Effect Of Alkaline To Fly Ash Ratio On Flyash Based Geopolymer Concrete

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This paper presents a study on mechanical properties and stress strain behavior of low calcium fly ash based geopolymer concrete. Geopolymer concrete is made from fly ash with sodium hydroxide and sodium silicate as alkaline activator. Three different mixes are cast varying alkaline activator to fly ash ratio as 0.25, 0.35 and 0.45. The geopolymer concrete is cured under oven curing at temperature 60^0C for 24 hours and left for room temperature. After 24 hours of curing at room temperature the cubes are tested for compressive strength, split tensile strength and stress strain behavior of GPC. The molarity of the NaoH solution was varied are 8M, 10M and 12M. Results indicated that geopolymer concrete has low alkaline to fly ash ratio indicating better strength. With increase in the molarity of GPC there is an increase in the mechanical properties of GPC.

Keywords— Fly ash, Compressive Strength, Split Tensile Strength, Stress strain curve, Oven Curing.

Introduction

Now-a-days the most suitable and widely used construction material is concrete. This building material, until these days, went through lots of developments. The most important part of concrete is cement. The production process of this raw material produces a lot of CO_2. It is well known, that CO_2 emission initiates harmful environmental changes. Nowadays researchers make efforts to minimize industrial emission of CO_2. The most effective way to decrease the CO_2 emission of cement industry, is to substitute a proportion of cement with other materials. These materials called supplementary cementing materials (SCM's). . Usually used supplementary cementing materials are Ground Granulated Blast Furnace Slag (GGBS), Fly Ash (FA), Silica Fume (SF), Trass or Metakaolin (MK). Geopolymer concrete is a new type of concrete that can be made from fly ash/metakaolin/slag and activated with alkaline solutions. Many studies confirmed that fly ash geopolymer concrete has good engineering properties **[1-3].** In the present investigation, low-calcium fly ash based geopolymer is used as the binder, instead of Portland cement and alkaline activator is used to produce this geopolymer concrete. The fly ash based geopolymer paste binds the loose coarse aggregates, fine aggregates and other un-reacted materials together to form the geopolymer concrete, with or without the presence of admixtures. The manufacture of geopolymer concrete is carried out using the usual concrete technology methods. The curing condition adopted is the oven curing (60^0C for 24 hours).

Literature Review

In 1978, J Davidovits **[4]** introduced a new material that can be used as an alternative binder to cement. This material is named as geopolymer for its reaction between alkaline liquid and geological based source material. Geo-polymers are members of the family of inorganic polymers. The chemical composition of the geo-polymer material is similar to natural zeolitic materials, but the microstructure is amorphous instead of crystalline **[5,6]. Hardjito et al [7]** *concluded* that a combination of sodium hydroxide and sodium silicate solutions can be a good application for activators and higher concentration of sodium hydroxide solution and curing temperature enable the concrete compressive strength to be higher. Various authors studied the importance of molar ratio of Na_2SiO_3/NaOH and suggested as 2.5 for maximum compressive strength at constant binder content **Pinto [8]**. **Rangan [9]** proposed a mix design methodology for geopolymer concrete with fly ash and **Anuradha et al [10]** suggested modifications in Indian Standard code for suitability of GPC. **Jarvis R Black [8]** carried out research on fly ash based geopolymer concrete considering different mix proportions and developed a mix design process by varying the water to geopolymer solids ratio with two different molarities of NaOH i.e. 8M and 12M. The research concluded that the flash set was a significant problem for GPC mixes. **Talha Junaid et al. [9]** conducted experiments on low calcium fly ash based geopolymer concrete by selecting the sodium silicate and sodium hydroxide as alkaline activators for determining the characteristics for GPC. The parameters considered to measure strength and workability were: water to geopolymer solids, alkaline liquid to fly ash ratio and alkaline liquid to water ratio. These relations were useful for determining the quantities of the mix proportions. **Subhash V et al. [10]** reported the utilization of pozzalanic material fly ash as the binder content for the preparation of Geopolymer concrete mix with high alkaline solution. A mix design procedure was proposed for normal and standard grade Geopolymer Concrete varying the ingredients such as quantity of fly ash, quantity of water, grading of fine aggregate, fine aggregate to total aggregate ratio by maintaining sodium silicate to sodium hydroxide ratio as 1 and sodium hydroxide molarity as 13 for all the mixes. With respect to the past work done on GPC, the present research work is planned considering the parameters viz. fly ash content, alkaline/fly ash ratio. The ratio of sodium silicate to sodium hydroxide is kept at 2.5 with molarity of NaOH as 8M, 10M and 12M. The investigation aims in studying the influence of these parameters on mechanical properties of Geopolymer concrete.

2 Research Significance

It is necessary to make geopolymer concrete because it has enormous potential applications for the concrete industry. This study examines the performance of geopolymer concrete as a structural grade for concrete application to meet target strength of GPC20-GPC40. A comprehensive assessment of mechanical properties has been evaluated for making geopolymer concrete as a structural-grade concrete.

3 Experimental Program

The experimental Program consisted of finding the mechanical properties of geopolymer concrete by casting specimens for different alkaline to binder ratios to meet the target strength of 20MPa-40MPa. Total of 27 cubes of size 150mmx150mmx150mm, 36 cylinders of size 150mmdia, and 300 mm height were cast and tested for determining mechanical properties i.e., characteristic compressive strength, split tensile strength and stress-strain behaviour of fly ash based geopolymer concrete.

4 Materials:

Materials used in the present investigation were

4.1.1. Fly ash is used as binder in this research work. Fly ash is obtained from National thermal power plant, Ramagundam, India. Specific gravity of Fly ash is 2.17 respectively. Chemical Composition details are shown in Table 1. Fly ash particles were spherical in shape. The Fly ash is mainly composed of large percentages of silica and alumina.

Table 1. Chemical composition of fly ash and GGBS (% by mass).

Chemical Composition	Fly ash
SiO_2	60.11
Al_2O_3	26.53
Fe_2O_3	4.25
SO_3	0.35
CaO	4.00
MgO	1.25
Na_2O	0.22
LOI	0.88

4.1.2. Fine Aggregate: The nearby river sand conforming to Zone-2 according to IS: 383 **[11]** is used as fine aggregate. The specific gravity and bulk density of sand are 2.65 and 1.45 gram/c.c. respectively.
4.1.3. Coarse Aggregate: Crushed granite of 20 mm nominal size obtained from a local crushing unit is used as coarse aggregate and the aggregate is well graded aggregate according to IS: 383**[11].** The specific gravity and bulk density are 2.80 and 1.5 gram/c.c.
4.1.4. Water: Potable water was used in the experimental work for preparation of alkaline Solution.
4.1.5. Super Plasticizer: Sulphonated Naphthalene formaldehyde based super plasticizer is used for improvement of workability.

4.2 Preparation of Alkaline Solution

The present experimental work examines the properties of geopolymer concrete for 8M, 10M and 12M NaOH. For 8M about 320 gms of Sodium hydroxide pellets are dissolved in Potable water to make one litre of 8M Sodium Hydroxide solution. The ratio of Sodium Silicate Solution to Sodium Hydroxide Solution is considered as 2.5 and the mixed solution is stored for 24 hours at room temperature (25 ± 2^0C) and relative humidity of 65% before it is used for casting, because dissolution of NaOH in water is an exothermic reaction and a substantial amount of heat is generated to use in concrete, the heat is to be reduced and come down to ambient temperature.

4.3 Mix Proportions

In the present investigation an experimental program was designed to determine the optimum mix proportions of concrete with fly ash content. Before carrying out actual experimentation several trials were carried out for control mixes as per IS: 10262-2009 for GPC20-GPC50 grades of concrete. The mix design of geo polymer concrete was similar to ordinary concrete but cement was replaced by fly ash content and water with alkaline solution. Sodium hydroxide solution and sodium silicate solution were used as alkaline activators. The alkaline activator to fly ash ratio was taken as 0.25, 0.35 and 0.45 for obtaining the required compressive strength. The ratio of sodium silicate solution (Na2SiO$_3$) to sodium hydroxide (NaOH) was taken as 2.5. Sodium Hydroxide solution concentration was maintained as 8 Molarity (320 grams of NaOH of 98% purity were dissolved in tap water to prepare one litre NaOH Solution).Preparation of alkaline solution is an exothermic reaction and hence the quantified NaOH and Na_2SiO_3 Solution were mixed and stored at room temperature for 24 hours prior to mix in concrete. After certain trail mixes and testing of cast specimens, a final mix proportion shown in Table 2 was adopted to carryout mechanical properties.

***(Table 2. Mix proportion of Geopolymer Concrete)**

Mix	Fly ash (Kg/m^3)	F.A (Kg/m^3)	C.A (Kg/m^3)	Alkaline (Kg/m^3)	Molarity (M)
GPC1	360	580	1275	162	8M
GPC2	440	635	1206	110	8M
GPC3	390	585	1287	136	8M
GPC1	360	580	1275	162	10M
GPC2	440	635	1206	110	10M
GPC3	390	585	1287	136	10M
GPC1	360	580	1275	162	12M
GPC2	440	635	1206	110	12M
GPC3	390	585	1287	136	12M

4.4 Casting of GPC Specimens

The individual dry material weighed were mixed using a rotating drum type 100 kg capacity pan mixer and the alkaline liquid and super plasticizer of optimum dosage were added. Proper homogenous mixing would be ensured by continuous mixing for 5 to 7 minutes and fresh property tests were carried out. The fresh mixes prepared were cohesive and segregation resistant. Immediately after mixing, the fresh concrete was transferred into moulds followed by table vibration for a period of 45 seconds. After compaction the top surface was levelled with a trowel.

Fig 1: Slump cone test of Geopolymer Concrete

4.5 Curing of GPC Specimens

The specimens were demoulded after 24 hours of casting and cured in oven for 60^{0}C 24 hours. The specimens, cured in hot air oven at 60^{0}C for 24 hours duration were considered as oven cured. After exposing to hot air in oven for 24 hours, specimens were kept at room temperature until the specified age of curing (i.e. 28 days).

Fig 2: Specimens were kept in Oven for curing

5 Testing Procedures for fresh and Hardened State GPC

5.1 Compressive Strength Test

The cube specimens are tested on compression testing machine of capacity 2000kN.The specimen is placed on the machine in such a manner that the load applied to opposite sides of the cubes as caste that is, not top and bottom. The axis of the specimen is carefully aligned at the center of the loading frame. The load applied is increased continuously at a constant rate until the resistance of the specimen to the increasing load breaks down and no longer can be sustained. The maximum load applied on the specimen is recorded. The rate of loading was adopted as per IS 516 **[12].**

5.2 Split tensile strength

Split tensile strength was evaluated as per the test procedure given in Indian Standards IS.5816. In order to evaluate the splitting tensile strength of geopolymer concrete, all the cylinder specimens were subjected to split tensile strength test in a 2000 KN. Specimens were placed in the machine in a horizontal manner in between the two parallel steel strips one at top and another at the bottom such that the load shall be applied along the 300 mm length. The maximum load applied to the specimen was recorded and the split tensile strength of the specimen was calculated using Equation

$$f_t = \frac{2P}{\pi DL}$$

Where ft is the split Tensile Strength, P is the maximum load applied to the specimen, D is the diameter of the specimen and L is the length of the specimen.

6 RESULTS AND DISCUSSIONS

6.1 Compressive Strength

Compressive strength is a major property used to assess the performance and quality of almost all types of concrete. Compressive strengths for 28 days obtained were in the range of 33 MPa to 44 MPa for oven curing. With proper formulation of mix ingredients, 28 days compressive strengths of 30 to 40 MPa can be easily achieved without any need for any cement content. This can be emphasized by the complete dissolution of the of Fly ash particles. With the increase in molarity there is an effect in the strength of GPC. The increase in the strength may due to dissolution and the faster polymerization process as the specimens are exposed to the oven curing. Thus geopolymer concrete with fly ash and shows encouraging results with temperature curing. Density results were the same as that of conventional concrete.

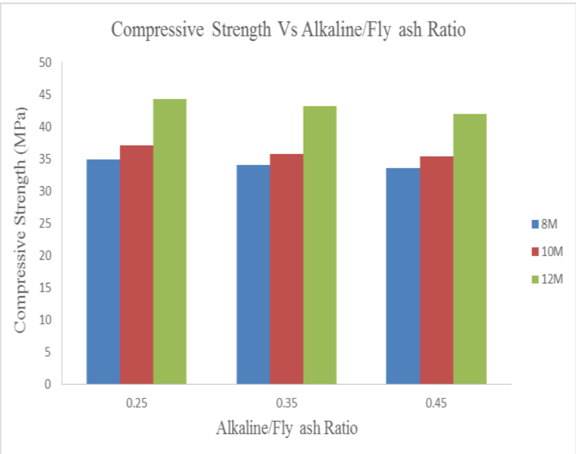

Figure 3: Compressive strength of geopolymer concrete Vs Alkaline to Fly ash Ratio

6.2 Split Tensile Strength

A direct measurement of ensuring tensile strength of concrete is difficult. One of the indirect tension test methods is split tension test. The split tensile strength test is carried out on the compression testing machine. The variation of split tensile strength of geopolymer concrete for different alkaline activator to binder ratios is presented in Fig 4. From the Fig.4, it can be observed that the split tensile strength of geopolymer concrete increases continuously with increase in the Alkaline/Binder Ratio. Increase in the alkaline activator content increased the tensile capacity of the geopolymer concrete. Molarity also plays an crucial role in attaining the GPC. The specimens of 12M gained the more strength compared with 8M and 10M.

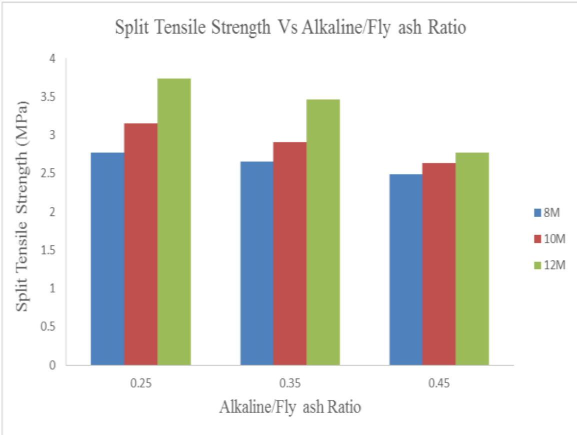

Figure 4: Split Tensile strength of geopolymer concrete Vs Alkaline to Fly ash Ratio

6.3 Stress-Strain behaviour of Fly ash based Geopolymer Concrete

Graph obtained by drawing a curve for the values of stresses and strains obtained during testing a material specimen of materials is called a stress - strain curve. By testing cylinders of standard size made with concrete, under uni-axial compression values of stresses and strains are obtained and the stress-strain curves are plotted. Even though the stress strain relation for cement paste and aggregate when tested individually is practically linear, it is observed from the stress-strain plots of concrete that, no portion of the curves is in the form of a straight line. In concrete the rate of increase of stress is less than that of increase in strain because of the formation of micro cracks, between the interfaces of the aggregate and the cement paste. Thus the stress strain curve is not linear. In conventional concrete the value of stress is maximum corresponding to a strain of about 0.002 and further goes on decreasing with the increasing strain, giving a dropping curve till it terminates at ultimate crushing strain.

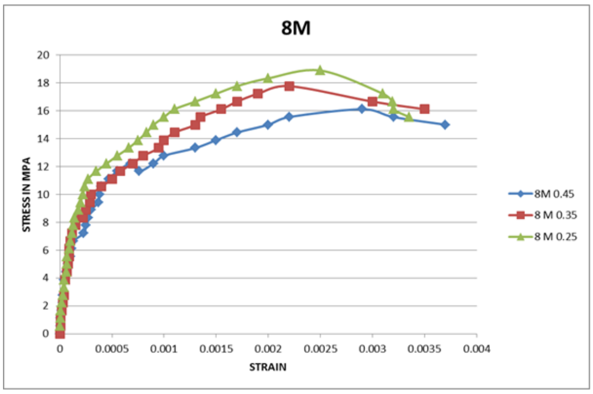

Figure 5: Stress-strain curve for GPC of 8M with different alkaline to Fly ash Ratio

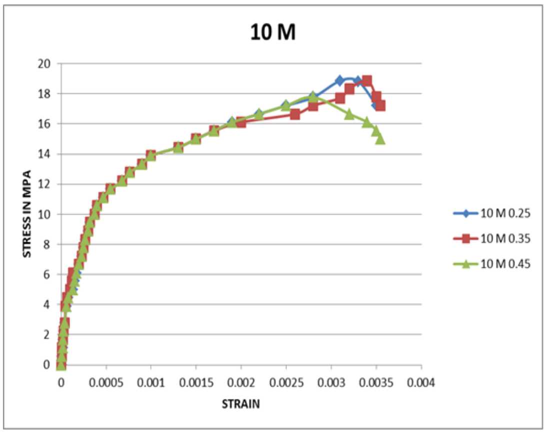

Figure 5: Stress-strain curve for GPC of 10M with different alkaline to Fly ash Ratio

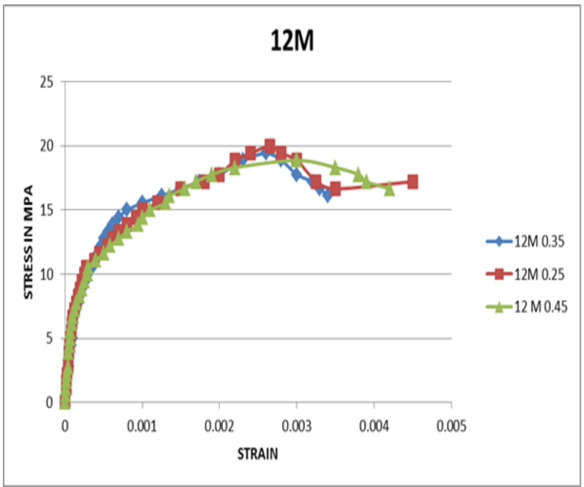

Figure 6: Stress-strain curve for GPC of 12M with different alkaline to Fly ash Ratio

7 Conclusions

1. Geoplymer concrete strength increases with an increase in the concentration (in terms of molarity) of sodium hydroxide.
2. Geoploymer concrete split tensile strength also increases with the increase of concentration (in terms of molarity) of sodium hydroxide.
3. Geopolymer concrete strength found maximum at Binder ratio is 0.25 this suggests that the increase in the fly ash content in the mix compressive strength and split tensile strength also increases.
4. The maximum compressive strength of geopolymer concrete is found 44.31 N/mm^2 at fly ash ratio 0.25 and 12M of NaOH.
5. The maximum split tensile strength of geopolymer concrete is found 3.74 N/mm^2 at fly ash ratio 0.25 and 12M of NaOH.
6. The ultimate stress is found at Binder ratio 0.25 and 12M of NaOH.
7. The strain correspondence to ultimate stress is 0.0028.
8. The maximum strain 0.0035 is found at Binder ratio 0.45 and 8M of NaOH.

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