Development of Alkali Activated Pervious Cementless Concrete

K. Aiswarya[1*], A. A. Alfiya[1], R. Deepak[1], V. S. Devadath[1] and K. P. Ramaswamy[2]

[1]Under Graduate Student, Department of Civil Engineering, TKM College of Engineering, Kollam
[2]Assistant Professor, Department of Civil Engineering, TKM College of Engineering, Kollam

*Corresponding author: aiswaryak371@gmail.com

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ABSTRACT

Pervious concrete is a topic of recent interest and finds vivid applications such as for discharging rain water, filtration of waste water etc. Pervious concrete made with cement as a binder poses serious threats to the environment due to the large amount of green house gases released, especially carbon dioxide, owing to the production of cement. Therefore, it is imperative to find a suitable substitute for cement in the production of concrete. This study presents about the production of pervious concrete, completely replacing cement with fly ash geopolymer binder system. Pervious geopolymer concretes were prepared from Class F fly ash, sodium silicate, sodium hydroxide solution, coarse aggregate and a little quantity of fine aggregate. The alkali to binder ratio of 0.50 by mass and sodium silicate to sodium hydroxide ratio of 2.50 were used. In order to improve the workability of mixture, a super plasticizer Conplast SP 430 (2-3% by weight of binder) was added. Temperature curing at 50 ºC for 24 hours was done. Compression, permeability and water absorption tests were conducted on the specimen at 7 days. The compressive strength of the mixture was found to be 11.66 MPa which is more than that of a brick and water absorption was nearly 2%. The permeability of water through the specimen was found to be 24.63 ml/sec for a pervious cubical specimen of size 10 cm. The pervious concretes produced in this work were not only environment friendly but also achieved better mechanical properties and water permeability. It is inferred that the fly ash geopolymer system could be used to produce pervious concrete.

Keywords: pervious concrete, geopolymer, fly ash, permeability, cement

1 Introduction

Pervious concrete is a special concrete possessing high porosity that allows water from precipitation and other sources to infiltrate through, thereby reducing the runoff from a site and also recharging ground water levels. Generally, pervious concrete has little or no fine aggregate and has just enough cementitious paste to coat the coarse aggregate particles while preserving the interconnectivity of the voids (Sata et al., 2013). Pervious concrete is traditionally used in parking areas, areas with light traffic, pedestrian walkways and greenhouses. Concrete is the widely consumed construction material worldwide, and Ordinary Portland cement (OPC) is one of its most important components. Concrete is produced to meet the annual demand of more than 1.5 billion tons. The production of Portland cement releases a significant volume of carbon dioxide (CO_2) to the atmosphere. For each ton of synthetic Portland cement, one ton of CO_2 is estimated to be emitted to the atmosphere contributing to global warming and sustainability issues. Thus, further investigation is needed in finding an alternative to the conventional cement and concrete. Fly ash which shows pozzolanic properties is being used as a partial replacement in concrete and is produced as a waste material from pulverized coal manufacturing units which is then grinded to the fineness less than that of cement for obtaining concrete with

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good durability properties. However, the recent developments in the geopolymer technology has allowed to prepare concrete without any cement and using industrial byproducts such as fly ash and slag.

Geopolymers are innovative materials that are formed by the polymerization of silicon, aluminum and oxygen species to form an amorphous three-dimensional framework structure. The precursor materials used for making geopolymers are typically rich in alumino-silicates and often these are found in metakaolin, fly ash, slag etc. (Davidovits, 1999). The stability of the chemical bonds and the high polycondensation degree of geopolymer makes it a distinct material compared to conventional cement-based systems. Their main advantages include high early age strength, high compressive strength, good bond strength, better durability especially in aggressive environments, exemplary resistance against acids etc. Geopolymers can be considered as a "Green Material" because less energy is involved in its production and the process also utilize various industrial wastes which otherwise would cause environmental pollution.

Geopolymerisation is a chemical reaction between various alumino-silicate oxides with silicates under highly alkaline conditions forming polymeric Si-O-Al-O bonds (Davidovits, 1999). Hence, geopolymers are also often referred to as alkali activated binder (AAB) systems. Various factors influence the fresh and hardened properties of geopolymer systems such as the mix proportioning, alkali to binder ratio, type of binder used, fineness of binder, chemical composition of binder, activator modulus, concentration of alkali hydroxide solution, type and quantity of superplasticizer used, method of curing etc. (Murali et al., 2018; Nath and Sarker, 2014). A lot of papers are available on the properties of geopolymers made from various precursors and alkali activators. However, there are hardly any papers on the pervious concrete made using geopolymer technology. Uma et al. (2020) investigated the properties of pervious geopolymer concrete made using fly ash, slag with a proportion of 60:40. They found that the permeability and voids decrease with an increase in molarity and alkali to binder ratio. The study stressed the need to optimize the mix proportions to achieve pervious alkali activated concrete. The geopolymer technology could be used to produce permeable pavement blocks which are conventionally made using cement.

The current paper elucidates a study conducted on the development of pervious geopolymer concrete, with the view of increasing the applicability level of pervious concrete. The work evaluates the properties of pervious geopolymer concrete so as to make it apt for pavement block construction.

2 Materials and Methods

2.1 Materials used

Geopolymer concrete was prepared without any cement. Class F fly ash, alkaline solution and coarse aggregate were the materials used for the casting of concrete specimens. Manufactured sand was used as fine aggregates in trace quantity as pervious concrete is typically a no-fines concrete. Super plasticizer, Fosroc Conplast SP 430 was added to enhance the workability of the concrete mix. Alkaline solution prepared by mixing sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH) in appropriate quantities act as activator. The 10M NaOH solution was obtained by dissolving 400gm of NaOH pellets in 1 litre of distilled water. Sodium silicate solution was then mixed with 10M sodium hydroxide to obtain the alkaline activator solution.

2.2 Mix Design and Specimen Preparation

Geopolymer concrete mix was designed by considering ACI 522R-10, by considering the parameters namely, fine aggregate to coarse aggregate ratio (FA/CA), alkali to binder ratio and sodium silicate to sodium hydroxide ratio (Na_2SiO_3/NaOH). Table 1 shows typical ranges of material proportions required for pervious concrete mix (conventional concrete) according to ACI522R-10. In this study, cement was completely replaced with fly ash, and geopolymer technology is used to prepare pervious concrete. The FA/CA was chosen to be 1:6 by weight. The alkali to binder ratio and Na_2SiO_3 solution/NaOH solution by weight was fixed as 0.5 and 2.5 respectively. Conplast 430 with dosage of 2% by weight of binder is utilized in the current study. Table 2 provides the quantities of materials required per m^3 of geopolymer pervious concrete.

Table 1. Ranges of material proportions for pervious concrete mix (ACI 522R-10)

Material Type	Proportions, lb/yd³ (kg/m³)
Cementitious Materials	450 to 700 (270 to 415)
Aggregate	2000 to 2500 (1190 to 1480)
w/cm by mass	0.27 to 0.34
Aggregate/cement ratio (by mass)	4 to 4.5:1
FA/CA (by mass)	0 to 1:1

Table 2. Quantity of materials used per m^3 of pervious geopolymer concrete

Material Description	Quantity/ m^3 of concrete (in kg)
Class F Fly ash	360
Alkaline Solution	180
Na_2SiO_3 solution	128.57
NaOH solution	51.43
M Sand	200
Coarse Aggregate (6 mm size)	1200
Superplasticizer	7.20

The alkali solution was prepared 24 hours prior to casting for the effective heat dissipation from the solution. Materials for the required volume were hand mixed at room temperature. After mixing, geopolymer concrete was cast in 10 cm cubical moulds and sufficient compaction was provided by using a vibrating table. Thereafter, the cast specimens were kept at room temperature for 1 hour. These specimens along with mould were further kept in oven at 50°C for 24 hrs, as fly ash require temperature/heat curing for geopolymerisation. Specimens were then demoulded the next day, after temperature curing for 24 hours. Figures 1 to 3 shows the geopolymer pervious concrete mix, the cast specimens and demoulded specimens respectively.

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Figure 1. Geopolymer Concrete Mix

Figure 2. Cast Concrete Specimens

Figure 3. Demoulded Specimens

2.3 Test Methods

The properties of pervious concrete were assessed using tests such as compressive strength test, water absorption test and permeability test. These tests were done on concrete after 7 days of casting. The specimens were air cured till the time of testing post the demoulding. The specimens were loaded gradually at a standard loading rate in a compression testing machine and the maximum load at which the specimens failed is noted down and compressive strength is calculated. Three specimens were tested and the average was reported as the mean compressive strength of pervious concrete. The water absorption test was conducted by immersing the cured concrete cubes in water for a period of 2 days, finding the wet mass and then keeping those specimens in oven at 110°C for 24 hours to find out the oven dry mass. The wet and dry masses of specimens were measured by using an electronic weighing balance. The percentage of water absorption is calculated as the ratio of water absorbed by the specimen (difference of wet and dry mass) to the oven dry mass of concrete specimen. The discharge or permeability through the pervious concrete cubes were determined by conducting a permeability test. An experimental set up was created in the laboratory (shown in Figure 4) based on the principle of variable head permeameter for the current study. A pipe was fixed on one of the surfaces of the specimen covering maximum area and well-sealed with silicone gel. A definite quantity of water was poured through the pipe and the discharge in certain time duration was measured. The discharge is measured as the ratio of volume of water passed through the specimen to the time required for the passage.

Figure 4. Experimental set up to measure discharge through the geopolymer concrete specimens

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3 Results and Discussions

This section discusses in detail, the results obtained from compression test, water absorption test and permeability test.

3.1 Compressive Strength

The average compressive strength was calculated to be 11.6 MPa ± 0.58 MPa. As per ACI 522R-10, for pervious concrete mixes with cement, single sized coarse aggregate and water/cement ratio between 0.27 to 0.3, the 28 day compressive strength of conventional cement concrete ranges from 4MPa to 20MPa. The 7 day compressive strength of geopolymer pervious concrete is 11.6 MPa.

3.2 Water Absorption

The average water absorption was found to be 1.91%. The percentage of water absorption of brick should be less than 12% (Izzati et al., 2019). As the water absorption is less, the concrete mix formulated may also be used for preparing pervious bricks or pavement blocks.

3.3 Permeability

The discharge was calculated to be 24.63mL/sec (or 1.48 L/min) from the permeability test conducted. The increased discharge confirms that the concrete prepared is pervious and can be used for interlocking applications to drain the rain water and recharging the ground in the process.

4 Conclusions

The study was conducted to assess the suitability of cementless geopolymer pervious concrete for pavements and parking lots. Pervious pavement block is capable to suffice the problem of water runoff and would aid in seepage of water into the ground. A pervious block of sufficient strength that could replace the ordinary pavement block was achieved from the experimental study. The alkali activated pervious concrete was devoid of any cement and utilised Class F fly ash making this concrete, an eco-friendly and a sustainable product. The conclusions drawn from this preliminary work are as follows:

- The average compressive strength of pervious geopolymer concrete obtained is 11.6 MPa which is in the range (4-20 MPa) as specified for pervious concrete mixes as per ASTM C39.
- Water absorption was found to be 1.91% for the mix, which satisfies the requirements for a pavement block.
- The discharge measured was 1.48 L/min and the high discharge through the concrete confirms that the concrete prepared is pervious and can be used for interlocking applications to drain the rain water and recharging the ground in the process.

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