Research Article

Geopolymer Concrete using Kaolinite clay, Fly ash and GGBS

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Abstract
In order to meet the environmental pollution effects caused by concrete made using ordinary Portland cement, geopolymer concrete has been developed which is also known In order to meet the environmental pollution effects caused by concrete made using ordinary Portland cement, geopolymer concrete has been developed which is also known as cementless concrete. It is known that alkali-activated aluminosilicates are able to produce alumino-silicate geopolymers. This study focuses on producing geopolymer concrete using a combination of kaolinite, flyash and GGBS in various proportions and their compressive strengths at different stages have been studied. Initially in 100% fly ash based Geopolymer concrete, fly ash was replaced with kaolinite clay by 10%, 20%, 30%, 40%, 50% and 60% by weight. Later on in 100% kaolinite based Geopolymer concrete, kaolinite clay was replaced with GGBS by 10% 20% and 30% by weight. Finally a combination of kaolinite clay, fly ash and GGBS in the ratio of 80:10:10 were tried for making geopolymer concrete. Sodium silicate and sodium hydroxide and solution were used as the alkali activator for the polymerization process. It is observed that as the percentage of GGBS is increased, the strength of the geopolymer concrete is also increased. At 28 days, $F_{80}K_{10}G_{10}$ cube specimens attained a compressive strength of 29.8 N/mm^2. Similarly at 28 days, $K_{70}G_{30}$ cube specimens attained a compressive strength of 22.31 N/mm^2. Likewise $F_{80}K_{20}$ cube specimens attained a compressive strength of 17.42 N/mm^2 at 28 days.

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Introduction

Concrete is one of the most far used construction materials in the world. Portland cement, an essential constituent of concrete is not an environmentally friendly material. The production of Portland cement not only depletes significant amount of natural resources but also liberates a considerable amount of Carbon dioxide (CO_2) and other greenhouse gases. The production of one ton of cement liberates about one ton of CO_2 to atmosphere. In order to address environmental effects associated with Portland cement, there is need to develop alternative binders to make concrete. The development and application of high volume fly ash concrete, which enabled the replacement of OPC up to 60% by mass is a significant development. Davidovits 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 and rice husk ash. Davidovits termed these binders as geopolymers. When compared with ordinary Portland cement concrete, geopolymer show many advantages. Low-calcium fly ash based geopolymer concrete has excellent compressive strength, suffers very little drying shrinkage and low creep, excellent resistance to sulphate attack, and good acid resistance.Geopolymer concrete is suitable for structural applications and the design provisions contained in the current standards and codes can be used to design reinforced fly ash-based geopolymer concrete structural members . On the other hand, geopolymer concrete that is produced by a polymeric reaction of alkaline liquid with a by-product material like fly ash with total replacement of cement by fly ash have several limitations such as necessity of heat curing and delay in setting time. Geopolymers made from calcined source materials, such as metakaolin (calcined kaolin), fly ash, and slag yield higher compressive strengths when compared to those synthesized from non-calcined materials, such as kaolin clay. This study focused on producing a geopolymer concrete by a combination of calcined and non-calcined source materials..

Experimental Program

Materials

Kaolinite clay is one of the most common minerals mined as kaolin and occurs in abundance in soils that have formed from chemical weathering of rocks in hot moist climate. It has specific gravity of 2.20 and is sieved in IS 600 micron. Class F fly ash is one of the residues generated in combustion, and comprises the fine particles that rise with the flue gases was used as the source material to make geopolymer concrete in the laboratory. It has specific gravity of 2.38. Ground-granulated blast-furnace slag (GGBS or GGBFS) is obtained by quenching molten iron slag (a by-product of iron and steel-making) from a blast furnace in water or steam, to produce a glassy, granular product that is then dried and ground into a fine powder. It has specific gravity of 2.80. Fine Aggregate (sand) which is passed through IS sieve 20 mm and retained on IS sieve 16 mm is taken as a fine aggregate. Fine aggregate having a specific gravity of 2.42, bulk density of 1600 kg/m^3 and fineness modulus of 2.30 was used. Coarse aggregates that are passed through IS sieve 20mm and retained on IS sieve 16 mm having a fineness modulus of 6.56, bulk density of 1780.74 kg/m^3 and specific gravity of 2.75 were used. Water conforming to the requirements of water for concreting and curing was used throughout. In this investigation, a combination of Sodium hydroxide solution and sodium silicate solution was used as alkaline activators for polymerization. Sodium hydroxide is available commercially in flakes or pellets form. For the present study, sodium hydroxide flakes with 98% purity were used for the preparation of alkaline solution. Sodium silicate is available commercially in solution form and hence it can be used as such. The chemical composition of sodium silicate is: Na_2O-14.7%, SiO_2-29.4% and Water 55.9% by mass. Conplast SP430 is a chloride free, super plasticizing admixture, a brown solution which instantly disperses in water. It disperses the fine particles in the concrete mix, enabling the water content of the concrete to perform more effectively.

Mix Design of Geopolymer Concrete

In the design of geopolymer concrete (GPC mix), coarse and fine aggregates together were taken as 77% of entire mixture by mass. This value is similar to that used in OPC concrete in which it will be in the range of 75% to 80% of the entire mixture by mass. Fine aggregate was taken as 30% of the total aggregates. From the past literatures it is clear that the average density of fly ash-based geopolymer concrete is similar to that of OPC concrete (2400kg/m^3).Knowing the density of concrete, the combined mass of alkaline liquid and fly ash can be arrived. By assuming the ratios of alkaline liquid to fly ash as 0.4, mass of fly ash and mass of alkaline liquid was found out. To obtain mass of sodium hydroxide and sodium silicate solutions, the ratio of sodium silicate solution to sodium hydroxide solution was fixed as 2.5. Extra water (other than the water used for the preparation of alkaline solutions) and super plasticizer Conplast SP 430 based on Sulphonated Naphthalene Polymers were added to the mix by 10% and 3% by weight of cementitious materials used respectively to achieve workable concrete. The mix proportion for geopolymer concrete is given in **Table 1** and the different combinations of fly ash, GGBS and Kaolinite clay investigated are given in **Table 2.**

Table 1 Mix Proportions

Materials used	Cementitious materials	Fine aggregate	Coarse aggregate	NaOH	Na_2SiO_3	SP430	Water
Quantity of materials in kg/m^3	394.285	554.4	1293.6	45.06	112.65	11.83	39.43

Table 2 Combinations of Fly ash, GGBS and Kaolinite clay

Mix ID	Fly ash in %	Kaolinite in %	GGBS in %
$F_{90}K_{10}$	90	10	-
$F_{80}K_{20}$	80	20	-
$F_{70}K_{30}$	70	30	-
$F_{60}K_{40}$	60	40	-
$F_{50}K_{50}$	50	50	-
$F_{40}K_{60}$	40	60	-
$K_{90}G_{10}$	90	10	-
$K_{80}G_{20}$	80	20	-
$K_{70}G_{30}$	70	30	-
$K_{80}G_{10}F_{10}$	10	80	10
$K_{10}G_{10}F_{80}$	80	10	10

Preparation of Geopolymer concrete

To prepare 12 molarity concentration of sodium hydroxide solution, 480 grams (molarity x molecular weight) of sodium hydroxide flakes was dissolved in distilled water and makeup to one litre. The mass of NaOH solids was measured as 354.45 grams per kg of NaOH solution of 12M concentration. The sodium hydroxide solution thus prepared is mixed with sodium silicate solution one day before mixing the concrete to get the desired alkaline solution. The solids constituents of the GPCC mix i.e. kaolinite clay, fly ash, GGBS and the aggregates were dry mixed in the pan mixer for about three minutes. After dry mixing, alkaline solution was added to the dry mix and wet mixing was done for 4 minutes. Finally extra water along with super plasticizer was added to achieve workable GPCC mix.

Figure 1 Cast Specimens

In this experimental work a total of 63 numbers of Geopolymer concrete specimens were cast with various mix ratios as shown in **Figure 1**. The specimens are of 100 mm side. Before casting machine oil was smeared on the inner surfaces of the cast iron mould. Concrete was poured into the moulds and compacted thoroughly using a tamping rod. The top surface was finished using a trowel. The GPC specimens were removed from the mould after 1or 2 days based on setting of specimens. The specimens were left at room temperature till the day of testing. Compressive strength test was conducted using a 2000kN Digital Compression testing machine. The test was conducted as per the relevant Indian standard specifications.

Results and Discussion

Compressive strength

The compressive strength of kaolinite based geopolymer concrete at the age of 3 days 7 days and 28 days are presented in the **Figure 2, Figure 3 and Figure 4**.

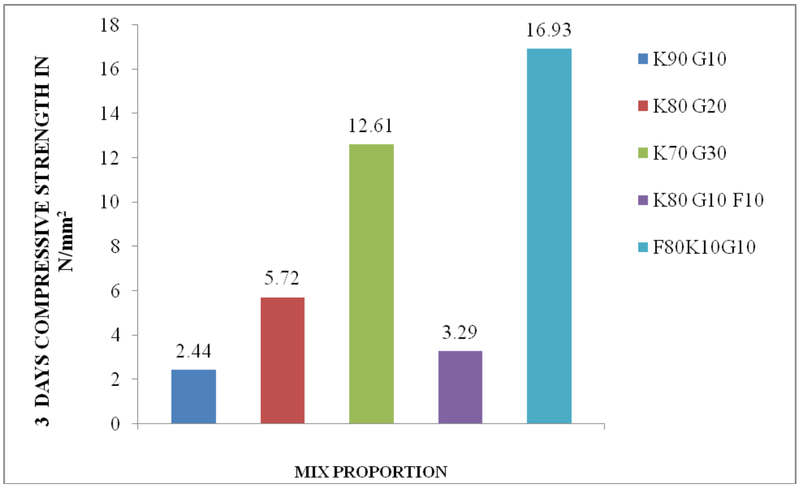

Figure 2 Compressive Strength at 3 Days

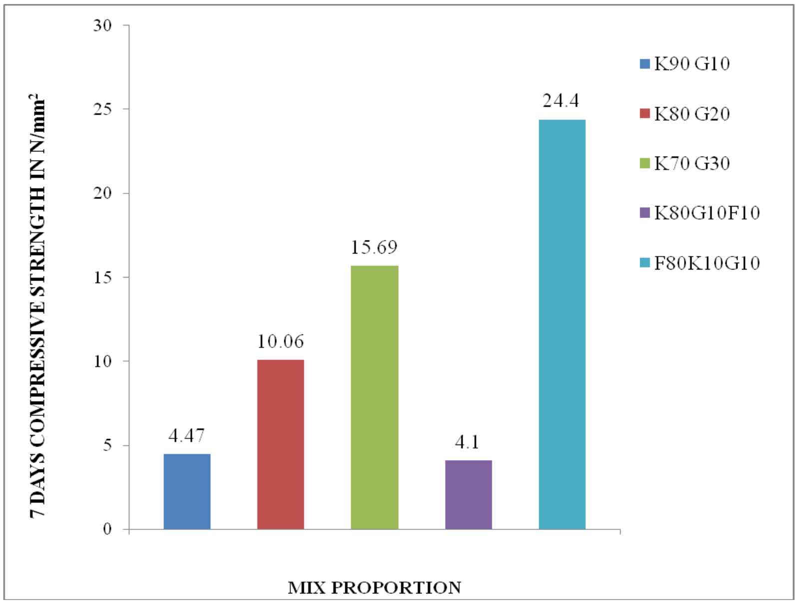

Figure 3 Compressive Strength at 7 Days

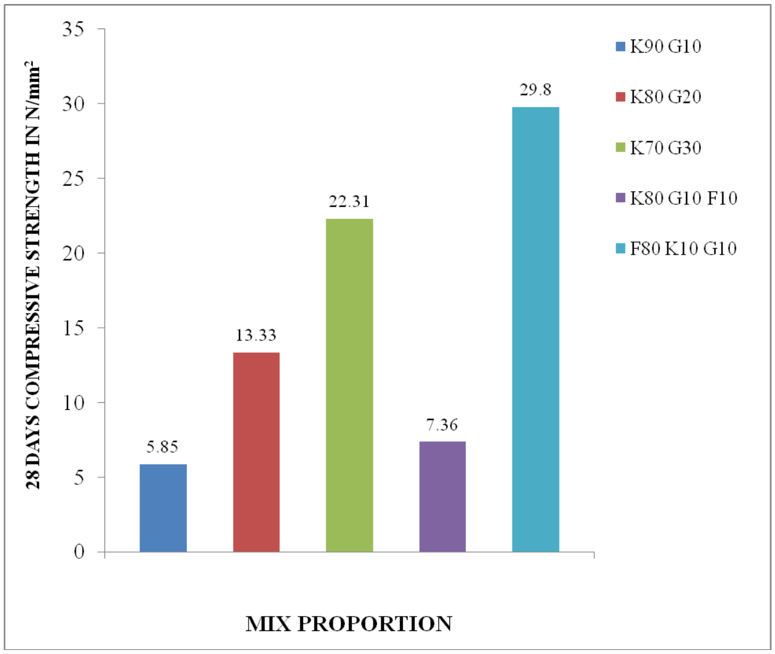

Figure 4 Compressive Strength at 28 Days

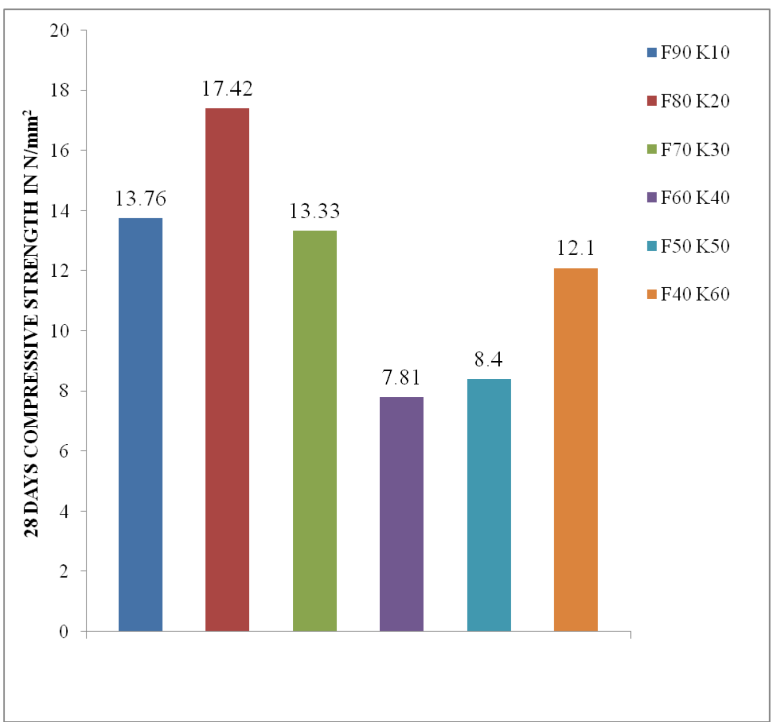

Figure 5 Compressive strength for fly ash and Kaolinite clay based GPC

The compressive strength of fly ash based kaolinite clay geopolymer concrete at the age of 28 days is presented in **Figure.5**. At 3 days, the mix proportion $F_{80}K_{10}G_{10}$ has the highest compressive strength of 16.93 N/mm^2 and the mix proportion of $K_{90}G_{10}$ gave the lowest compressive strength at 3 days. At 7 days, the mix proportion $F_{80}K_{10}G_{10}$ gives the highest compressive strength of 24.4 N/mm^2 and the mix proportion $K_{80}G_{10}F_{10}$ gives the lowest compressive strength. At 28 days, $F_{80}K_{10}G_{10}$ cube specimens attained a compressive strength of 29.8 N/mm^2. Similarly at 28 days, $K_{70}G_{30}$ cube specimens attained a compressive strength of 22.31 N/mm^2. Likewise $F_{80}K_{20}$ cube specimens attained a compressive strength of 17.42 N/mm^2 at 28 days. It is seen from the results that when the percentage of GGBS is increased the compressive strength of the geopolymer concrete also increases in kaolinite based geopolymer concrete. Though addition of GGBS, increases the compressive strength in kaolinite based geopolymer concrete, fly ash based geopolymer concrete shows the high compressive strength.

Conclusions

Based on the experimental investigations carried out, the following conclusions are drawn:

- At 28 days, $F_{80}K_{10}G_{10}$ cube specimens attained a compressive strength of 29.8 N/mm^2. Similarly at 28 days, $K_{70}G_{30}$ cube specimens attained a compressive strength of 22.31 N/mm^2. Likewise $F_{80}K_{20}$ cube specimens attained a compressive strength of 17.42 N/mm^2 at 28 days.
- Based on the test results, the following three combinations of source material are recommended for making geopolymer concrete used in structural applications
  - 80% Fly ash, 10% Kaolinite clay and 10% GGBS
  - 70% Kaolinite & 30% GGBS
  - 80% Fly ash & 20% Kaolinite clay

References

[1] Roy DM (1999) Alkali-activated cements, opportunities and challenges: Cement and Concrete Research No. 2, 29**:** 249-54.

[2] Malhotra VM (2002) High-performance high-volume fly ash concrete: ACI Concrete International, 7, 24:1-5.

[3] Malhotra VM (2002) Introduction: sustainable development and concrete technology: ACI Concrete International ,No. 7, 24: 22.

[4] Davidovits J . Chemistry of geopolymeric systems, terminology: Geopolymer' 99 International Conference, France ,1999.

[5] Wallah SE, Rangan BV. Low-Calcium Fly Ash-Based Geopolymer Concrete: Long- Term Properties, Research Report GC 2 Engineering Faculty in Curtin University of Technology Perth, Australia, 2006.

[6] Vijaya Rangan B, Dody Sumajouw, Steenie Wallah, and Djwantoro Hardjito, Studies On Reinforced Low – Calcium Fly Ash – Based Geopolymer Concrete Beams and Columns, International Conference on Pozzolana Concrete and Geopolymer, Khon Kaen, Thailand, May 24-25, 2006.

[7] Davidovitis J . Geopolymer chemistry and properties. Proc. of the First European Conference on Soft Mineralogy, 1988, p 25-48.

[8] Rangan B V. Engineering Properties of Geopolymer Concrete. Chapter 13 in Geopolymers: Structures, Processing, Properties, and Applications, Editors: J.Provis and J. van Deventer, Woodhead Publishing Limited, London, 2009.

[9] Mustafa Al Bakri, Kamrudin H Mohamed, Ruzaidi C M, Rafiza A R, Muhammad Faheem M T and Izzat A M (2011) Properties and Microstructural Characteristics of Geopolymers using Fly Ash with different percentages of Kaolin at Room Temperature Curing:Australian Journal of Basic and Applied Sciences, 5(10): 824-828.

[10] IS: 516.Methods of tests for strength of concrete, Bureau of Indian Standards, New Delhi, 1959.

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