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Experimental Investigation on Compressive Strength of Geopolymer Concrete Paver Block

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Abstract

Portland cement is the most widely used binder material for concrete. However, it is a very energy intensive material resulting in production and release of global warming green house gas CO_2, besides causing degradation of earth due to mining activities for limestone. This necessitates the development of eco friendly binder material and geopolymer concrete is one such potential material. This concrete utilizes fly ash, which is an abundantly available industrial byproduct. The present study examines the strength properties of fly ash based geopolymer concrete. Mix proportion was done based on the earlier research studies for M35 geopolymer concrete and the test results were analyzed for the similar strength control cement concrete. The geopolymer concrete specimens were cast and without de-moulding the specimens exposed to 80^{o}C in the oven for 72 hours then after de-moulding the specimens were left at atmospheric curing for the desired period. Compressive strength test result revealed that the compressive strength of the Geopolymer concrete paver block was 14.4 % less than the control concrete paver block of grade M35 after 20 days of atmospheric curing.

Keywords: Fly ash, compressive strength, atmospheric curing

INTRODUCTION

A. General

The demand for concrete as a material of construction will increase as the demand for infrastructure development increases, especially in countries such as China and India. In order to meet this demand, the production of Portland cement must increase. However, the contribution of green house gas emission from the Portland cement production is about 1.35 billion tons annually or about 7% of the total greenhouse gas emissions to the earth's atmosphere. Furthermore, Portland cement is also among the most energy-intensive construction materials, after aluminium and steel.

Environmental issue has become a crucial issue in concrete industry. This is mostly because of the emission of greenhouse gasses from the production of Portland cement, a primary binder in making concrete. Many efforts have been made to reduce the use of Portland cement in concrete that in turn will reduce the greenhouse gas emission. Those efforts include use of supplementary cementing materials and finding alternatives for Portland cement.

B. Fly Ash

Fly ash is an artificial pozzolana produced from coal fired thermal power plants and for every 300 MW of power generated, about 500 Kg of fly ash is produced. The annual production of fly ash in India is about 75 million tons. In India there are more than 50 thermal power plants. The fly ash requires some treatment before they used, but these facilities are not available in all the thermal power plants in our country. Therefore, the quality of fly ash generated in different plants varies from one another to a large extent so that they cannot be directly used for constructions and a large portion of the fly ash is disposed off in ash ponds. Due to these limitations the usage of fly ash is reduced. The disposal of fly ash has become a serious environmental problem. This has created the necessity for developing a new eco-friendly concrete where large quantity of fly ash is used.

The following are the some of the problems that are solved when fly ash is used in large proportions:

- It reduces the usage of Portland cement.
- It reduces the emission of CO_2.
- The natural materials/resources like limestone, clay etc., can be conserved, which are used during the cement manufacturing.

C. Geopolymer Concrete

Geopolymers are a class of binders manufactured by activation of solid aluminosilicate source material with a highly alkaline activating solution and aided by thermal curing. In the past few decades, Geopolymer binders have emerged as one of the possible alternative to ordinary Portland cement binders due to their reported high early strength and resistance against acid and sulphate attack apart from its environmental friendliness.

To totally replace the use of Portland cement as concrete binder, fly ash needs to be activated, usually using alkaline solutions. Palomo described two different models of activation of fly ash. In the first model, the material containing essentially silicon and calcium is activated by low to mild concentration of alkaline solution. The main product of the reaction is calcium silicate hydrate (C-S-H). On the contrary, the material used in the second model contains mostly silicon and aluminium, and is activated using highly alkaline solution. The chemical process in this case is polymerisation.

D. Need For The Present Study

The greatest challenge for any technology looking to be adopted in the construction industry is fundamentally two-fold. They are the technological and engineering aspects and the certification of the product in market. As geopolymers are made from materials such as fly ash, ground granulated blast furnace slag, and metakaolin etc., and these raw materials vary from source to source and batch to batch, they require a large investigation in formulation and certification from each source.

When, concrete materials are used in construction it should be durable to withstand a highly aggressive environment. In earlier days the strength of concrete was only considered in the design mix procedures, but after the introduction of IS 456-2000 the importance is focused towards durability. Although GPC was introduced during 1970's, no exhaustive research data are available towards durability.

E. Scope Of The Investigation

To develop geopolymer concrete of different grades using locally available fine and coarse aggregate using fly ash as a binder material. Commercially available chemicals will be used for preparing alkali solutions for activation of fly ash to act as binder material.

LITERATURE REVIEW

A. Hardjito D, Wallah Se, Rangan Bv (2002) used granulated blast furnace slag as active filler in making of geopolymers. It was found that geopolymer setting time was influenced by temperature, potassium hydroxide concentration, metakaolinite and sodium silicate addition. The initial setting time for geopolymer concrete ranged from 35 minutes to 89 minutes and the final setting time in the range of 63 minutes to 142 minutes. The physical and mechanical properties of the geopolymer concrete were also correlated well with the concentration of alkaline solution and the amount of metakaolinite added. The highest compressive strength achieved was 79 MPa.

B. Wallah SE, Hardjito D, Sumajouw DMJ, Rangan BV (2003) identified the difference between the alkali-activated materials, such as cement concrete, and the aluminosilicate polymer or geopolymer materials. Although both of these materials are the result of alkali activation, the starting situations are different. In the case of alkali-activated materials, the source material is activated by a mild alkaline solution (such as lime) and the main reaction product is a C-S-H gel. The composition of the source material essentially contains high silicon (Si) and calcium (Ca). On the other hand, the source material for geopolymers contains high silicon (Si) and aluminium (Al), and is activated by a high alkaline liquid. The end product of this process is an amorphous polymeric material.

C. B Hardjito D, Wallah Se, Sumajouw Dmj, Rangan Bv. (2005), used ground blast furnace slag to produce geopolymer binders. This type of binders patented in USA under the title "Early High Strength Mineral Polymer" and used as a supplementary cementing material in the production of precast concrete products. In addition, a readymade mortar package that required only the addition of mixing water to produce a durable and very rapid strength gaining material was produced and utilized in restoration of concrete airport runways, aprons and taxiways, highway and bridge decks, and for several new constructions when high early strength was needed.

D. Rangan B.V. Et Al (2006), carried out experiments on geopolymers using two types of fly ash. They found geopolymers are fire resistant. They found that the compressive strength after 14 days was in the range of 5 to 51 MPa. The factors affecting the compressive strength were the mixing process and the chemical composition of the fly ash. A higher CaO content decreased the microstructure porosity and, in turn increased the compressive strength. Besides, the water-to-fly ash ratio also influenced the strength. It was found that as the water-to-fly ash ratio decreased, the compressive strength of the binder increased.

E. Lloyd, N. And Rangan, V (2009), presented brief details of fly ash-based geopolymer concrete. A simple method to design geopolymer concrete mixtures has been described and illustrated by an example. Geopolymer concrete has excellent properties and is well-suited to manufacture precast concrete products that are needed in rehabilitation and retrofitting of structures after a disaster. The economic benefits and contributions of geopolymer concrete to sustainable development have also outlined.

F. D.B. Raijiwala And H.S. Patil (2011), investigated the effect of temperature (30º C and 60ºC for 1, 7 and 28 days) on compressive strength test on fly ash mortar, concluded that higher mixing temperature and higher curing temperature resulted in higher compressive strength at early stages and compressive strength increases further with longer curing. When the samples were mixed at 25º C and cured at 30ºC, the compressive strength was low at an early stage, but gradually increased and finally, had as high strength as those of higher temperature cured mortars.

G. Aaron Darius Vaz, Donal Nixon D'Souza, Noothan Kaliveer, Satish K.T And Amar S.M, M.S.Ramaiah (2012), reported that, on the use of geopolymer concrete in precast concrete paver blocks and compares the performance with the commercial available OPC paver blocks of the same mix proportions. The mix design with a target strength of 47 MPa was developed to create paver blocks suitable for highways.

MATERIALS AND METHODOLOGY

A. Materials Used In The Study

The following are the materials used in the investigation.

- Cement (Ordinary Portland Cement)
- Class 'F' fly ash
- Crushed Granite Aggregates (CGA)
- Catalytic Liquid System (CLS)
- River sand

B. Materials Properties

Ordinary Portland cement confirming to IS 12269: 1987 (Specification for 53 grade ordinary Portland cement), fine aggregates, coarse aggregates and potable water were used for the control Ordinary Portland cement concrete specimens. The geopolymer concrete was obtained by mixing calculated quantities of fly ash, fine aggregates, coarse aggregates with optimized Catalytic Liquid System (CLS). Fly ash confirming to grade 1 of Indian Strandard 3812:2003 (Specifications of fly ash) was used. River sand available in Chennai was used as fine aggregates and tested as per IS 2386: Part I: 1963 (Methods of Test for Aggregates for Concrete). In this investigation locally available blue granite crushed stone aggregates of maximum size 20 mm was used and characterization tests were carried out as per IS 2386: Part I: 1963 (Methods of Test for Aggregates for Concrete).

C. Fly Ash

In the present investigation, fly ash obtained from Ennore Thermal Power Station was used. It's typical properties were satisfying the requirements of IS:3812:2003. It is well known that fly ash is the finely divided residue resulting from the combustion of ground or powdered coal (to a fineness of 70% to 80% passing through 75 µm sieve) and it is transported from the firebox through the boiler by flue gases. Fly ash is also known as Pulverized Fuel Ash (PFA).

*D. **Crushed Granite Aggregate***

In the present investigation, locally available crushed granite aggregate obtained from the local source was used. The course aggregate was found with specific gravity 2.68, bulk density 1.61 gm/cm^3 and water absorption 0.53%.

E. River Sand

River sand obtained from local source was used as a fine aggregate. The sand was screened at site to remove deleterious materials and tested as per procedure given in IS: 2386 (Part I) – 1963 (Methods of test for aggregates for concrete - part 1 - particle size and shape).

F. Geopolymerisation Reactions

The geopolymeric reaction occurs as a result of reaction of aluminosilicate oxides with alkali (NaOH, KOH) and soluble alkali polysilicates. The synthesis of geopolymer consists of three steps. The first is dissolution of aluminosilicate under strong alkali solution. The second is reorientation of free ion clusters. The last is polycondensation. Geopolymer mortar can be prepared using locally available river sand as inert filler material. Geopolymerisation involves the chemical reaction of aluminosilicate oxides (SiO_2, Al_2O_3) with alkali polysilicates yielding polymeric Si – O – Al bonds. Polysilicates are generally sodium or potassium silicate supplied by chemical industry or manufactured from fine silica powder, which is a by-product of ferro-silicon metallurgy.

EXPERIMENTAL INVESTIGATIONS

A. Development Of Geopolymer Concrete Mix

The present study is aimed at identifying and optimizing the salient parameters which influences the mixture proportions of the geopolymer concrete. Also an attempt has been made to simplify the process of manufacturing geopolymer concrete compared to earlier production methods by avoiding very high alkaline concentrations, which can be injurious, so that the process involved is almost similar that of the conventional concrete. In order to develop the fly ash based geopolymer concrete, a meticulous trial-and-error process was used. The compressive strength was selected as the standard parameters to finalize the mixtures.

B. Procedure Adopted In Formulating The Mixtures

Unlike conventional cement concrete geopolymer concretes are a new class of construction materials and therefore no standard mix design approaches are available for geopolymer concretes. Number of trail mixes were cast and tested for compressive strength at end of 14 days and 28 days. The ratio of alkali activated solution to geopolymer solids were varied suitably. The primary objective for performing the trial and error procedure is to obtain desired compressive strength of 35 MPa to 40 MPa at the end of 28 days. The secondary objective was to obtain a good cohesive mix with good workability. The proportions of geopolymer solids and alkali activated solution were so decided that the strength could be realized.

C. Preparation Of Test Specimens And Curing

In this experimental work, low-calcium Class 'F' dry fly ash obtained from a local Thermal Power Station (Ennore) was used as the source material. Analytical grade sodium hydroxide (NaOH with 98% purity) flakes dissolved in water and sodium silicate solution (Na_2O=14.7%, SiO_2=29.4% and water=55.9% by mass) were used. Both the liqids were mixed together and the activator solution was prepared at least one day prior to its use.

The aggregates and fly ash were mixed in a pan mixer for about 3 minutes. Then added with the activator solution, The fresh geopolymer concrete had a stiff consistency and glossy appearance. The specimens left in oven of 80^{o}C for 72 hours and after demoulding the specimens were placed at the room temperature, for further curing to the desired periods. Figure 4.1 shows the various stages involved in the preparation of geo polymer concrete mix.

TABLE 4.1 PROPORTION OF INGREDIENT MATERIAL FOR GEOPOLYMER CONCRETE

S.No.	Material	Mass, Kg / m³
1	Coarse Aggregate - 20 mm - 10 mm	425 Kg 425 Kg
2	Fine Aggregate	600 Kg
3	Fly Ash	425 Kg
4	Sodium Silicate Solution (SiO_2/Na_2O)	200 Kg
5	Sodium Hydroxide Solution (8 Molar)	75 Kg

D. Tests Conducted

At the end of desired curing period, the casted specimens were subjected to the compressive strength test with the specimen of size 200mm x 100mm x 60mm to study the effectiveness of geopolymer concrete paver block.

a) *Compressive Strength Test*

The compressive strength test was carried out as per BIS 516-1968 -Methods of Tests for Strength of Concrete, to find the compressive strength of geopolymer concrete. The specimens of size 200mm x 100mm x 60mm were casted with geopolymer concrete. Totally four specimens were casted. The test was carried out for the age of 20 days and test results are compared with control concrete specimens.

Compression Testing Machine of capacity 3000kN was used for the test. The specimen was placed between upper and lower platens such that finished surface form the side of the specimen and exactly placed on the central axis. The load was applied gradually without shock at a rate of 8-10 kN/sec. The test was continued and the failure load was noted. The compressive strength of the specimen was calculated as follows.

$$\text{Compressive strength} = P/A \text{ (MPa)}$$

Where, P - Failure load in N

A - Cross section area of concrete specimens in mm^2

RESULTS AND DISCUSSIONS

A. Compressive Strength Test

Table 5.1 shows the observation on compressive strength test for geopolymer concrete and Figure 5.1 shows the comparison of compressive strength for geopolymer concrete with the control cement concrete paver block. It can be seen that strength attainment at 20 days is 38.5 MPa.

Table 5.1: Observation on compressive strength of geopolymer concrete

S.No.	Description	Specimen1	Specimen2	Specimen3	Specimen4	Average Compressive Strength
1.	Control concrete – M35	44.8	44.75	45.30	45.50	45.00 MPa
2.	Geopolymer concrete	38.65	38.60	38.30	38.60	38.50 MPa

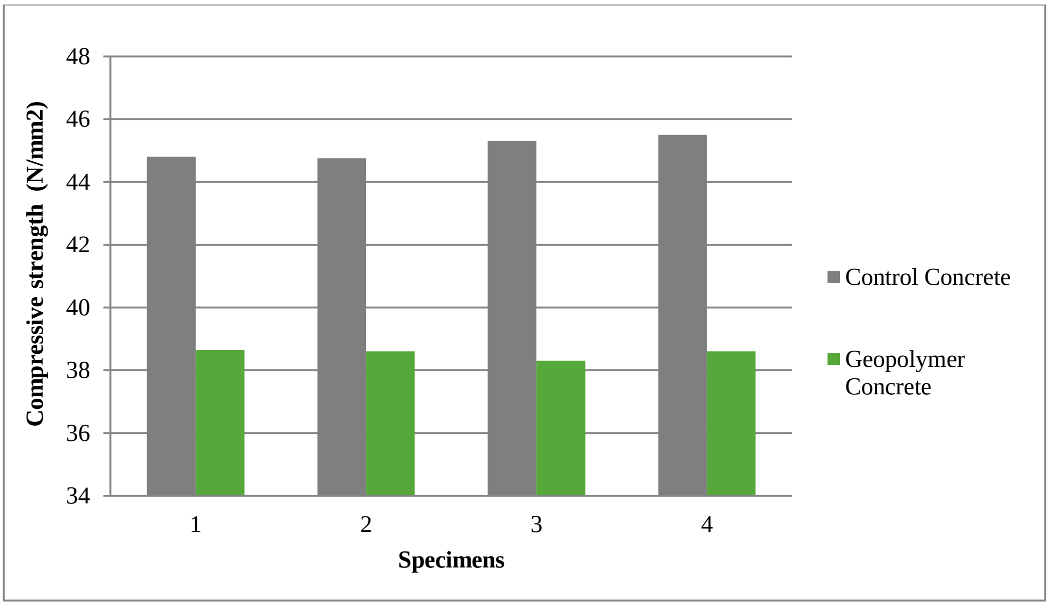

Figure 5.1: Comparison of compressive strength of geopolymer concrete

CONCLUSIONS

A. General

Totally 16 specimens were tested to study the compressive strength property of geopolymer concrete. The obtained test results are compared with the control concrete as indicated in Indian Standards (IS 456:2000) for similar strength of cement concrete.

B. Conclusions

Based on the tests results and further analysis, the following conclusions were drawn:

- The compressive strength of the geopolymer concrete paver block is 38.5 MPa , which is 14.4% less than the control concrete paver block of grade M35.
- The strength property of geopolymer concrete is improved by adequate modification in mixing and curing methods by appropriate proportion.

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