Effect of Sodium Hydroxide Concentration on Various Properties of Geopolymer Concrete

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***Abstract*— Concrete is one of the most extensively used construction material, it is commonly related with Portland cement as an essential constituent for making concrete. It leads to the release of significant amount of CO_2 and other greenhouse gases to pollute the atmosphere. Reuse and recycle of industrial solid wastes and by products in concrete is necessary to produce even "greener" concrete. The use of fly ash is more environmental friendly due to the reduced CO_2 emissions and costs compared to OPC, which requires the burning of large quantities of fuel and the decomposition of limestone and can result in significant CO2 emissions. This paper presents the study on various properties of geopolymer concrete using fly ash as a source material. NaOH and Na_2SiO_3 are used as an alkaline solution. M30 grade of geopolymer concrete with different molarities i.e; 8M, 12M and 16M were chosen. Compressive strength, flexural strength and tensile strength tests were conducted on fly ash based geopolymer concrete. Compressive strength of concrete increases with the increasing concentration from 8M to 16M.The maximum compressive strength of 40.21N/mm^2 was observed at 28 days with the alkaline liquid to fly ash ratio of 0.4. Durability test such as water absorption test is also conducted. Based on the study carried out, it can be concluded that the concrete made using geopolymer technology is environmental friendly and could be considered as part of the sustainable development.**

***Index Terms*— Geopolymer concrete; fly ash, alkaline solution, compressive strength, flexural strength, split tensile strength, water absorption.**

I. Introduction

Concrete has been the most preferred construction material for over five decades. The demand for concrete is increasing day by day all over the world due to its versatility, mould ability, high compressive strength and many more advantages. Hence the use of concrete as a construction material has increased. Production of cement depletes significant amount of natural resources and releases large volume of carbon dioxide add to the pollution of environment is a well known fact to civil engineers and environmentalists [1]. Cement production is also highly energy intensive, after steel and aluminium. On the other hand, coal burning power generation plants produce extremely large quantities of fly ash. The development of fly ash-based geopolymer concrete is in response for the need of a 'greener' concrete in order to reduce the carbon dioxide emission from the cement production [2]. According to the World Commission on Environment and Development: sustainability means "Meeting the needs of the present without compromising the ability of the future generations to meet their own needs". Sustainability is an idea for concern for the well being of our planet with continued growth and human development [3].

A. Geopolymers

The geopolymer technology was first introduced by Davidovits in 1978. Geopolymers is an inorganic polymeric materials formed by activating silica aluminum rich minerals with alkaline hydroxide or alkaline silicate solution at ambient or higher temperature level [4]. The chemical composition of geopolymer 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 minerals results in a three-dimensional polymeric chain and ring structure consisting of Si-O-Al-O bonds. The reaction of a solid aluminosilicate with a highly concentrated aqueous alkali hydroxide or silicate solution produces a synthetic alkali aluminosilicate material generically called a 'Geopolymer' [5].

B. Constituents of Geopolymer

There are two main constituents of geopolymers, namely the source materials and alkaline liquid.

Source materials

Any material that contains mostly Silicon (Si) and Aluminum (Al) in amorphous form is a possible source material for the manufacture of geopolymer. Several mineral and industrial by- product materials have been investigated in the past. The calcined source materials such as fly ash, slag, calcined kaolin demonstrated a higher compressive strength when compared to non-calcined materials [6]. Fly ash, one of the source materials for geopolymer binders, is available abundantly worldwide, but to date its utilization is limited. Currently, 90 million tonnes of fly ash are being generated annually in India. By exploring use of the fly ash based geopolymer concrete two environment related issues are tackled simultaneously i.e. the high amount of CO_2 released to the atmosphere during production of OPC and utilization of this fly ash. The production of geopolymer concrete is carried out using the conventional concrete technology methods. Fly ash does not have any binding properties by itself. The reactivity of fly ash depends on its fineness, percentage of reactive silica present in it and the quality of coal used as fuel. The fly ash based geopolymer concrete consists of 75% to 80% by mass of aggregate, which is bound by a geopolymer paste formed by the reaction of silicon and aluminum within the fly ash and the alkaline liquid made up of sodium hydroxide and sodium silicate solution with addition of superplasticiser [7]. India is also facing the problem of depletion on natural resources such as limestone which is the most important ingredient to produce cement and in turn the concrete in India. In this situation, detailed study of geopolymer concrete which is the concrete with zero cement in concrete naturally becomes very important [8].

Alkaline liquids
The most common alkaline liquid used in geopolymerisation is a combination of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3). However, potassium hydroxide and potassium silicate can also be used. Alkaline liquid plays an important role in the polymerization process [9]. Reactions occur at a high rate when the alkaline liquid contains soluble silicate, either sodium or potassium silicate, compared to the use of only alkaline hydroxides. The addition of sodium silicate solution to the sodium hydroxide solution as the alkaline liquid enhanced the reaction between the source material and the solution. Furthermore, after a study of the geopolymerisation of sixteen natural Al-Si minerals, they found that generally the NaOH solution caused a higher extent of dissolution of minerals than the KOH solution [10].

C. Objectives

There are three main objectives of this research.
1. To develop Geopolymer concrete using Fly ash as a source material.
2. To calculate the density of Geopolymer concrete.
3. To study the effect of sodium hydroxide concentration on strength and durability properties of fly ash based Geopolymer concrete.

II. EXPERIMENTAL PROGRAME

A. Materials

Fly Ash
Low calcium fly ash sample collected from Yamuna Nagar Thermal power plant having specific gravity 2.1 was used in this study. The colour of fly ash was light grey. The sample satisfied the requirements of IS 3812(Part1).
The chemical properties of fly ash are given in table 1.

Table 1: Chemical composition of Fly Ash

Constituents	Composition (%)	Requirements as per IS 3812- 2003
SiO_2	85.03	>35
Al_2O_3	10.12	
CaO	1.82	< 10
MgO	1.31	< 5
Na_2O	0.02	< 1.5
Fe_2O_3	4.70	
LOI	1.72	< 5
$SiO_2+Al_2O_3+Fe_2O_3$	99.85	> 70

Fine aggregate: Sand conforming to Zone II of IS 383-1970 having specific gravity 2.59 and fineness modulus 2.62. Water absorption and bulk density were 0.89% and 1.3kg/m^3.
Coarse aggregate: Crushed angular stone of 10mm and 20mm obtained from local quarry confirming to IS: 383-1970 having specific gravity 2.63 and 2.69, fineness modulus of 6.95 and 6.36 were used.
Water: Distilled water is used for making NaOH solution.
Alkaline Solutions: Alkaline Solution plays an important role in geopolymerisation process. In this case the mixture of Sodium Hydroxide (NaOH) was purchased from V.K Chemicals & Instruments Ambala and Sodium Silicate (Na_2SiO_3) was purchased from Ambala Silicate Udyog were used. Sodium hydroxide in pellets form with 98% purity and Sodium silicate solution having composition of SiO_2 = 30.04%, Na_2O = 9.5% and water = 60.1% by mass were used as the alkaline activators. The other characteristics of the sodium silicate solution were specific gravity=1.36 g/cc, melting point = 1300^{o}C and viscosity at 20^{o}C=58 cp. In order to make sodium hydroxide solution, sodium hydroxide pellets were dissolved in potable water. Both the liquid solutions were then mixed together and alkaline solution was prepared.
Superplasticiser: Addition of superplasticiser to concrete mix reduces its water reducing efficiency. A dosage of 1 to 3 percent by weight of cement is advisable depending on the solid content of the mixture. Sulphonated naphthalene formaldehyde superplasticiser has been used for obtaining workable concrete at low w/c ratio.

B. Mix proportions

In this experimental work, M30 grade of geopolymer concrete was prepared with three different molarities of sodium hydroxide solutions i.e; 8M, 12M and 16M. The Molecular weight of Sodium hydroxide is 40gm. Sodium hydroxide is prepared by dissolving pellets in water. The mass of NaOH varied depending on the concentration of solution. Ratio of Sodium hydroxide to Sodium silicate used in this study is 2.5.

Fig 1: Mixing of alkaline solution

To prepare 8M Sodium Hydroxide solution, 320 grams of NaOH pellets are weighed and can be dissolved in distilled water to form 1 liter solution. Firstly, take the volumetric flask of I liter capacity, sodium hydroxide pellets are added slowly to distilled water to prepare 1 liter solution. The mass of NaOH solids for 98% purity was measured as 260 grams per kg of NaOH solution of 8M concentration. Similarly, the mass of NaOH solids per kg of the solution for other concentrations were measured as 12M: 361 grams and 16M: 444 grams. The alkaline solution is prepared 24 hours before the casting.
The weights to be added to get required molarity are given in table 2.

Table 2: Weight of NaOH pellets

Required Molarity	Weight of NaOH in grams
8M	260
12M	361
16M	444

As such there are no code provisions for the mix design of geopolymer concrete, the density of geopolymer concrete is assumed as 2400 Kg/m^3. The rest of the calculations are done by considering the density of concrete. The total volume occupied by fine and coarse aggregate is adopted as 75%. The alkaline liquid to fly ash ratio is kept as 0.4. The ratio of sodium hydroxide to sodium silicate is kept as 2.5.The conventional method used in the making of normal concrete is adopted to prepare geopolymer concrete.

C. Casting and Curing

The fly ash and the aggregates were first mixed together for about 3-4 minutes. Superplasticizer is then added and should be taken as 1.5% of the cementitious material. The liquid component of the mixture i.e. alkaline liquid prepared one day before casting, was then added to the dry materials and the mixing continued for further about 6-8 minutes to manufacture the fresh concrete. The fresh concrete could be handled up to 120 minutes without any sign of setting and without any degradation in the compressive strength. The cubes of size 150x150x150 mm, 100x100x100 mm, cylinder of size (π/4) x 150x150x300 and beam of size 100 x 100 x 500mm were casted for geopolymer concrete. The geopolymer concrete was placed in the moulds and compacted by manual strokes and thereafter on vibrating table. All specimens were heat cured in an oven at 65^0C. After that the specimens were removed from the moulds and taken out from oven. The specimens are left open to air up to the testing. The fly ash-based geopolymer concrete did not harden immediately at room temperature.

D. Quantity of Materials required in $1m^3$ of Concrete

Several mix designs were proposed for geopolymer concrete. The mix design for the investigation is adopted from the journal "strength characteristics of low calcium fly ash based geopolymer concrete" [11]. Quantity of materials required in 1 m^3 of concrete is shown in the Table 3.

Table 3: Optimum mix proportion of geopolymer concrete

Materials		Mass (kg/m^3)	Amount required (kg)
Fly ash		428.57	43.73
Coarse aggregate	20mm	819	83.58
	10mm	441	45.01
Fine aggregate		540	55.11
Sodium hydroxide		48.97	4.99
Sodium silicate solution		122.44	12.49
Superplasticiser		6.42	0.655
Extra water		42.8	4.36

III. RESULTS AND DISCUSSION

The various strength tests that are to be done listed as below.

- Slump test
- Compressive strength
- Split tensile strength
- Flexural strength
- Water absorption

A. Slump test

The results of slump test is tabulated in table 4 and plotted in fig 2.

Table 4.4 states that slump increases with increasing the molarity of geopolymer concrete with respect to reference mix. Generally workability decreases with increasing the concentration of NaOH in geopolymer concrete. Maximum slump was recorded for mix M_3. Maximum slump loss was obtained for mix M_1.

Table 4: Slump value for different mixes

Mix	Molarity	Slump (mm)
M1	8M	35
M2	12M	100
M3	16M	145

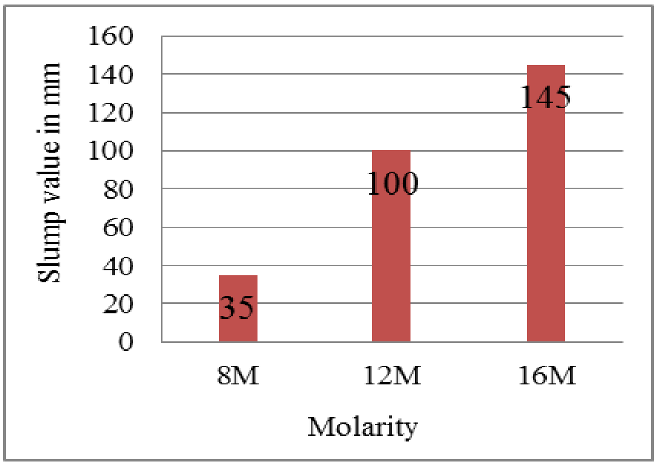

Fig2: Slump value for all mixes of M30 grade GPC

B. Compressive strength test

The compression tests on cubes were conducted according to Indian Standard specifications (IS: 516 – 1959). The variation in compressive strength at 7 and 28 days are listed in Table 5. From the test results, it was observed that the compressive strength increases with the increase of molarities. The maximum compressive strength was observed in M3 at 28 days.

Table 5: Compressive strength of geopolymer concrete

Mix	Molarity	Average Compressive strength (N/mm^2)	
		7 days	28 days
M1	8M	24.58	32.36
M2	12M	26.14	37.25
M3	16M	27.84	40.21

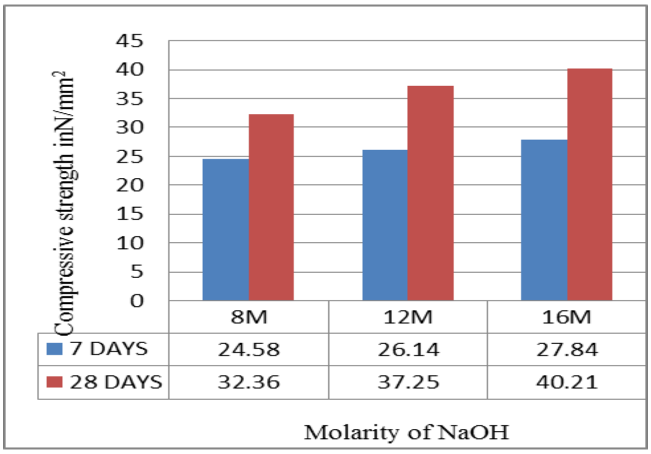

Fig 3: Compressive strength of M30 grade GPC

C. Split tensile strength

The variation of split tensile strength at the age of 7 and 28 days were given below. From the test results, it was observed that with the increase in concentration of sodium hydroxide, the split tensile strength of geopolymer concrete increases for all cases. The maximum tensile strength of geopolymer concrete was observed in M3 at 28 days.

Table 6: Tensile strength of geopolymer concrete

Mix	Molarity	Average Tensile strength (N/mm^2)	
		7 days	28 days
M1	8M	2.42	3.27
M2	12M	2.56	4.00
M3	16M	2.70	4.31

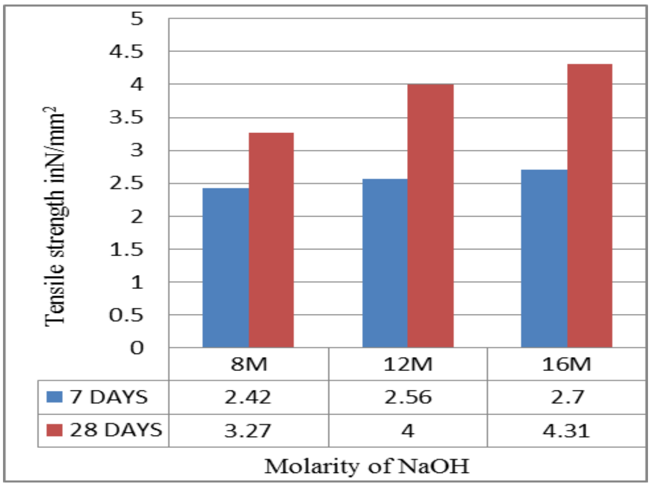

Fig 4: Tensile strength of M30 grade GPC

D. Flexural strength

The results of flexural strength of concrete at the age of 7 and 28 days are presented in Table 7. The variations in flexural strength at the age of 28 days with different concentration of NaOH were plotted .From the test results, it was observed that concentration of NaOH increases, the flexural strength of concrete also increases. The maximum flexural strength of geopolymer concrete was observed in M3.

Table 7: Flexural strength of geopolymer concrete

Mix	Molarity	Average Flexural strength (N/mm^2)	
		7 days	28 days
M1	8M	5.38	6
M2	12M	5.78	6.5
M3	16M	6.1	7.1

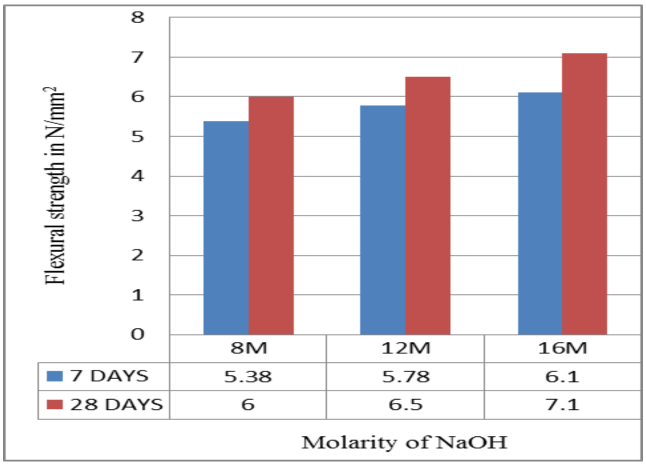

Fig 5: Flexural strength of M30 grade GPC

E. Water absorption

Table 8 and Fig 6 shows the results of water absorption test at 28 days. The increase in water absorption was observed at 28 days with increase in NaOH concentration from 8M to 16M. The maximum water absorption was observed in M3.

Table 8: Water absorption of geopolymer concrete

Mix	Molarity	Average %age of water absorption at 28 days
M1	8M	3.00
M2	12M	3.20
M3	16M	3.79

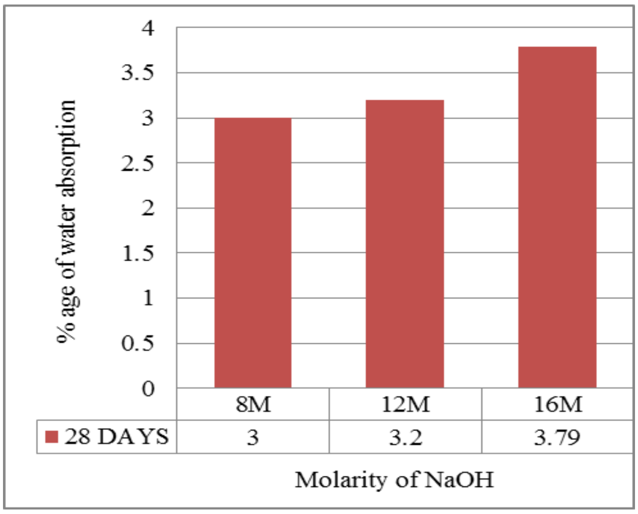

Fig 6: %age of water absorption of M30 grade GPC

IV. CONCLUSIONS

[1] M30 grade geopolymer concrete can be formed by adopting nominal mix of 1:1.26:2.94 (fly ash: fine aggregates: coarse aggregates) and fixing alkaline liquid to fly ash ratio as 0.4.

[2] The fresh fly ash based geopolymer concrete is easily handled up to 120 minutes without any sign of setting and without any degradation in the compressive strength.

[3] Compressive strength of geopolymer concrete increases with increase in molarity of sodium hydroxide (NaOH) solution.

[4] Increasing the concentration of NaOH from 8 M to 12 M resulted in an enhancement of compressive strength by about 15.6% and 48.9% for 7 days and 28 days respectively under heat curing in an oven at 65^0C temperature.

[5] When the concentration of NaOH solution is further increased from 12 M to 16 M, the compressive strength also increases by about 17% and 29.6% for both 7 days and 28 days.

[6] The maximum compressive strength of 40.21N/mm^2 was observed in 16M concentration of NaOH at 28 days. Increasing the concentration of NaOH solution from 8 M to 12 M resulted in an enhancement of split tensile strength by about 14% and 73% for 7 days and 28 days respectively.

[7] When the concentration of NaOH solution is further increased from 12 M to 16 M, the split tensile strength also increases by about 14% and 31% for 7 days and 28 days respectively.

[8] Increasing the concentration of NaOH solution from 8 M to 12 M resulted in an improvement of flexural strength by about 40% and 50% at 7 days and 28 days under heat curing at 65^0c temperature in an oven.

[9] The flexural strength also increases by about 32% and 60% at 7 days and 28 days when the concentration of NaOH solution is further increased from 12 M to 16 M.

[10]The increase in water absorption was observed at 28 days with increase in NaOH concentration from 8M to 16M.

[11]The average increase in percentage of water absorption was observed as 32% from 8M to 12M and 59% for 12M to16M concentration.

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