F) dry fly ash from local market. The chemical compositions of the fly ash from all batches as determined by X-Ray Fluorescence (XRF) analysis are given in Table2.2

Table 2.2 Test Report on Fly ash Analysis (ASTM Class F)

| Sr. No. | Constituents | % Composition |
|---------|---|---------------|
| 1. | Silica (as SiO ₂) | 48 |
| 2. | Alumina (as Al ₂ O ₃) | 29 |
| 3. | Ferric Oxide (as Fe ₂ O ₃) | 12.7 |
| 4. | Calcium Oxide (as CaO) | 1.76 |
| 5. | Magnesium Oxide(MgO) | 0.89 |
| 6. | Sodium (as Na ₂ O) | 0.39 |
| 7. | Potassium (as K ₂ O) | 0.55 |
| 8. | Sulphur (as SO ₃) | 0.5 |
| 9. | Loss On Ignition | 1.61 |

Alkaline Activators

The alkaline liquid used was a combination of sodium

silicate solution and sodium hydroxide solution. The NaOH solids were dissolved in water to make the solution. The mass of NaOH solids in a solution depends on the concentration of

the solution and is expressed in terms of Molar (M). NaOH solution with a concentration of 8 M consisted of $8 \times 40 = 320$ grams of NaOH solids (in flake or pellet form) per litre of the solution, where 40 is the molecular weight of NaOH. The mass of NaOH solids was measured as 262 grams per kg of NaOH solution of 8M concentration. Similarly the mass of NaOH solids per kg of the solution for 14M concentration

was measured as 404 grams and for 16M mass of NaOH solid is 444 grams. Chindaprasirt et al (2007) found that, to produce a higher strength geopolymer the optimum sodium silicate to sodium hydroxide ratio was in range of 0.67 to 1.00. Alternatively the concentration of NaOH between 10M and 20M give small effect on the strength.

Table 2.3: Test Result of Sodium Silicate

| Sr. No. | Constituents | Percentage Composition |
|---------|-------------------|------------------------|
| 1. | Na ₂ O | 13.7 |
| 2. | SiO ₂ | 29.4 |
| 3. | Water | 55.9 |

Aggregates

Aggregates are inert granular materials such as sand, gravel or crushed stone which, along with water and Portland cement, constitute an essential ingredient in concrete. Good concrete mix aggregates need to be clean, hard, strong particles free of absorbed chemicals or coatings of clay and other fine materials that could cause the deterioration of the concrete. Aggregates which account for 60 to 75 percent of the total volume of concrete are divided into two distinct categories fine and coarse. Fine aggregates generally consist of natural sand or crushed stone with most particles passing through a 4.75 mm sieve. Coarse aggregates are particles retained in 4.75 mm sieve. Gravels constitute the majority of coarse aggregate used in concrete with crushed stone making up most of the remainder.

Fine Aggregate

River sand available in Chennai was used as a fine aggregate and tested as per IS: 2386 (part III). Sieve analysis results of fine aggregate are shown in Table 3.4.

Table 3.4 Sieve Analysis Result of Fine Aggregate

| IS Sieve size | M. R. on Sieve (gm) | C. M.R. (gm) | C. % M. R. | C. % P. |
|---------------|---------------------|--------------|------------|---------|
| 4.75mm | - | - | - | - |
| 2.36mm | 70 | 70 | 3.5 | 96.5 |
| 1.18mm | 98 | 168 | 8.4 | 91.6 |
| 600μ | 985.5 | 1153.5 | 57.68 | 42.33 |
| 300μ | 726.5 | 1880 | 94 | 6 |
| 150μ | 95 | 1975 | 98.75 | 1.25 |
| Pan | 25 | 2000 | 100 | 0 |

Table 3.5 Sieve Analysis Result of Coarse Aggregate

| IS sieve Size | M.R. on each sieve (gm) | C.M.R. (gm) | C. % M.R. | C. % P. |
|---------------|-------------------------|-------------|-----------|---------|
| 12.5mm | 181.0 | 181.0 | 9.05 | 90.95 |
| 10mm | 714.3 | 895.5 | 44.7 | 55.2 |
| 4.75mm | 55.5 | 1987 | 99.3 | 0.6 |

This chapter enlists the materials used for making geopolymer concrete, mixture proportions, manufacturing and curing of the test specimens. Fly ash used in this study was low-calcium (ASTM Class F) dry fly ash from Ennore thermal power station, Chennai. The alkaline liquid comprises a combination of sodium silicate solution and sodium hydroxide solids. Coarse and fine aggregates used in the local concrete industry were used. The coarse aggregates were crushed granite-type aggregates comprising 20 mm, 14 mm and 7 mm and the fine aggregate was fine sand. The mixture proportions used in this study were developed based on previous study on fly ash-based geopolymer concrete (Hardjito and Rangan, 2005). Molarity of sodium hydroxide (NaOH) solution was chosen in the range of 8M to 14M. Ratio of activator solution-to-fly ash by mass was fixed to be 0.40.

Methodology

III. RESULT AND DISCUSSION

A. Introduction

to study the mechanical and chemical property of geopolymer concrete for various curing conditions in which fly ash was used as a replacement of cement. The behaviour of geopolymer brick masonry prism for varying height was compared with that of ordinary clay brick masonry prism.

B. Workability of Concrete

The workability of geopolymer concrete which uses fly ash as a substitute for cement was studied and the slump values for four mixes are furnished in Table 5.1. The workability of the geopolymer concrete decreases with increase in the grade of the concrete, this is because of the decrease in the ratio of water to geopolymer solids. As the molarity of the NaOH solution increases the workability of the geopolymer concrete decreases, because of the decrease in the water content. This means that as the grade of the concrete increases, the mix becomes stiffer reducing the workability.

Table 5.1 Slump Values for Different Grades of GPC

| S.No | Mix Designation | Slump (mm) |
|------|-----------------|------------|
| 1 | GP1 | 213 |
| 2 | GP2 | 210 |
| 3 | GP3 | 200 |
| 4 | GP4 | 198 |

C. Mechanical Property

Laboratory tests were conducted to find the characteristic mechanical properties such as compressive strength, Split tensile strength and flexural strength for GPC solid block and GPC hollow block for 7, 14 and 28 days of testing and for curing at room temperature and elevated temperature.

Compressive Strength of GPC Solid Block

Compressive strength is considered to be the paramount property of concrete. The effect of introduction of fly ash as a replacement of cement on compressive strength of solid block is presented in Tables 5.2 and 5.3 and also as illustrated in Figures 5.1 and 5.2. The strength of concrete is dependent on the quantity of the alkaline chemical used and the concentration of the sodium hydroxide (NaOH) called Molarity. The higher the molarity of the NaOH solution, the more proportionate is the increase in the strength of the concrete. This aspect is revealed on casting and testing of trial mixes using variable molar NaOH solutions from 8M, 12M and 16M. The ratio of alkaline liquid-to-fly ash, by mass, was not varied. This ratio remained approximately around 0.4 and the concentration of NaOH solutions were varied as 8M, 10M, 12M and 16M. The measure 7th day 14th day and 28th day for two different curing conditions is given in Table 5.2 and 5.3. The difference between the mixtures is the concentration of NaOH in terms of molar and the curing condition. GP4 with higher concentration of NaOH solution yielded higher compressive strength. The 28th day compressive strength of the concrete for the mix GP1, GP2, GP3 and GP4 was observed to be in the range of 29.12 MPa to 36.24 MPa for specimen cured at room temperature, whereas the strength varied between 32.11 MPa to 37.12 MPa for specimen cured at 60°C. The data illustrates that the compressive strength of oven cured fly ash based geopolymer concrete achieves a good compressive strength. A maximum compressive strength of 37.12 MPa was observed for GP4 mix cured at 60°C.

Figure 5.1 and 5.2 shows that the compressive strength of all mixes increased with concrete age and also the strength increase with the molarity of NaOH. From Table 5.2 and 5.3 it is clear that the range of compressive strength development over the 28 day strength for specimen cured at room temperature varies from 61.39% to 81.74% and for specimen cured at 60°C the

variation was 65.05% to 85.88%. The compressive strength of ambient cured geopolymer concrete significantly increases with the age. Fly ash-based geopolymer concrete specimens cured at 60°C for 24 hours reach substantially larger 7th day compressive strength than those cured in ambient conditions. Table 5.4 compares the 28 days compressive strength value of heat cured and ambient cured specimen and clearly shows the increase in strength. The result shown in Figure 5.3 confirms that higher curing temperature resulted in higher compressive strength.

Table 5.2 Compressive Strength of GPC Concrete Block at 30°C

| Mix Designation | Molarity Of NaOH | Curing Condition | Compressive Strength (MPa) (Days) | | |
|-----------------|------------------|------------------|-----------------------------------|-------|-------|
| | | | 7 | 14 | 28 |
| GP1 | 8M | 30°C | 22.25 | 25.37 | 29.12 |
| GP2 | 10M | 30°C | 27.22 | 30.14 | 31.12 |
| GP3 | 12M | 30°C | 29.23 | 32.14 | 34.12 |
| GP4 | 14M | 30°C | 30.45 | 34.22 | 36.24 |

Table 5.3 Compressive Strength of GPC Concrete Block Cured at 60°C

| Mix Designation | Molarity of NaOH | Curing Condition | Compressive Strength (MPa) (Days) | | |
|-----------------|------------------|------------------|-----------------------------------|-------|-------|
| | | | 7 | 14 | 28 |
| GP1 | 8M | 60°C | 24.15 | 27.76 | 32.11 |
| GP2 | 10M | 60°C | 28.12 | 30.43 | 33.36 |
| GP3 | 12M | 60°C | 30.12 | 32.11 | 36.16 |
| GP4 | 14M | 60°C | 32.45 | 34.12 | 37.12 |

Table 5.4 Compressive Strength Value

| Mix ID | Compressive Strength of Concrete Block for 28 Days Specimen (MPa) | |
|--------|---|-------------|
| | Ambient Curing | Heat Curing |
| GP1 | 29.12 | 32.11 |
| GP2 | 31.12 | 33.36 |
| GP3 | 34.12 | 36.16 |
| GP4 | 36.24 | 37.12 |

Split Tensile Strength of GPC SolidBlock

The tensile strength characteristics of concrete are of considerable importance and the split tensile test is a simple and reliable method of measuring the tensile strength. These test results show that the tensile strength of geopolymer concrete is only a fraction of the compressive strength, as in the case of Portland cement concrete. The variation of split tensile strength with the age of curing at 30°C and 60°C curing temperatures. The specimens of 100 mm diameter cylinder have been tested at

the age of 7, 14 and 28 days for GP1, GP2, GP3 and GP4 grade concretes. It can be seen from the Figures and Tables that the tensile strength increases with increase in concentration of NaOH. The split tensile strength of concretes mix varies between 1.05 to 4.12 MPa at 60°C and 1.2 to 3.30 MPa at 30°C room temperatures respectively for 7 day, 14 days and 28 days for concretemixes.

The test data shows that the tensile strength of heat cured geopolymer concrete is larger than that of specimen cured in room temperature. The range of tensile strength development over the 28 day strength for specimen cured at room temperature varies from 34.28% to 77.92% and for specimen cured at 60°C the variation was 25.48% to 49.52%.

Table 5.5: Split Tensile Strength of GPC Concrete Block at 30°C

| Mix Designation | Molarity of NaOH | Curing Condition | Split Tensile Strength (MPa) (Days) | | |
|-----------------|------------------|------------------|-------------------------------------|------|------|
| | | | 7 | 14 | 28 |
| GP1 | 8M | 30°C | 1.2 | 1.76 | 2.23 |
| GP2 | 10M | 30°C | 1.54 | 2.36 | 2.56 |
| GP3 | 12M | 30°C | 1.98 | 2.65 | 2.95 |
| GP4 | 14M | 30°C | 2.32 | 2.87 | 3.50 |

Table 5.6: Split Tensile Strength of GPC Concrete Block at 60°C

| Mix Designation | Molarity of NaOH | Curing Condition | Split Tensile Strength (MPa) (Days) | | |
|-----------------|------------------|------------------|-------------------------------------|------|------|
| | | | 7 | 14 | 28 |
| GP1 | 8M | 60°C | 1.05 | 2.34 | 2.98 |
| GP2 | 10M | 60°C | 2.12 | 2.56 | 3.2 |
| GP3 | 12M | 60°C | 2.78 | 2.65 | 3.68 |
| GP4 | 14M | 60°C | 3.45 | 3.57 | 4.12 |

Table 5.7: Comparison of Split Tensile Strength

| Mix ID | Split Tensile Strength of Concrete Block for 28 Days Specimen (MPa) | |
|--------|---|-------------|
| | Ambient Curing | Heat Curing |
| GP1 | 2.23 | 2.98 |
| GP2 | 2.56 | 3.2 |
| GP3 | 2.95 | 3.68 |
| GP4 | 3.50 | 4.12 |

Table 5.7: Comparison of Flexural Strength

| Mix Designation | Molarity of NaOH | Curing Condition | Flexural Strength (MPa) | | |
|-----------------|------------------|------------------|-------------------------|------|------|
| | | | (Days) 7 | 14 | 28 |
| GP1 | 8M | 30°C | 1.25 | 1.5 | 2.32 |
| GP2 | 10M | 30°C | 1.34 | 1.67 | 2.45 |
| GP3 | 12M | 30°C | 1.67 | 2.53 | 3.25 |
| GP4 | 14M | 30°C | 1.95 | 2.76 | 3.75 |

Flexural Strength of GPC SolidBlock

The increase in flexural strength of specimen from GP1 to GP4 can be seen. The range of flexural strength for specimen cured at room temperature is 1.25 MPa to 3.75 MPa. The flexural strength increases with increase in concentration of NaOH .

Water Absorption of Geopolymer Concrete

Water absorption tests were performed for 7, 14 and 28 days on geopolymer concrete cubes of size 150 x 150 x 150 mm. Sample cured at room temperature and at 60°C were tested for water absorption. Figure 5.14 shows the results of water absorption tests. The percentage of water absorption varied in the range 2% to 4.33% and 1.33% to 3.42% for specimen cured at room temperature and at 60°C. The water absorption of fly ash geopolymer normally varies between 3% and 5% (Sathia et al, 2008) and (Song, 2007). The percentage of water absorption decreases with increase in concentration of NaOH from GP1 to GP4 which can be seen from the Figure5.14. The percentage of water absorption is found to be less for specimen cured at elevated temperature than for the specimen cured at room temperature. The percentage of water absorption of 28 days specimen cured at room temperature and at elevated temperature is shown in Table 5.15 and Table 5.16. Table 5.17 compares the percentage of water absorption which clearly shows that the specimen cured at elevated temperature has low water absorption. The final absorption results of these mixes shows that the geopolymer concretes has lower absorption rate.

Table 5.15 Water Absorption for Specimen Cured at30°C

| Mix Designation | Weight of Concrete Before Specimen (kg) | Weight of Concrete Cubes After 28 Days of Casting (After Acid Immersion) (Days) (kg) | | | Percentage of WaterAbsorption of Specimen After Immersion | | |
|-----------------|---|--|------|------|---|------|------|
| | | 7 | 14 | 28 | 7 | 14 | 28 |
| GP1 | 7.39 | 7.61 | 7.68 | 7.71 | 2.98 | 3.92 | 4.33 |
| GP2 | 7.45 | 7.65 | 7.71 | 7.74 | 2.8 | 3.6 | 3.9 |
| GP3 | 7.5 | 7.68 | 7.72 | 7.75 | 2.5 | 3 | 3.4 |
| GP4 | 7.56 | 7.71 | 7.75 | 7.78 | 2 | 2.5 | 2.9 |

Table 5.16 Water Absorption for Specimen Cured at 60°C

| Mix Designation | Weight of Specimen (kg) | Weight of Concrete Cubes After 28 Days of Casting (After Acid Immersion) (Days) (kg) | | | Percentage Weight of Water Absorption of Specimen After Immersion | | |
|-----------------|-------------------------|--|------|------|---|------|------|
| | | 7 | 14 | 28 | 7 | 14 | 28 |
| GP1 | 7.30 | 7.45 | 7.52 | 7.55 | 2.05 | 3.01 | 3.42 |
| GP2 | 7.41 | 7.55 | 7.62 | 7.66 | 1.89 | 2.83 | 3.37 |
| GP3 | 7.46 | 7.58 | 7.65 | 7.68 | 1.61 | 2.55 | 2.95 |
| GP4 | 7.5 | 7.6 | 7.67 | 7.70 | 1.33 | 2.40 | 2.67 |

Table 5.17 Comparison of Percentage of Water Absorption

| Mix Designation | Percentage of Water Absorption for 28 Days Specimen | |
|-----------------|---|----------------------|
| | Room Temperature | Elevated Temperature |
| GP1 | 4.33 | 3.42 |
| GP2 | 3.9 | 3.37 |
| GP3 | 3.4 | 2.95 |
| GP4 | 2.9 | 2.67 |

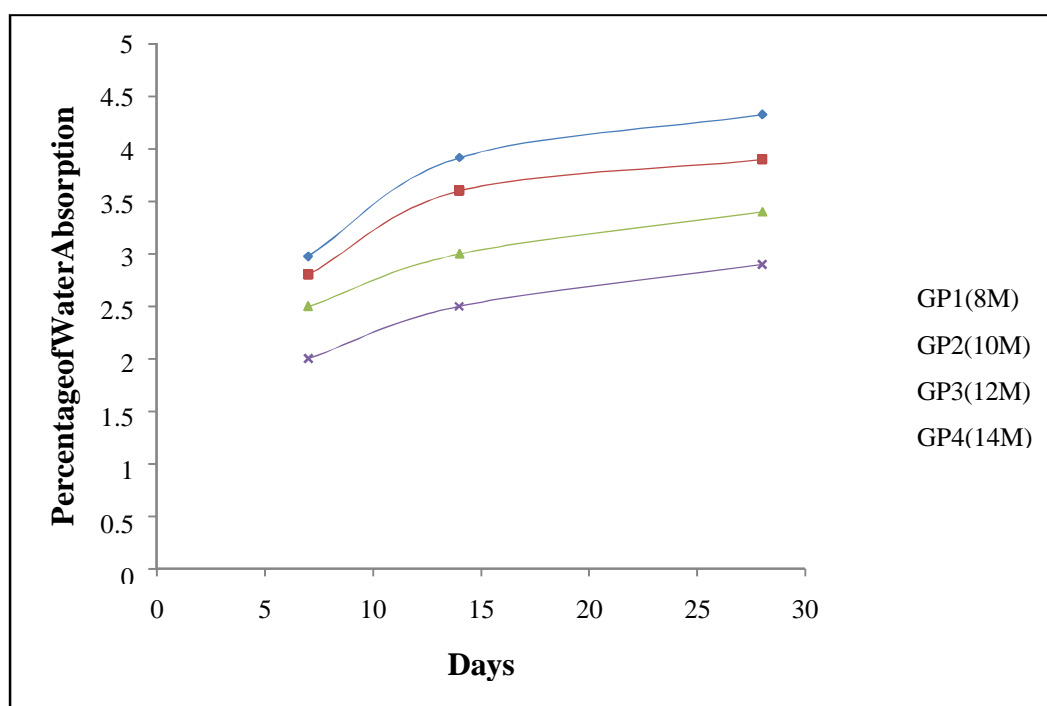


Figure 5.14 Percentage of Water Absorption for Specimen Cured at 30°C

D. Visual Inspection

Specimens did not show any noticeable change in color in sulphuric acid. Specimens were seen to remain structurally intact though surface turned a little softer. The deterioration of the surface was seen to increase with time though extent of deterioration among the series of samples could not be easily differentiated through visual inspection.

Change in Weight

In order to study the effects of exposure to acidic environment, specimens were immersed in 3% solution of sulphuric acid. Tests were carried out at regular intervals after 7 days, 14 days and 28 days of exposure. The weight loss on exposure to sulphuric acid for specimen cured at room temperature and at 60°C was about 0.53% to 2.01% and 0.2% to 1.02% after 28 days of casting. The weight changes for the Geopolymer concrete are presented in Table 5.18 and 5.20. Percentage weight loss on acid immersion for specimen cured at room temperature and at 60°C is shown in Table 5.19 and 5.21. The Percentage of mass loss. The exposure of geopolymer in acid solution shows that the weight loss is less than 3%. Results of the weight change for the geopolymer concrete sample cured in elevated temperature of 60°C shows a minimum weight loss of 1.02%. From the results of the study, it is also observed that oven dried specimen show less change in weight loss when immersed in sulphuric acid. Negligible change in mass of geopolymers on exposure to sulphate, as seen in the present case, was also reported by (Bakharev, 2005b). Hence geopolymer concrete showed an excellent resistance to acid attack.

Table 5.18 Weight Change of Specimen Cured at 30°C

| Mix Designation | Weight of Concrete Cubes After 28 Days of Casting And Before Acid Immersion (Days) (kg) | | | Weight of Concrete Cubes After Acid Immersion (Days) (kg) | | |
|-----------------|---|------|------|---|------|------|
| | 7 | 14 | 28 | 7 | 14 | 28 |
| GP1 | 7.54 | 7.62 | 7.81 | 7.50 | 7.58 | 7.77 |
| GP2 | 7.81 | 7.86 | 7.92 | 7.78 | 7.82 | 7.87 |
| GP3 | 7.89 | 7.92 | 7.99 | 7.85 | 7.86 | 7.92 |
| GP4 | 7.95 | 8.01 | 8.12 | 7.90 | 7.94 | 8.03 |

Table 5.19 Percentage Weight Loss on Acid Immersion for Specimen Cured at 30°

| Mix Designation | Percentage Weight Loss of Concrete Cubes After Acid Immersion | | |
|-----------------|---|------|------|
| | Age of Acid Immersion (Days) | | |
| | 7 | 14 | 28 |
| GP1 | 0.53 | 0.66 | 0.72 |
| GP2 | 0.64 | 0.78 | 0.89 |
| GP3 | 0.89 | 0.91 | 1.92 |
| GP4 | 1.0 | 1.69 | 2.08 |

Table 5.20 Weight Change of Specimen Cured at 60°C

| Mix Designation | Weight of Concrete Cubes After 28 Days of Casting and Before Acid Immersion (Days) (kg) | Weight of Concrete Cubes After Acid Immersion (Days) (kg) |
|-----------------|---|---|
| | | |

| | 7 | 14 | 28 | 7 | 14 | 28 |
|-----|------|------|------|------|------|------|
| GP1 | 7.54 | 7.62 | 7.81 | 7.50 | 7.57 | 7.75 |
| GP2 | 7.81 | 7.72 | 7.92 | 7.76 | 7.66 | 7.85 |
| GP3 | 7.85 | 7.65 | 7.78 | 7.78 | 7.58 | 7.63 |
| GP4 | 7.95 | 7.78 | 7.82 | 7.87 | 7.64 | 7.66 |

Table 5.21 Percentage Weight Loss on Acid Immersion for Specimen Cured at 60°C

| Mix Designation | Percentage Weight Loss of Concrete Cubes After Acid Immersion | | |
|-----------------|---|------|------|
| | Age of Acid Immersion (Days) | | |
| | 7 | 14 | 28 |
| GP1 | 0.2 | 0.4 | 0.5 |
| GP2 | 0.35 | 0.46 | 0.61 |
| GP3 | 0.52 | 0.72 | 0.82 |
| GP4 | 0.6 | 0.85 | 1.02 |

Table 5.20 and 5.21 represent the percentage loss of residual compressive strength for geopolymer concrete specimens immersed in a 3% sulphuric acid solution. The residual compressive strength for specimen after immersion for both curing condition was found to vary between 15.09 MPa to 20.14 MPa and 20.09 MPa to 28.1 MPa as shown in Table 5.22 and 5.23. The percentage reduction in compressive strength observed for GPC specimens for specimen cured at 30°C and 60°C were 7%, 14%, 22% and 6%, 12%, 20% for 7, 14 and 28 days of exposure is shown in Table 5.24 and 5.25. The strength of geopolymer specimen gradually decreases as the days of exposure increases. The degradation on strength is related to depolymerisation of aluminosilicate polymers in acidic media and the formation of zeolites as reported by Shankar et al (2012).

Table 5.22 Residual Compressive Strength on Acid Immersion for Specimen Cured at 30°C

| Mix Designation | Compressive Strength at 28 Days (Before Acid Immersion) (MPa) | Compressive Strength (After Acid Immersion) (Days) | | |
|-----------------|---|--|-------|-------|
| | | 7 | 14 | 28 |
| GP1 | 19.29 | 17.94 | 16.59 | 15.09 |
| GP2 | 21.37 | 19.88 | 18.38 | 16.67 |
| GP3 | 23.25 | 21.63 | 20.05 | 18.14 |
| GP4 | 26.11 | 24.29 | 22.51 | 20.41 |

Table 5.23 Residual Compressive Strength on Acid Immersion for Specimen Cured at 60°C

| Mix Designation | Compressive strength at 28 days (Before Acid Immersion) (MPa) | Compressive strength (After Acid Immersion) (MPa)(Days) | | |
|-----------------|--|--|-------|-------|
| | | 7 | 14 | 28 |
| GP1 | 25.11 | 23.61 | 22.1 | 20.09 |
| GP2 | 28.36 | 26.66 | 24.96 | 22.69 |
| GP3 | 33.16 | 31.26 | 29.26 | 26.53 |
| GP4 | 35.12 | 33.02 | 30.92 | 28.1 |

Table 5.24 Percentage Loss in Compressive Strength for Specimen Cured at 30°C

| Mix Designation | Percentage Loss in Compressive Strength (Days) | | |
|-----------------|--|-------|-------|
| | 7 | 14 | 28 |
| GP1 | 6.9 | 13.9 | 21.77 |
| GP2 | 6.97 | 13.99 | 21.99 |
| GP3 | 6.96 | 13.76 | 21.97 |
| GP4 | 6.97 | 13.78 | 21.83 |

Table 5.25 Percentage Loss in Compressive Strength for Specimen Cured at 60°C

| Mix Designation | Percentage Loss in Compressive Strength (Days) | | |
|-----------------|--|-------|-------|
| | 7 | 14 | 28 |
| GP1 | 5.97 | 11.98 | 19.99 |
| GP2 | 5.99 | 11.98 | 19.97 |
| GP3 | 5.72 | 11.76 | 19.99 |
| GP4 | 5.97 | 11.95 | 19.98 |

Table 5.26 Residual Split Tensile Strength on Acid Immersion for Specimen Cured at 30°C

| Mix Designation | Split Tensile Strength at 28 Days (Before Immersion) (MPa) | Split Tensile Strength (After Immersion) (MPa) (Days) | | |
|-----------------|---|---|------|------|
| | | 7 | 14 | 28 |
| GP1 | 2.23 | 2.14 | 1.99 | 1.81 |
| GP2 | 2.56 | 2.46 | 2.28 | 2.08 |

| | | | | |
|-----|------|------|------|------|
| GP3 | 2.95 | 2.83 | 2.63 | 2.39 |
| GP4 | 3.50 | 3.36 | 3.11 | 2.84 |

Table 5.27 Residual Split Tensile Strength on Acid Immersion for Specimen Cured at 60°C

| Mix Designation | Split Tensile Strength at 28 days (before immersion) (MPa) | Split Tensile Strength(after immersion) (MPa) | | |
|-----------------|--|---|------|------|
| | | 7 | 14 | 28 |
| GP1 | 2.98 | 2.89 | 2.69 | 2.45 |
| GP2 | 3.2 | 3.11 | 2.88 | 2.63 |
| GP3 | 3.68 | 3.56 | 3.24 | 3 |
| GP4 | 4.12 | 3.99 | 3.7 | 3.37 |

Table 5.28 Percentage Loss in Split Tensile Strength for Specimen Cured at 30°C

| Mix Designation | Percentage loss in Split Tensile Strength (Days) | | |
|-----------------|--|-------|-------|
| | 7 | 14 | 28 |
| GP1 | 4.03 | 10.76 | 18.83 |
| GP2 | 3.9 | 10.9 | 18.75 |
| GP3 | 4.06 | 10.84 | 18.98 |
| GP4 | 4 | 11.1 | 18.85 |

Table 5.29 Percentage Loss in Split Tensile Strength for Specimen Cured at 60°

| Mix Designation | Percentage Loss in Split Tensile Strength (Days) | | |
|-----------------|--|------|------|
| | 7 | 14 | 28 |
| GP1 | 3 | 9.73 | 17.7 |
| GP2 | 2.8 | 10 | 17.8 |
| GP3 | 3.2 | 11.9 | 18.4 |
| GP4 | 3.1 | 10 | 18.2 |

pH Value of Solution

The initial value of pH for a 3 % sulphuric acid solution prior to immersion of specimen was 1. After 2 weeks of exposure pH increased considerably in the solution containing GP1, GP2, GP3 and GP4 specimens. The increase in pH was rapid till the ninth day and it was not so appreciable thereafter. The increase in pH may be attributed to migration of alkalis from specimen into the solution. The rate of

migration of alkali appears to be higher within the initial days as indicated by the rapid rise in pH value.

IV. CONCLUSION

A. General

In this research the properties of low-calcium fly ash-based geopolymer concrete such as physical, mechanical and chemical property of geopolymer concrete block were studied.

B. Summary

Fly ash-based geopolymer concrete in this study has 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 pellets form dissolved in water. Coarse and fine aggregates used in the local concrete industry were used. The coarse aggregates were crushed granite-type aggregates comprising 20 mm, 14 mm and 7 mm and the fine aggregate was fine sand. The mixture proportions used in this study were developed based on previous study on fly ash-based geopolymer concrete (Hardjito and Rangan, 2005). Molarity of sodium hydroxide (NaOH) solution was chosen in the range of 8M to 14M. Ratio of activator solution-to-fly ash by mass was fixed to be 0.40. Curing at elevated temperatures was done in two different ways, i.e. curing at room temperature and in the laboratory oven at 60°C. Ratio of sodium silicate solution-to-sodium hydroxide solution by mass is 2.5.

The fly ash and the aggregates were first mixed together in a mixing pan for about 5 minutes manually. After the dry mix is made the prepared alkaline solution is thoroughly mixed with the dry mix for another 5 minutes to make fresh geopolymer concrete. Fresh concrete was placed in the mould. The specimens were compacted with three – layer placing and tamping using a rod. This was followed by an additional vibration of 10 seconds using a vibrating table. Specimens such as cubes, cylinders and beams were cast and tested. After casting the concrete mix was allowed to settle down in the moulds for 30 minutes. Different batches were adopted for 7 days, 14 days and 28 days of testing.

After casting, the specimens were cured under two curing conditions such as curing at room temperature (30°C) and in the laboratory oven at 60°C. For heat-curing, dry (oven) curing was used.

C. Specific Conclusion

Mechanical Property of Geopolymer Solid and Hollow Block

- Compressive strength and split tensile strength increases with increase in concentration of NaOH from 8M to 14M.
- Maximum compressive strength achieved for GPC solid block for curing at 60°C was 37.12 MPa. The maximum value of split tensile strength for GPC solid block cured at 60°C was 4.12 MPa.

Water Absorption of Geopolymer Concrete

Water absorption decreases with increase in concentration and curing time. The percentage of water absorption was found to decrease with increase in concentration of NaOH. The percentage of water absorption varied in the range from 2% to 4.33% and 1.33% to 3.42% for specimen cured at room temperature and at 60°C

Acid Resistance of Geopolymer Concrete to Sulphuric Acid

- Geopolymer concrete has a very good resistance in acid medium in terms of weight loss. The weight

loss on exposure to sulphuric acid in GPC for specimen cured at room temperature and at 60°C was about 0.53% to 2.01% and 0.2% to 1.02% after 28 days curing respectively.

- The reduction in compressive strength observed for GPC specimens for specimen cured at 30°C and 60°C were 7%, 14%, 22% and 6%, 12%, 20% for 7, 14 and 28 days of exposure.
- The residual tensile strength for specimen after immersion in 3% sulphuric acid for curing at 30°C and 60°C was found to vary between 1.81 MPa to 3.36 MPa and 2.45 MPa to 3.99 MPa

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