ASIAN JOURNAL OF CIVIL ENGINEERING (BUILDING AND HOUSING) VOL. 13, NO. 6 (2012)
PAGES 841-853

Technical Note

AN EXPERIMENTAL INVESTIGATION ON PROPERTIES OF GEOPOLYMER CONCRETE (NO CEMENT CONCRETE)

V. Bhikshma[*a], M. Koti Reddy[b] and T. Srinivas Rao[a]
[a]Department of Civil Engineering, University College of Engineering, Osmania University, Hyderabad, India
[b]Department of Civil Engineering, Chaitanya Bharathi Institute of Technology, Hyderabad, India

Received: 5 June 2011, **Accepted**: 10 December 2011

ABSTRACT

One of the efforts to produce more environmentally friendly concrete is to reduce the use of OPC by replacing the cement in concrete with geopolymers. In geopolymer concrete no cement is used, instead fly ash and alkaline solutions such as sodium hydroxide (Na OH) and sodium silicate (Na_2O, SiO_2) and potassium hydroxide (KOH) are used to make the binder necessary to manufacture the concrete. One tone of fly ash can be utilized for manufacturing about 2.5 cubic meter of high quality Geopolymer concrete. Test experiments proved as fly ash based Geopolymer concrete has excellent Compressive strength, suffers very low drying shrinkage, low creep, excellent resistant to sulphate attack and good acid resistance. Trial mixes were done and noted the properties of the concrete both in fresh state and in hardened conditions. The workability of the concrete in terms of slump and compacting factor are observed to be excellent. The geopolymer concrete in fresh state observed to be highly viscous and good in workable. Collapsed slump was observed with compaction factor of 0.95. Cube compressive strength of the geopolymer concrete cubes verified at the age the concrete 28 days from the date of their casting. Based on the test results of the trial mixes, this experimental study is carried out for 5 different mix proportions of fly ash to alkaline chemical ratios of concrete specimen. Test specimen of standard sizes of cubes (30nos), cylinders (30nos), and prisms (15nos) were cast and tested for workability in terms of slump and compacting factors in fresh state and for mechanical properties such as Compressive Strength, Splitting Tensile Strength, Flexural Strength, and Modulus of Elasticity of concrete in hardened state. The test experiment proved that a concrete of compressive strength of 30MPa could be achieved in geopolymer concrete by adopting alkaline solution to fly ash ratio of 0.50 at 16 molarity of Na OH.

Keywords: Geopolymers; alkaline solutions; geopolymer concrete; sulphate attack; workability; fly ash ratio molarity

[*] E-mail address of the corresponding author: v.bhikshma@yahoo.co.in (V. Bhikshma)

1. INTRODUCTION

The global warming is caused by the emission of greenhouse gases, such as CO_2, CO to the atmosphere by human activities. Among the greenhouse gases, CO_2 contributes about 65% of global warming (McCaffrey [1]). The cement industry is responsible for about 7% of all CO_2 emissions, because the production of one ton of Portland cement emits approximately one tone of CO_2 into the atmosphere (Davidovits [2], McCaffrey [1]).In this respect, the geopolymer technology proposed by Davidovits shows considerable promise for the concrete industry as an alternative binder to OPC.

In terms of reducing the global warming, the geopolymer technology could reduce the CO_2 emission to the atmosphere caused by cement and aggregates industries by about 80%. One of the efforts to produce more environmentally friendly concrete is to reduce the use of OPC by replacing the cement in concrete with geopolymers (i.e. 100% fly ash in place of OPC).

1.1 Fly ash-based geopolymer concrete

Inspired by the geopolymer technology (no cement concrete) and the fact that fly ash is a waste material abundantly available, in 2001, the Geopolymer Concrete Research Group at Curtin University of Technology in Australia commenced a comprehensive research programme on 'Fly Ash-Based Geopolymer Concrete**'.** The first part of research studied for the development of mix proportion, manufacture of fly ash-based geopolymer concrete, the effect of main parameters on the short-term as well long-term engineering properties of fresh and hardened concrete (Davidovits [3]). One tone of low calcium fly ash can be utilized to produce about 2.5 cubic meter of high quality Geopolymer concrete. Test experiments proved as fly ash based concrete has excellent compressive strength, suffers very little drying shrinkage low creep, excellent resistant to sulphate attack and good acid resistance. Given the fact that the fly ash is considered as a waste material, the fly ash based geopolymer is therefore some how cheaper than the OPC concrete. Moreover reduction of one tone of CO_2 yields one tone of carbon credit and the monetary value of that one carbon credit is approximately 20 Euros. This carbon credits significantly adds to the economy offered by the Geopolymer.

1.2 Definition of geopolymer

Davidovits of France first coined the term Geopolymer concrete and proposed that an alkaline liquid could be used to react with the silica (Si) and the Alumina (Al) in the source material of geological origin or in by-product materials such as fly ash, and rice husk ash to produce binders. The chemical composition of geopolymer materials is similar to natural Zeolitic materials, but the microstructure is amorphous. The polymerization process involves a substantially fast chemical reaction under alkaline condition on Si-Al materials that results in a three dimensional polymeric chain reaction consisting a ring of Si-O-Al-O bonds. Thus the concrete is named as geopolymer concrete.

1.3 Application of geopolymer materials

Based on the Silica to alumina atomic ratio present in the polymers, the geopolymers are widely used in Bricks, ceramics, fire protection works, in manufacturing of low CO_2 cements and concretes, radioactive and toxic waste encapsulations, fire protection fiber glass composites etc.

1.4 Need for the work

Manufacture of one tone of ordinary Portland cement liberates one tone of carbon dioxide in to the atmosphere, which in turn affects the phenomenal feature of global warming. In reducing this global warming effect and to study the suitability of geopolymer concrete as an alternative to the OPC to obtain a structural grade concrete this investigation has been carried out.

1.5 Aims and objectives

The objectives of this experiment are

1. To study and determine the properties of the geopolymer concrete in fresh state,
2. To determine mechanical properties of geopolymer concrete for different chemical to fly ash ratios, called as chemical ratios (0.30, 0.35, 0.40, 0.45,0.50) at the concentration of sodium hydroxide (in terms of molarity) at16.

1.6 Scope of work

In the present study fly ash is used as the base material for making geopolymer concrete. Five mix proportions with ratio of alkaline liquids to fly ash ratios of 0.30 to 0.50 are prepared and standard specimens of cubes (30 No's), cylinders (30No's) and prisms (15 No's) were cast and tested for mechanical properties such as compressive strength , splitting tensile strength , flexural strength and modulus of elasticity. Brief literature review is given below:

1.7 literature review

The term 'Geopolymer' was first introduced by Davidovits [4], Geopolymer Institute Saint Quentin France in 1978 to describe a family of mineral binders with chemical composition similar to zeolites but with an amorphous microstructure.

Davidovits, has also distinguished 3 types of polysialates, namely the Poly (sialate) type1 (-Si-O-Al-O), the Poly (sialate-siloxo) type2 (-Si-O-Al-O-Si-O) and type3 (-Si-O-Al-O-Si-O). Chemical structures of polysialates polymerization involves the chemical reaction of alumino-silicate oxides (Si_2O_5, Al_2O_2) with alkali polysilicates yielding polymeric Si – O – Al bonds. Polysilicates are generally sodium or potassium silicate supplied by chemical industry or manufactured fine silica powder as a by-product of Ferro-silicon metallurgy.

The schematic formation of geopolymer material can be shown as described by Equations $n(Si_2O_5,Al_2O_2)+2nSiO_2+4nH_2O+NaOH$ or KOH ℵ Na+, K+ + $n(OH)_3$-Si-O-Al--O-Si-$(OH)_3n(OH)_3$-Si-O-Al--O-Si-$(OH)_3$ + Na OH or KOH ℵ (Na+, K+)-(-Si-O-Al--O-Si-O-)+$4nH_2O$ (Geopolymer backbone) ii) an Jaarsveld [5], Unlike ordinary Portland/ pozzolanic cements, geopolymers do not form calcium silicate- hydrates (CSHs) gel for matrix formation and strength, but utilize the poly-condensation of silica and alumina precursors and a high alkali content to attain structural strength. Therefore, geopolymers are sometimes referred to as alkali activated alumina silicate binders. Among the waste or by-product materials, fly ash and slag are the most potential source of geopolymers. Several studies have been reported related to the use of these source materials.

Palomo [6], reported the study of fly ash-based geopolymers. He used combinations of sodium hydroxide with sodium silicate and potassium hydroxide with potassium silicate as alkaline liquids. It was found that the type of alkaline liquid is a significant factor affecting the mechanical strength, and that the combination of sodium silicate and sodium hydroxide gave the highest compressive strength. Gurley [7], stated that the presence of calcium in fly ash in significant quantities could interfere with the polymerization setting rate and alters the microstructure. Therefore, it appears that the use of Low Calcium (ASTM Class F) fly ash is more preferable than High Calcium (ASTM Class C) fly ash as a source material to make geopolymers. There are two main constituents in the geopolymers, namely source material and the alkaline liquids. The alkaline liquids are from soluble alkali metals that are usually sodium or potassium based. The most common alkaline liquids are combination of sodium hydroxide (Na OH) or Potassium Hydroxide (KOH) and sodium silicate or potassium silicate. Palomo et al. [8], studied the influence of curing temperature, curing time and alkaline solution-to-fly ash ratio on the compressive strength. It was reported that both the curing temperature and the curing time influenced the compressive strength. The utilization of sodium hydroxide (Na OH) combined with sodium silicate (Na_2SiO_3) solution produced the highest strength. Compressive strength up to 60 MPa was obtained when cured at 85^0C for 5 hours. Xu and van Deventer [9], investigated the geo-polymerization of 15 natural Al-Si minerals. It was found that the minerals with a higher extent of dissolution demonstrated better compressive strength after polymerization. The percentage of calcium oxide (Ca O), Potassium oxide (K_2O), the molar ratio of Si-Al in the source material, the type of alkali and the molar ratio of Si/Al in the solution during dissolution had significant effect on the compressive strength. Swanepoel and Strydom [10], conducted a study on geopolymers produced by mixing fly ash, kaolinite, sodium silica solution, (Na OH) and water. Both the curing time and the curing temperature affected the compressive strength, and the optimum strength occurred when specimens were cured at 60^oC for a period of 48 hours.

Van Deventer and Lukey [11], studied the interrelationship of certain parameters that affected the properties of fly ash-based geopolymer. They reported that the properties of geopolymer were influenced by the incomplete dissolution of the materials involved in geo-polymerization. The water content, curing time and curing temperature affected the properties of geopolymer; specifically the curing condition and calcining temperature influenced the compressive strength. When the samples were cured at 70^oC for 24 hours a substantial increase in the compressive strength was observed. Curing for a longer period of time reduced the compressive strength. Past studies on fly ash-based geopolymer concrete members are extremely limited. Palomo investigated the mechanical characteristics of fly ash based Geopolymer concrete. It was found that the characteristics of the material were mostly determined by curing methods especially the curing time and curing temperature. Their study also reported some limited number of tests carried out on reinforced geopolymer concrete sleeper specimens.

2. EXPERIMENTAL PROGRAAME

Fly ash used in this study was dry fly ash procured from the Ramagundam thermal project. The sample of the batch was sent to Indian Institute of Chemical Technology at Taranaka, Hyderabad India and the chemical composition of the of the fly ash has been found out, and the chemical analysis report of the fly ash is given in Table 1. The aggregates used in the mix met with the requirements of conventional concrete. The fineness modulus of fine and coarse aggregates is 3.25 and 7.07 respectively.

Table 1: Properties of fly ash

Characteristics	Results/% by mass
Loss on Ignition	1.90
Silica, SiO_2	52.16
Alumina, Al_2O_3	36.93
Iron, Fe_2O_3	4.23
Calcium, CaO	4.67
Magnesium, MgO	Nil

Note: Composition of fly ash as determined by XRF (mass %)

Table 2: Physical properties of coarse aggregate

Property	Values
Specific gravity	2.65
Fineness modulus	7.07
Bulk density	
a) Loose	1498kg/m^3
b) Compacted	1710kg/m^3
Aggregate impact value	17.3%
Water absorption	0.25%
Crushing strength	22

2.1 Alkaline Liquid

The alkaline liquid used was a combination of sodium silicate solution and sodium hydroxide solution. The sodium silicate solution (Na_2O= 13.7%, SiO_2=29.4%, and water=55.9% by mass) was purchased from a local market in bulk. The sodium hydroxide (Na OH) in flakes or pellets from with 97%-98% purity was also purchased from a local market. The Na OH flakes were dissolved in water to make the solution with required Molarity.The Sodium hydroxide solids (Na OH) with 97-98% purity is purchased from the local Market and mixed with water to required Molarity. The solution comprises 26.2% of Na OH solids and73.80% water by mass.

2.2 Mix design process.

Mix design process is illustrated for the concrete mix designed for the trial mix with Chemical ratio 0.35 and molarity of 8

1.	Assume normal density of the concrete	2400kg/m^3
2.	Take mass of combined aggregates 77% mass concrete	1848kg/m^3
3.	Mas of fly ash and alkaline liquid (2400-1848)	552kg
4.	Take Alkaline liquid to fly ash ratio	0.35
	Molarity of Na OH	8
5.	Mass of fly ash 552/(1+0.35)	408kg
6.	Mass of alkaline liquid (552-408)	144kg
7.	Taking ratio of Sodium silicate (Na_2O SiO_2) to Na OH as 2.5	
	Mass of Na OH 144/ (1+2.5)	41kg
	Mass of sodium silicate (144-41)	103kg
	Water in the sodium silicate is 55.90%therefore 103X0.559	58kg
	Solids in sodium silicate (103-58)	45kg
	Solids in Na OH 26.2% (41X0.226)	11kg
	Water in the Na OH solution is (41-11)	30kg
	Total mass of water (58+30)	88kg
	Mass of geopolymer solids (408+45+11)	464kg
	ABSTRACT OF QUANTITIES	
	Combined aggregate	1848kg
	Sodium silicate	103kg
	Na OH (30kg wate+11kg Na OH flakes)	41kg
	Fly ash	408kg

2.3 Preparation of liquids

The sodium hydroxide (Na OH) flakes were dissolved in water to make the solution. The mass of Na OH solids in a solution varied depending on the concentration of the solution expressed in terms of molar, M. For instance, Na OH solution with a concentration of 8M consisted of 8x40 = 320 grams of Na OH solids (in flake or pellet form) per liter of the solution, where 40 is the molecular weight of Na OH. The mass of Na OH solids was measured as 262 grams per kg of Na OH solution of 8M concentration. Similarly, the mass of Na OH solids per kg of the solution for 16M concentration was measured as 444 grams. Note that the mass of Na OH solids was only a fraction of the mass of the Na OH solution, and water was the major component.

The sodium silicate solution and the sodium hydroxide solution were mixed together at least one day prior to use to prepare the concrete. The chemical mix can be kept up to 48 hours also. On the day of casting of the specimens, the alkaline liquid would be mixed with extra water (if any) to prepare the liquid component of the mixture for better workability. In this experiment no extra water was used before mixing.

2.4 Curing of test specimens

The temperature required for curing can be as low as 30 ^{o} C. In tropical climates, this range of temperature can be provided by the ambient conditions. Preliminary tests revealed that fly ash-based geopolymer concrete did not harden immediately at room temperature. When the room temperature was less than 30^{o}C, the hardening did not occur at least for 24 hours. Also, the handling time is a more appropriate parameter (rather than setting time used in the case of OPC concrete) for fly ash-based geopolymer concrete. After casting, the test specimens were covered with vacuum bagging film to minimize the water evaporation during curing at an elevated temperature. The sample specimen laid in trial mixes were left with the moulds in the open air in the ambient temperature ranging from 40 to 44^{o}C and de-moulded samples were left in the air for 28 days and were tested for cube compressive strength.

Similarly the test specimen also along with moulds were kept in the open air for 24, as the geopolymer concrete remain in fresh state very long period up to 2 to 3 hours. After de-moulding, the specimens were left to air-dry in the laboratory until the day of test.

Tests show that the unit-weight of the fly ash-based geopolymer concrete is similar to that of Portland cement concrete. As granite-type coarse aggregates were used, the unit-weight of the geopolymer concrete varied between 23.55 and 24.15kN/m^3 .The cube compressive test carried out as per IS 516-1959. All the tests were presented in Tables.

Table 3: 28 days cube compressive strength of geopolymer concrete with chemical ratio 0.30 and morality 16

S. No	Weight of sample in kg	Density in kg/m^3	Load at failure in kN	Cube compressive strength in MPa
1	8.00	2370.37	660	29.33
2	8.05	2385.19	640	28.44
3	8.10	2400.00	630	28.00
4	7.99	2367.41	420	18.67
5	8.05	2385.19	380	16.89
6	8.00	2370.37	640	28.44

Average compressive stress 24.96MPa

Table 4: 28 days cube compressive strength of geopolymer concrete with chemical ratio 0.35 and morality 16

S. No	Weight of sample in kg	Density in kg/m^3	Load at failure in kN	Cube compressive strength in MPa
1	8.10	2400.00	578	25.69
2	7.95	2355.56	575	25.56
3	8.11	2402.96	610	27.11
4	8.05	2385.19	600	26.67
5	8.15	2414.81	580	25.78
6	8	2370.37	575	25.56

Average compressive stress 26.06MPa

Table 5: 28 days cube compressive strength of geopolymer concrete with chemical ratio 0.40 and morality 16

S. No	Weight of sample in kg	Density in kg/m^3	Load at failure in kN	Cube compressive strength in MPa
1	8.15	2414.84	610	27.11
2	8.10	2400.03	620	27.56
3	8.0	2370.37	620	27.11
4	8.1	2400.00	620	27.11
5	8.0	2370.37	630	28.00
6	7.99	2367.41	640	28.44

Average compressive stress 27.55MPa

Table 6: 28 days cube compressive strength of geopolymer concrete with Chemical ratio 0.450 and morality 16

S. No	Weight of sample in Kg	Density in kg/m^3	Load at failure in kN	Cube compressive strength in MPa
1	8.10	2400.00	640	28.44
2	7.95	2355.56	630	28.00
3	8.15	2414.81	650	28.89
4	8	2370.37	610	27.11
5	8.05	2385.19	620	27.56
6	7.99	2367.41	620	27.56

Average compressive stress 27.92MPa

Table 7: 28 days cube compressive strength of geopolymer concrete with Chemical ratio 0.50 and morality 16

S. No	Weight of sample in kg	Density in kg/m^3	Load at failure in kN	Cube compressive strength in MPa
1	8.10	2400.00	680	30.22
2	7.95	2355.56	670	29.78
3	8.15	2414.81	665	29.56
4	8.0	2370.37	680	30.22
5	8.05	2385.19	680	30.22
6	7.99	2367.41	690	30.66

Average compressive stress 30.11MPa

Table 8: 28 days flexural strength of the concrete with morality 16

Sl. No	Flexural strength in MPa vs chemical ratio				
	0.30	**0.35**	**0.40**	**0.45**	**0.50**
1	5.27	5.44	5.64	5.89	6.03
2	5.15	5.30	5.54	5.79	5.74
3	5.25	5.35	5.59	5.94	5.63
Average	5.22	5.36	5.59	5.87	6.03

Table 9: 28 days splitting tensile strength of concrete with molarity 16

Sl No	Splitting tensile strength vs chemical ratio				
	0.30	**0.35**	**0.40**	**0.45**	**0.50**
1	3.83	4.01	4.18	4.36	4.86
2	3.59	3.96	4.12	4.64	5.03
3	3.74	4.03	4.09	4.86	4.97
Average	3.72	4.00	4.13	4.62	4.95

Table 10: Modulus of elasticity for different chemical ratios

Sl No	Modulus of elasticity				
	0.30	**0.35**	**0.40**	**0.45**	**0.50**
1	26.50	27.50	29.25	30.10	30.85
2	26.85	27.80	29.35	29.85	29.9
3	27.05	28.25	29.60	30.10	29.40

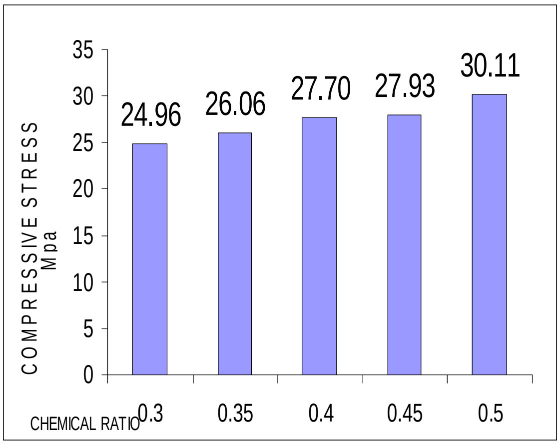

Figure 1. Compressive strength vs chemical ratio

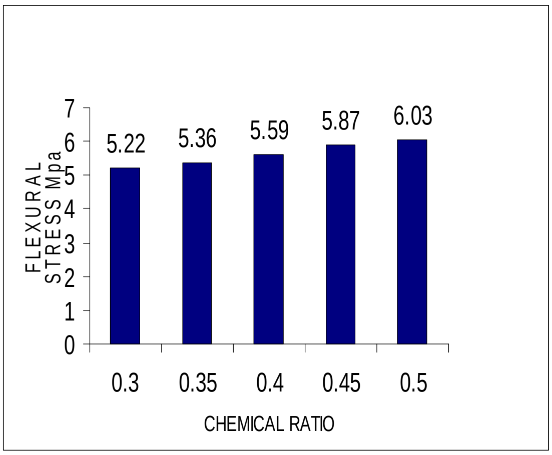

Figure 2. Flexural strength vs chemical ratio

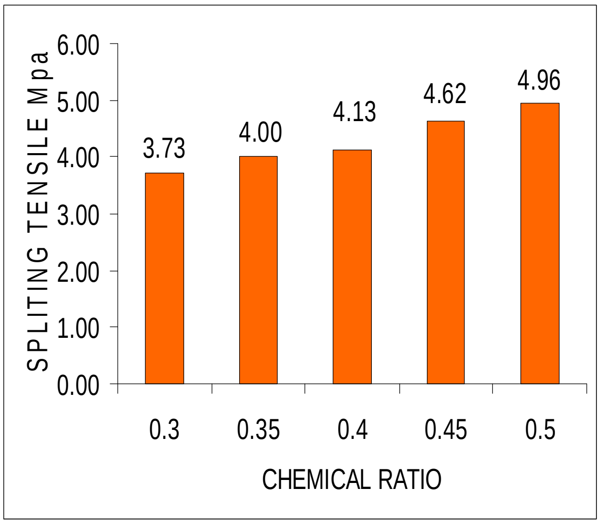

Figure 3. Splitting tensile strength vs chemical ratio

Table 11: Typical mix design quantities for geopolymer concrete

Molarity of Na OH		16	M
Mass of Na OH in 1kg Water for Molar of	16	44.4%	
Ratio of Alkaline Liquid to Fly Ash		0.3	
No. of Cubes - 150 mm x 150mm x150mm - For 7 Days - 3 Nos, For 28 Days - 3 Nos,		6	
Volume		0.02025	
No. of Cyliders - 150 mm Dia - 300 mm Length -For 7 Days - 3+3 Nos, For 28 Days- 3+3 Nos,		12	
No. of Prisms - 100mm x 100mm x 500 mm Long - For 7 Days - 3 Nos, For 28 Days-3 Nos,		6	
For 7 Days - 3 Nos, For 28 Days - 3 Nos,Volume		0.03	
Required Volume		0.11387	m^3
Add Extra	15%	0.01708	m^3
Total Volume of Geo Polymer Concrete		0.13095	m^3
Assume that Normal Density aggregates in SSD condition are to be used and Unit - Weight of Concrete is		2400	kg/m^3
Let the percenatge of Mass of Combined Aggregates is		77%	
Therfore Weight of Combined Aggregates are		1848	kg
20 mm Aggregates -	15%	277.2	kg/m^3
14 mm Aggregates -	20%	369.6	kg/m^3
7 mm Aggregates -	35%	646.8	kg/m^3
Fine Aggregates -	30%	554.4	kg/m^3
Mass of Fly Ash + Alkaline Liquid		552.0	kg/m^3
Mass of Fly Ash		424.6	kg/m^3
Mass of Alkaline Liquid		127.4	kg/m^3
Let the Ratio of Sodium Silicate to Sodium Hydroxide Solution		2.5	
Mass of Sodium Hydroxide Solution - NaOH		36.40	kg/m^3
Mass of Sodium Silicate Solution - SiO_2+Na_2O		90.99	kg/m^3
In Sodium Silicate Solution -SiO2+Na2O			
Mass of Water	55.90%	50.9	kg/m^3

Mass of SiO2 + Na2O @ 2:1 Ratio (i.e SiO2 - 29.4% + Na2O - 14.7%)	44.10%	40.1	kg/m^3
In Sodium Hydroxide Solution - NaOH		16	Molar
Mass of NaOH	44.40%	16.16	kg/m^3
Mass of Water	55.60%	20.24	kg/m^3
Total Mass of Water		71.1	kg/m^3
Total Mass of Geo Polymer Solids = Fly Ash +SiO2 + Na2O Solids + NaOH Solids		480.9	kg/m^3
Water - to - Geo Polymer Solids Ratio by Mass		0.15	
Quantites Required :-			
20 mm Aggregates -		36.3	kg
14 mm Aggregates -		48.4	kg
7 mm Aggregates -		84.7	kg
Fine Aggregates -		72.6	kg
Mass of Fly Ash		55.6	kg
Mass of Alkaline Liquid	16.68		
Mass of Sodium Silicate Solution - SiO_2+Na_2O	11.91		
Mass of Sodium Hydroxide Solution - NaOH	4.77		
Sodium Silicate Solution -SiO2+Na2O			
Mass of Water		6.66	kg
Mass of SiO2 + Na2O @ 2:1 Ratio		5.25	kg
Sodium Hydroxide Solution - NaOH - 16 Molar			
Mass of NaOH		2.12	kg
Mass of Water		2.65	kg
	Total	314.3	kg
	Check	314.3	kg

3. DISCUSSIONS

3.1 Workability

The geopolymer concrete in fresh state observed to be highly viscous and good in workable. No extra water is added. The aggregate use was in SSD condition. Collapsed slump has been observed with compaction factor of 0.95. This reflects in the high dense concrete with a unit weight of 2415kg/m3 Plate 2 shows the mix condition after mixing.

3.2 Compressive strength

The 28 days compressive strength of the concrete for the mix with chemical ratio of 0.30 observed to 24.96MPa, 26.06MPa for the chemical ratio of 0.35, 27.55MPa for chemical ratio of 0.40, 27.92MPa for 0.45chemical ratio and it was 30.11 MPa for the chemical ratio of 0.50. Compressive strength of the geopolymer concrete is increasing while the chemical ratio i.e., Ratio of the alkaline solutions to fly ash is increased. The strength increment is not much rapid in proportionate increment molarity of Na OH and the chemical ratio. Also the strength of the concrete is dependent on the quantity of the alkaline chemical used and the concentration of the sodium hydroxide (Na OH) called Molarity. The higher the molarity of the Na OH solution the increase of the strength of the concrete is proportionate. This aspect is revealed on casting and testing of trail mixes using variable molar Na OH solutions from 8M, 12Mand 16M and Chemical Ratio's from 0.30, 0.35, 0.40, 0.45, and 0.50.

3.3 Splitting tensile strength

As it is seen from the test results it is observed that the splitting tensile strength of the geopolymer concrete is varying from 3.72MPa to 4.95MPa for the chemical ratios ranging from 0.30 to 0.50 and from the comparative study the splitting tensile strength of the geopolymer concrete is also increasing proportionate to the increase of the chemical ratio.

3.4 Flexural splitting tensile strength of the geopolymer concrete.

Similarly it is observed from the test results the flexural strength of the geopolymer concrete is varied from 5.22 MPa to 6.03 MPa with the change of the chemical ratio and from the comparative study Graphs the Flexural strength of the concrete is also increasing proportionate to the increase of the chemical ratio ranging from 0.35 to 0.50. The concentration of the sodium hydroxide is kept constant at 16 for the above specimen.

3.5 Modulus of elasticity

The modulus of elasticity values tabulated in the table revealed more than the desired/ theoretical values i.e. for M30.

4. CONCLUSIONS

1. The fresh concrete is easily being handled up to 120 minutes without any sign of setting and without any degradation in the compressive strength.
2. The investigation values obtained revealed that the geopolymer concrete is highly viscous and workable. However collapse slump is observed with a compacting factor of 0.95 and the colour of the geopolymer concrete is similar to that of the OPC concrete. The unit weight of the hardened concrete observed to be in the range of 23.55 and 24.15 kN/m^3.
3. Several trial mix proportions with 0.30 chemical ratio and molarity of the Na OH ranging from 8 to 16 were done and standard cubes of 150x150x150mm size were cast and tested for the compressive stress at the age of 28 days of their casting. Based on the test results of the trial mixes this experiment has been taken up.
4. Totally 5 mix proportions with chemical ratios ranging from 0.30 to 0.50 were adopted for the study and behavior of the geopolymer concrete and tested for the mechanical properties of the concrete. The compressive strength of the concrete is found to be ranging from 25.00 MPa to 30.00 MPa, splitting tensile strength of the concrete is found to be ranging from 4.00 MPa to 5.00 MPa. Similarly the flexural strength of the concrete is ranging from 5.00 MPa to 6.00 MPa. It is concluded that higher the concentration (in terms of Molarity) of sodium hydroxide solution results in higher compressive strength of the fly ash based geopolymer concrete.
5. Similarly the higher the ratio of alkaline solution to fly ash, i.e., chemical ratio, higher is the compressive strength of the concrete.
6. The modulus elasticity of the fly ash based geopolymer concrete is observed as on par strength when compared to conventional concrete.
7. Fly ash based geopolymer concrete in this investigation identified as an alternative structural grade concrete.

REFERENCES

1. Mc Caffrey R . Climate change and the cement industry, Global cement and lime magazine (Environmental special issue), **8**(2002) 15-9.
2. Davidovits J. et al. Process for obtaining geopolymeric alumino-silicate and products thus obtained, US patent USA 5, **342(**1994) 595.
3. Davidovits J . Green-Chemistry and Sustainable Development Granted and False Ideas About Geopolymer-Concrete. International Workshop on Geopolymers and Geopolymer Concrete (GGC), Perth, Australia, **31**(2005) 62-9.
4. Davidovits J. *Soft Mineralurgy and Geopolymers*. Paper presented at the Geopolymer, First European Conference on Soft Mineralurgy, Compiegne, France *3-5,* **88**(1988) 18-4.
5. Davidovits J. Geopolymers, Inorganic Polymeric New Materials. *Journal of Thermal Analysis* 5-12, **37**(1991) 1633-56.
6. Davidovits J. High-Alkali Cements for 21st Century Concretes. Paper presented at the V. Mohan Malhotra Symposium on Concrete Technology: Past, Present And Future, University of California, Berkeley 2-7, **13**(1994) 112-8.
7. Davidovits J. Properties of Geopolymer Cements. In Kiev (Ed.), *First International Conference on Alkaline Cements and Concretes* Kiev, Ukraine: Kiev State Technical University. 16-23, **53(**1994) 131-49.
8. Fernández-Jiménez AA. Palomo N. Characterization of fly ash and *potential reactivity as alkaline cements fuel*, 18-27, **82**(2003) 2259-65.
9. Fortune J. Global Dimming, BBC Proceedings, concrete for future construction 24-31, **73**(2005) *1235-41*.
10. Gourley JT. Geopolymers, opportunities for environmentally friendly construction materials, conference, *adaptive materials for a modern society, Sydney, Institute of materials engineering Australia,* Nos. (15-26), **49(**2003) 1455-61.
11. Malhotra, VM. Making concrete greener, with fly ash, *ACI Journal*, 17-29, **21**(1999) 61-6.