

# Experimental Investigation on Flyash Based Geopolymer Concrete

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## **ABSTRACT**

Finding means of utilizing waste products is a very important field of research at the moment. In this study, fly ash, a waste product of the electricity and petrochemical industries, was investigated as a basic ingredient of a new geopolymeric material. The similarity of fly ash to natural pozzolon as has encouraged the use of this waste product in the synthesis of geopolymers, which, in turn, can best be viewed as consisting of a polymeric Si–O–Al framework. Manufacturing of the geopolymers was conducted by mixing fly ash, sodium silicate solution, NaOH and water. The samples were cured at 40, 50, 60 and 70 degree Centigrade for different time intervals (6, 24, 48 and 72 h). The optimum condition was found to be at 60 degree Centigrade for a period of 48 h. Compressive strength measurements show a maximum strength of almost 8 MPa after 28 days.

In this study fly-ash was utilized as the base material for making geopolymer concrete. The fly-ash was produced from only one source, i.e. from a local power station RTPS (Ramagundam thermal power station) and distributed by Ashok Manufacturers, Kurnool District. It conformed to Grade I of IS 3812 : 1981. It was tested in accordance with IS 1727-1967 and IS 3812-1992. A combination of sodium silicate and sodium hydroxide solutions was used as activator. The

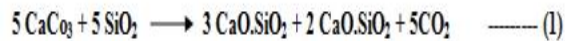
technology and the equipment currently used to manufacture OPC concrete were used to make the geopolymer concrete.

The concrete properties studied include the compressive strength, flexural strength and workability of fresh concrete. Compressive strength test is performed at the age of 3, 7, 21 and 28 days.

## **INTRODUCTION**

To produce one tonne of ordinary Portland cement about 1.5 tonnes of raw materials are acquired and at the same time one tonne of carbon dioxide (CO<sub>2</sub>) is released into the environment. Therefore the production of Portland cement is extremely resources and energy intensive process. In this circumstance, an inorganic alumino silicate polymer called geopolymer was introduced as binder material instead of cement paste. The geopolymer paste binds fine, coarse aggregates and other unreacted materials together to form the geopolymer mortar. As in the Portland cement mortar, the aggregates occupy the largest volume of nearly 75 to 80% by mass in the geopolymer mortar also. Fly ash is used which is rich in silica and alumina, further fly ash is a byproduct of thermal power station and it is abundantly available. Silica and alumina in fly ash are activated by a alkaline liquid i.e. combination of sodium hydroxide and sodium silicate solutions to form the geopolymer paste.

De-carbonation of lime stone in the kiln during manufacturing of cement is responsible for the liberation of one ton of carbon dioxide into the atmosphere for the production of each ton of Portland cement, as can be seen from the following reaction equation:



World wide, the estimated production of coal ash in 1998 was more than 390 million tons. Only about 14% of this fly ash was utilized, while the rest was just disposed off in landfills. By the year 2010, the amount of fly-ash produced worldwide is estimated to be about 780 million tons annually. Ordinary Portland cement (OPC) is conventionally used as the primary binder to produce concrete. On the other hand, when fly-ash is used as a partial replacement of OPC, in the presence of water and in ambient temperature, fly-ash reacts with the calcium hydroxide during the hydration process of OPC to form the calcium silicate hydrate (C-S-H) gel. The development and application of high volume fly-ash concrete, which enabled the replacement of OPC up to 60% by mass has been a significant development.

**Table-1 :-**Production of cement in major countries for 1975 and 1990.

	1975		1990	kg per capita
World total	719	World total	719	221
1 USSR	122	1. China	208	184
2 Japan	65	2. USSR	137	463
3 USA	59	3. Japan	85	680
4 China	47	4. USA	69	322
5 Italy	34	5. India	47	58
6 W Germany	33	6. Italy	41	750
7 France	29	7. South Korea	33	687
8 Spain	24	8. Spain	28	704
9 Poland	18	9. W. Germany	2	420
10 Brazil	17	10. Brazil	26	179
11 UK	17	11. France	26	448
12 India	16	12. Turkey	24	420
		13. Mexico	24	255
		14. Taiwan	19	905
		15. Thailand	18	340

Assuming 2.5 to 5% yearly increase in world cement-carbon dioxide production, there will be 3500 million tones (M.T) of carbon dioxide emission at 2015. This address the need for solution and new

technologies adopted to the economy of the developing countries.

Two traditional methods may help reduce chemical CO<sub>2</sub> emission in cement in cement manufacture.

- (1) Re absorption of atmospheric carbon – dioxide during the carbonation of Concrete.
- (2) Blending of Portland cement with industrial by product.

### Blending of Portland cement

The search for Portland cement replacement material has become a challenge for the international cement community. These minerals are either of natural origin, like natural pozzolonas or industrial by products. Some times considered as waste like blast furnace slag and fly ash, a residue of the combustion of the finely ground coal in the generation of Portland cement. With these animals additives has been intensively studied for over thirty years in several laboratories.

### Natural pozzolonas

True pozzolonas are vitreous pluralistic materials produced by violent eruptive volcanic action. The ancient Romans used natural pozzolonas for producing their famous roman cement, obtained by blending lime and pozzolonas, properties of the blended cements obtained by replacing a certain amount of Portland cement with natural zeolitic tuffs, have been studied and in use in some countries china, for example, is presently producing 70 million tons of cement containing 10% to 30% of zeolite material. The extraction of 15-20 million tons of zeolites in china equals the port land cement production of the United Kingdom. In terms of mechanical strength, the highest replacement is in the 30% range.

### Iron Blast furnace slag

Blast furnace slag is formed in processes such as pig iron manufacture from iron ore,

combustion residue of coke, and fluxes such as limestone or serpentine and other materials. If the molten slag is fast-cooled by high-pressure water, a vitreous Ca–Al–Mg silicate fine grain glass is formed. Generally, the way to utilize granulated blast furnace slag is in partially replacing Portland cement.

### Alkali-activated/alkaline cements

In this treatment, we will discuss both alkali-activated systems and materials for which the “activator” becomes a more essential component of the product. The discussion is organized as follows, with a major emphasis on the history/background leading to the current state of knowledge and need for future developments: history/background, status of current knowledge, systems/materials, mechanisms, characterization, properties, and new methods of study, applications, needed knowledge, and future directions. The last century has focused quite properly its technology on Portland cements, those cementitious materials based on compositions in the MeO-Me<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub> system. Concentrating on the development of binding systems consisting of the high calcium content minerals, C<sub>3</sub>S, C<sub>2</sub>S, C<sub>3</sub>A, and C<sub>4</sub>AF. These systems have served well, but not without some drawbacks: synthesis of high CaO minerals involves large fuel and energy consumption.

$$5 \text{CaCO}_3 + 5 \text{SiO}_2 \longrightarrow 3 \text{CaO} \cdot \text{SiO}_2 + 2 \text{CaO} \cdot \text{SiO}_2 + 5 \text{CO}_2$$
and the use of fossil fuel in the kiln. The production of 1 ton of Portland cement accounts for 1 ton of CO<sub>2</sub>. Furthermore, there are certain limitations regarding the durability of the Concrete products.

### Alkali-activated fly ashes

The alkali activation of waste materials (especially those coming from industrial and mining activities) has become an important area of research in many laboratories because it is possible to use these materials to synthesize

inexpensive and ecologically sound cement like construction materials. Davidovits described the alkali activation process of metakaolin in terms of a polymerical model. Temperature and time of curing of specimens together with the solution/fly ash ratio are some of the variables that were studied. These variables have been shown to notably influence the development of the mechanical strength of the final product. Mechanical strengths with values in the 60 MPa range were obtained after curing the fly ash at 85 °C for only 5 hours.

### Geopolymerisation of multiple minerals

Geopolymerisation is being considered for replacing traditional structural materials and offers a possible solution to the immobilization of toxic and radioactive wastes as well as the treatment of industrial wastes to produce value added construction materials. Therefore, there is an increasing need for multiple source materials to be jointly geopolymerised to maximally exploit the respective properties of the individual sources regarding compressive strength, stability and durability. Previous research has shown that the strength of geopolymers is dependent on the nature of the source materials.

### Aggregate grading

An aggregate grading that yields maximum solid density and maximum particle interlock is highly desirable for both bound mixtures, such as plain and reinforced concrete, and for unbound mixtures such as those used in base courses. Maximum particle interlock leads to high strength. Whereas minimum voids in a certain material composition is conducive to high strength and low compression. Aggregate grading may be obtained, for instance, from the ASTM, which is based on laboratory tests. Durability is the most important property for asphalt concrete pavements. Durability is the resistance of Asphalt pavements to

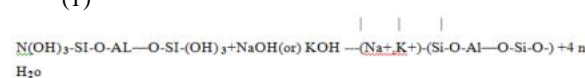
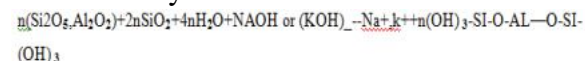
the action of temperature and temperature changes, action of air and water, and the action of traffic.

### The effect of composition and temperature on the properties of fly ash based geopolymers

Geopolymers are the synthetic analogues of natural zeolitic materials. Geo-polymeric materials possess excellent mechanical properties, including fire and acid resistance. These properties make geo-polymers an alternative construction material compared to Portland cement, and as a consequence, geo-polymer technology has attracted a great deal of attention internationally in the past 20 years.

### The geopolymerisation of aluminosilicate minerals

Geopolymers are similar to zeolites in chemical composition, but they reveal an amorphous microstructure. They form by the co-polymerisation of individual aluminosilicate species, which originate from the dissolution of silicon and aluminium containing source materials at a high pH in the presence of soluble alkali metal silicates. Since 1978, Joseph Davidovits has developed amorphous to semi-crystalline three-dimensional aluminosilicate materials, which he called "geopolymers" (mineral polymers resulting from geochemistry). Geopolymerisation involves a chemical reaction between various aluminosilicate oxides with silicates under highly alkaline conditions, yielding polymeric Si-O-Al-O bonds, which can be presented schematically as follows:



The above two reaction paths indicate that any Si-Al materials might become sources of geopolymerisation. According to Davidovits (1994), geopolymeric binders are the amorphous analogues of zeolites and require similar hydrothermal synthesis conditions. Reaction times, however, are substantially faster, which results in amorphous to semi-crystalline matrices compared with the highly crystalline and regular zeolitic structures. The electron diffraction analysis conducted by Van Jaarsveld et al. (1999) showed that the structure of geopolymers is amorphous to semi-amorphous. In aluminosilicate structures silicon is always 4 coordinated, while aluminium ions can be 4 or 6 coordinated. It is possible that the coordination number of aluminium in the starting materials will have an effect on its eventual bonding in the matrix.

### Pozzolonic activity

Fly Ash (FÁ) exhibits pozzolonic activity. A pozzolon is defined as a siliceous and aluminous mixture which in itself possesses little or no cementing properties but which will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementing properties. Pozzolonic activity is mostly related to the reaction between the reactive silica and the alumina of the pozzolon and calcium hydroxide.

### Advantages of geopolymer concrete

Compared with Portland cement, Geo-polymer concrete possesses the following characters.

### Abundant raw material resources:

Any pozzolonic compound or source of silicates or aluminosilicates that is readily dissolved in alkaline solution will

sufficient as a source of the production of geo-polymer. fly-ash has great potential as a cement replacement material in concrete.

### **Energy saving and environment protection:**

Geo-polymer do not require large energy consumption thermal processing of natural aluminosilicates at relative low temperature (600°C to 800°C ) provides suitable geopolymeric raw materials resulting in 3/5 less energy consumption than Portland cement in addition, a little CO<sub>2</sub> is emitted.

### **Simple preparation techniques:**

Geo-polymer can be synthesized simple by mixing aluminosilicate reactive material and strongly alkaline solutions, then curing at room temperature. In a short period a reasonable strength will be gained. It is very similar to the preparation of Portland cement concrete.

### **Reasonable strength gain In short time:**

Geo-polymer can obtain 70% of the final compressive strength in first 4 hours of setting.

### **Reduction in water demand of large volumes of fly ash**

The International Centre for Sustainable Development of Cement and Concrete (ICON), CANMET has an ongoing research project dealing with the use of large volumes of fly ash in concrete. The concrete so developed has become known as high-volume fly ash (HVFA) concrete. The air-entrained HVFA concrete has a low water-to-cementitious ratio of about 0.30, and the replacement of cement by fly ash is about 55% by mass basis. The high slumps are achieved by using large dosages of super plasticizers. However, in developing countries, the super plasticizers are relatively expensive. Fly ash utilization could be increased in developing countries if less costly super plasticizers were developed or if mixtures proportions were

refined to preclude the need for super plasticizers.

### **Durability:**

Geo-polymer concrete can withstand longer than Portland concrete.

### **High fire resistance and low thermal conductivity:**

Geo-polymer can withstand 1000 °C to 1200 °C without losing functions. The heat conductivity of geo-polymer varies from 0.2 w/m-k to 0.3w/m-k compared well with light weight refractory bricks (0.3w/m-k to .438w/m-k). Geo-polymer with properties such as abundant raw source, little CO<sub>2</sub> emission, less energy consumption, low production cost, high early strength, fast setting. These properties make geo polymer find great application in many fields of industry such as civil engineering automotive and aerospace industries, non-ferrous foundries, metallurgy, plastic industries waste management and decoration and retrofit of buildings.

### **Global warming :**

It is well known that a great amount of CO<sub>2</sub> is emitted during the production of Portland cement which is one of the main reason for the global warming. Studies have been shown that one tone of carbon dioxide gas released in to the atmosphere for every ton of production of Portland cement , which is made anywhere in the world. In contrast geo-polymer cement is manufactured in different ways than that of Portland cement. It does not require extreme high temperature treatment of lime stone. Only low temperature processing of naturally occurring as directly man made aluminosilicates provides suitable geo-polymeric raw materials. These leads to the significant reduce in the energy consumption and the CO<sub>2</sub> emission. It is reported by Davidovits that about less 3/5 energy was required and 80 to 90% less CO<sub>2</sub> is generated for the production of geo-polymer than that of Portland cement. Thus it is of great

significance in environmental protection for the development and application of geopolymer cement.

### **Fly-ash-based geopolymer concrete**

With Silicon (Si) and Aluminum (Al) as the main constituents, fly-ash has great potential as a cement replacement material in concrete. To replace the use of Portland cement (PC) as a concrete binder totally, fly-ash needs to be usually activated using alkaline solutions. The chemical process in this case is polymerization. In this work, fly-ash-based geopolymer is used as the binder, instead of Portland or other hydraulic cement paste, to produce concrete.

As in the case of OPC concrete, the aggregates occupy about 75-80 % by mass, in geopolymer concrete. The silica (SiO<sub>2</sub>) and the alumina (Al<sub>2</sub>O<sub>3</sub>) in the fly-ash react with an alkaline liquid, a combination of sodium silicate and sodium hydroxide solutions, to form the geopolymer paste that binds the aggregates and other unreacted materials.

### **Past research on geopolymer material**

In geopolymers, the polymerization process involves a chemical reaction under highly alkaline conditions on Si-Al minerals, yielding polymeric Si-O-Al-O bonds. The chemical composition of geopolymers is similar to Zeolites, but shows an amorphous micro structure. The mechanism of geopolymerisation may consist of dissolution, transportation or orientation and polycondensation and takes place through an exothermic process, as described by



Where,

- M is the alkaline element,
- indicates the presence of a bond,
- Z takes the values 1, 2 or 3,
- n is the degree of polymerization.

The strength of geopolymer depends on the nature of source materials,. Geopolymers made from calcined source

materials, such as metakaolin (calcined kaolin), fly-ash, slag etc., yield higher compressive strength when compared to those synthesized from non-calcined materials, such as kaolin clay. A combination of sodium or potassium silicate and sodium or potassium hydroxide has been widely used as the alkaline activator. Because heat is a reaction accelerator, curing of a fresh geopolymer is carried out mostly at an elevated temperature.

### **Scope of work**

In this study fly-ash was utilized as the base material for making geopolymer concrete. The fly-ash was obtained from only one source, i.e. from the RTPPS. It conformed to Grade I of IS 3812 : 1981. It was tested in accordance with IS 1727-1967 and IS 3812-1992. The technology and the equipment currently used to manufacture OPC concrete were used to make the geopolymer concrete.

The concrete properties studied include the compressive strength, flexural strength and workability of fresh concrete.

### **Fly-ash**

Fly-ash is defined in cement and concrete terminology (AC Committee 116) as 'the finely divided residue resulting from the combustion of ground or powdered coal, which is transported from the fire-box through the boiler by flue gases'. Fly-ash is a by-product of coal-fired electricity generating plants.

Fly-ash is sometimes called pulverized-fuel ash. It is a general term, which also includes coarser boiler bottom-ash and economizer-ash. Approximately 20% of the ash particles formed in a pulverized fuel boiler, aggregate into larger particles by fusion and get deposited at the bottom of the boiler and hence called bottom-ash. In general, in view of the stringent environmental norms, and also due to the high ash content in typical Indian

coals, electro-static precipitators (ESPs) with efficiency of 99.9% are usually employed. In ESP, static electricity is employed to initially charge the fly-ash particles and then to collect them on oppositely charged plates.

### Types of fly-ash

Certain coals contain significant proportion of lime (CaO) content, in them which results in high lime content in fly-ash. Depending on the lime content, fly-ash is categorized as low-calcium fly-ash (CaO<10%) and high-calcium fly-ash (CaO>10%). High-lime fly-ashes possess some cementing properties in addition to pozzolonic properties.

### Composition of fly-ash

Traditionally, the composition of fly-ash is expressed in terms of oxide composition, though there are constituents other than oxides also. The temperature in a pulverized fuel boiler would be around 1400 °C and the fuel gas velocity is such that the ash particles are removed out of the boiler rapidly, due to the rapid cooling of the fly-ash particles, they are mostly in glassy phase which is responsible for the reaction with Ca(OH)<sub>2</sub> and hence these particles have pozzolonic activity.

### Physical properties of fly-ash

Physically on a micro-scale, fly-ash particles are mostly spherical glassy articles of size ranging from 1 μ to 300 μ. The size distribution of the particles which denote the fineness of the fly-ash depends on the method of collection. Another method of measuring fineness is by weight of fly-ash retained on a certain sieve size, usually 45 μ, expressed in percentage terms. The specific gravity of fly-ash particles ranges from 2.0 to 2.4 depending on the source of coal. The loose bulk density ranges from 800 to 1000 kg/m<sup>3</sup>.

### Properties of fly-ash

#### Fineness:

It has been proved that the fineness of fly-ash broadly controls the water requirements, pozzolonic activity index and

workability. Though conventionally fineness is expressed in terms of surface area, the reliability of the method in correctly representing fineness is doubtful due to the wide range in density and porosity of the individual particles. In the proposed draft revision of Indian standard IS 3812, fly-ash is classified into two grades based on retention on 45 μ and other considerations. For practical applications such a method is quite simple, relatively reliable and economical.

**Loss-on-ignition:** This is essentially a measure of the unburnt carbon present in the fly-ash. The residual carbon content in the fly-ash depends on the operating conditions of the boiler. Carbon content in the fly-ash has the effect of — increasing the water requirement because of high porosity of carbon particles, reducing fineness and hence pozzolonic activity.

However there is a difference in opinion about the latter effect. Fly-ashes containing up to 12% loss on ignition were permitted for use in concrete in the standards, though presently it is being limited to 5-6%.

**Major oxides:** The potential reactive constituent of the fly-ash is the glassy content. The amount present influences the pozzolonic activity of fly-ash. Silica present in fly-ash, which is vitreous in nature is readily soluble in alkaline liquids and hence reacts with lime contributing to the pozzolonic activity of the fly-ash. There has been a general hypothesis that more the silica in the fly-ash, better is its pozzolonic property. Indian fly-ashes typically contain lesser soluble silica, in the range of 20 – 32%. Evidence shows that reactive alumina, which is present in Indian fly-ashes to a good extent, helps in the pozzolonic reaction. The draft revision of IS 3812 stipulates a minimum content of soluble silica of 35% in addition to specifying a minimum of 70% of silica + iron oxide + alumina by mass.

**Moisture content and weathering of fly-ash:**

Fly-ash particles, being hygroscopic in nature, attract moisture when exposed to atmosphere. However this moisture is not detrimental to the concrete. On the other hand, fly-ash is mixed with water and disposed off in slurry form for safe storage in ash-ponds. But such ash is found to have lost its pozzolonic property. The exact mechanism underlying this effect has not been established but has been traced to weathering of the ash and possibly to the loss of some portion of soluble silica present in the ash..

**EXPERIMENTAL INVESTIGATIONS**

**Study of materials used**

**Fly-ash**

In the present investigation work, the fly-ash used was obtained from Ramagundam Thermal Power Station in Andhra Pradesh (RTPS). Specific-gravity of fly-ash was found to be 2 to 2.5 Table 3.1 gives the chemical composition of fly-ash obtained from RTPS, which shows that the fly-ash used conforms to the various specifications of IS : 3812-1281.

**Fine aggregate:**

In the present investigations, river sand available in the local market was used as fine aggregate. The physical properties of fine aggregate such as gradation, specific gravity and bulk density were tested in accordance with IS : 2386-1963. These properties are listed in Tables 3.2 and 3.3. The gradation curve of the aggregate is shown in Fig.5.1

**Coarse aggregate:**

The coarse aggregate used in the investigations was of two sizes viz. 20mm and 6mm. The crushed coarse aggregate was obtained from the local crushing plants. The physical properties of the coarse aggregate such as gradation, fineness modulus, specific gravity and bulk density were tested in accordance with IS : 2386-1963 and IS : 383-1970. These properties are listed in Tables 3.4, 3.5, 3.6

and 3.7. The gradation curves of the aggregates are shown in Fig-5.2 and Fig-5.3.

**Super plasticizer:**

These days, super plasticizers are powerful enough to keep concrete mix highly workable for more time with much less water quantity. The use of super plasticizer is practiced for production of flowing, self-leveling and self-compacting concrete and for the production of high strength and high performance concrete. It is observed that fly-ash concrete is much stiff, resulting in decrease in workability. So naphthalene based super plasticizer with a brand name CONPLAST-SP430 was used in the preparation of fly-ash concrete.

**Water:**

This is the least expensive but most important component of concrete. The water, which is used for making concrete, should be clean and free from harmful impurities such as oil, alkali, acid etc. In general the water, which is fit for drinking, should be used for making concrete. To avoid the impurities distilled water was used in the experiments.

**Pre-experimental investigations**

**Fly-ash:**

In the present investigation work, the fly-ash used was obtained from Ramagundam Thermal Power Station in Andhra Pradesh. Chemical analysis of fly-ash is shown in Table 3.1 which shows that fly-ash conforms to the various specifications of IS : 3812-1987.

**TABLE 3.1:**

The oxide composition of fly-ash used:

S.No.	Characteristics	Quantity present in the fly-ash used percent by mass.
1	SiO <sub>2</sub> +Al <sub>2</sub> O <sub>3</sub> +Fe <sub>2</sub> O <sub>3</sub>	92.65
2	SiO <sub>2</sub>	61.18
3	MgO	NOT FOUND
4	Total sulphur as SO <sub>3</sub>	NOT FOUND
5	Available alkali as Na <sub>2</sub> O	0.051
6	Loss-on-Ignition	1.63

**Fine aggregate:**

Natural sand obtained from the local market was used as fine aggregate. The physical properties of fine aggregate like specific gravity, bulk density, gradation and



fineness modulus were tested in accordance with IS : 2386.

**TABLE 3.2:**

**Fineness modulus:** Sieve analysis results for fine aggregate

Weight of sample taken = 1kg.

S.No.	IS sieve size	Weight retained in gms	% weight retained	Cumulative % weight retained	% passing
1	40 mm	0	0	0	100
2	20 mm	0	0	0	100
3	10 mm	0	0	0	100
4	4.75 mm	3.0	0.3	0.3	99.7
5	2.36 mm	10.5	1.05	1.35	98.65
6	1.18 mm	74.0	7.4	8.75	91.25
7	600 µm	260.5	26.05	34.8	65.2
8	300 µm	512	51.2	86	14
9	150 µm	99	9.9	95.9	4.1

Fineness modulus of fine aggregate = 2.271

**TABLE 3.3:**

**Physical properties of fine aggregate:**

S.No.	Properties	Results
1	Fineness modulus	2.271
2	Specific gravity	2.43
3	Bulk density in loose state	1646.6kg/m <sup>3</sup>

**Coarse aggregate:**

The crushed coarse aggregates of 20mm and 6mm maximum size obtained from the local crushing plants were used in the present investigation. The physical properties of coarse aggregate such as specific gravity, gradation, and fineness modulus were tested in accordance with IS : 2386.

**TABLE 3.4:**

**Fineness modulus:**

Sieve analysis results for coarse aggregate of size 20mm

Weight of sample taken = 5kgs.

S.No.	IS sieve size	Weight retained in gms	% weight retained	Cumulative % weight retained	% passing
1	40 mm	0	0	0	100
2	20 mm	317	6.34	6.34	93.66
3	10 mm	4669	93.38	99.72	0.28
4	4.75 mm	14	0.28	100	0
5	2.36 mm	0	0	100	0
6	1.18 mm	0	0	100	0
7	600 µm	0	0	100	0
8	300 µm	0	0	100	0
9	150 µm	0	0	100	0

Fineness modulus of coarse aggregate of size 20mm is 7.0606

**TABLE 3.5:**

**Physical properties of coarse aggregate of size 20mm:**

S.No.	Properties	Results
1	Fineness modulus	7.0606
2	Specific gravity	2.637
3	Bulk density in loose state	1564.5 kg/m <sup>3</sup>

**TABLE 3.6:**

**Fineness modulus:**

Sieve analysis results for coarse aggregate of size 6mm

Weight of sample taken = 5kgs.

S.No.	IS sieve size	Weight retained in gms	% weight retained	Cumulative % weight retained	% passing
1	40 mm	0	0	0	100
2	20 mm	0	0	0	100
3	10 mm	86	1.7	1.72	98.28
4	4.75 mm	4138	82.76	84.48	15.52
5	2.36 mm	656	13.12	97.6	2.4
6	1.18 mm	47	0.94	98.54	1.46
7	600 µm	73	1.46	100	0
8	300 µm	0	0	100	0
9	150 µm	0	0	100	0

Fineness modulus of coarse aggregate of size 6mm is = 5.8234

**TABLE 3.7:**

**Physical properties of coarse aggregate of size 6mm:**

S.No.	Properties	Results
1	Fineness modulus	5.8234
2	Specific gravity	2.63
3	Bulk density in loose state	1522 kg/m <sup>3</sup>

**TABLE 3.8:**

**Combined fineness modulus:**

Sand : Coarse aggregate (6mm) : coarse aggregate (20mm) = 0.4 : 0.3 : 0.3

S.No.	IS sieve size	Weight retained in gms			Total %wt retained	Cumulative % weight retained	% passing
		Sand (0.4)	C.A 6mm (0.3)	C.A 20mm (0.3)			
1	40 mm	0	0	0	0	0	100
2	20 mm	0	0	6.34	1.902	1.902	98.098
3	10 mm	0	1.72	93.38	28.3	30.432	69.568
4	4.75 mm	0.3	82.76	0.28	25.032	55.464	44.536
5	2.36 mm	1.05	13.12	0	4.356	59.82	40.18
6	1.18 mm	7.4	0.94	0	3.242	63.062	36.938
7	600 µm	26.05	1.46	0	10.858	73.92	26.08
8	300 µm	51.2	0	0	20.48	94.4	5.6
9	150 µm	9.9	0	0	3.96	93.6	1.64

Combined fineness modulus = 4.773

**Alkaline solution:**

The sodium hydroxide used in this experiment was in flake form and of 98% purity. The sodium silicate solution used was obtained at a local chemist. The composition of the solution is Na<sub>2</sub>O=12.65%, SiO<sub>2</sub>=29.93%, H<sub>2</sub>O=56.42% by mass.

**Water:**

Locally available distilled water was used.

**Working procedure:**

- In the present experimental program, low-calcium dry fly-ash obtained from the silos at a local power station was used as the base material. And small quantity of cement obtained from local available market is also used.

- Analytical grade sodium hydroxide in flakes form (NaOH of 98% purity) and sodium silicate solution ( $\text{Na}_2\text{O}$ =12.65%,  $\text{SiO}_2$ =29.93% and water = 56.42% by mass), were used as the alkaline activators.
- To avoid the effect of unknown contaminants in the mixing water, the sodium hydroxide flakes were dissolved in distilled water.
- The activator solution (NaOH solution +  $\text{Na}_2\text{SiO}_3$ ) was prepared one day prior to its use.
- Three types of locally available aggregates, viz. 20mm, 6mm coarse aggregates and fine aggregate in saturated surface dry condition were mixed together in the ratio 0.3:0.3:0.4 respectively.
- The grading of this combined aggregate had a fineness modulus of 4.773.
- The aggregates and the fly-ash were mixed dry in a pan mixer for 3 minutes
- The alkaline solution and the super plasticizer were mixed together, then added to the fly-ash-aggregate mixture in the mixing plant and mixed for another 3 to 5 minutes.
- The fresh concrete had a stiff consistency and was glossy in appearance.
- The mixture was cast in 100×100×100 mm size cubes by using hand held vibrator.
- Immediately after casting, the samples were covered to avoid the loss of water due to evaporation while they were left in room temperature for 30 – 60 minutes; specimens were cured in an oven at a specified temperature of 60°C for a period of 24 hours.
- At the end of curing period the 100×100×100 mm cubes were removed from the moulds.
- The specimens were then left to air-dry at room temperature, until they are loaded in compression testing machine at the specified age.

### Sample calculations:

To start with, the following parameters were fixed, based on estimations and results of previous experiments submitted in the research paper by B.VIJAYA RANGAN published in ICI JOURNAL(OCT-DEC 2006).

For each  $1\text{m}^3$  of concrete

- Weight of fly-ash = 400kg
- Alkaline liquid solution/fly-ash ratio = 0.5
- Sodium silicate/sodium hydroxide ratio = 2.5

Mass of NaOH =  $(400 \times 0.5)/(1+2.5) = 57.14$  kg

Mass of  $\text{Na}_2\text{SiO}_3 = 240 - 57.14 = 182.86$  kg

Mass of aggregates =  $2400 - 400 - 240 = 1760$  kg

sand: coarse aggregate (6mm): coarse aggregate (20mm) = 0.4: 0.3: 0.3

Mass of sand =  $0.4 \times 1760 = 704$  kg

Mass of coarse aggregate (20mm) = 528kg

Mass of coarse aggregate (6mm) = 528 kg

Super plasticizer = 1.5 % of weight of fly ash

$\text{Na}_2\text{SiO}_3 : \text{NaOH} : \text{fly-ash} : \text{sand} : \text{C.A (20mm)} :$

$\text{C.A (6mm)} = 0.358:0.142:1:1.8:1.35:1.35$

Numerous trial mixes of geopolymer concrete were made and tested in the laboratory. The data collected from these studies indicated that the salient parameters affecting the compressive strength of geopolymer concrete are as listed below.

1. As concentration of sodium hydroxide (NaOH) varies from 10 M to 16 M compressive strength of concrete increases;
2. As curing temperature increases compressive strength increases. There is insignificant increase in compressive strength beyond 60° C Optimum curing temperature 60° C.

It must be noted that only the binder (which usually occupies around 20 to 25% of total mass) is different in geopolymer concrete when compared to OPC concrete. Therefore, the effects of properties and

grading of aggregates were not investigated in this study.

### **3.5 Slump test:**

Slump test is the most commonly used method for measuring consistency and workability of concrete, which can be employed either at the laboratory or at the site of work. It is not suitable for very wet or very dry concrete. It does not measure all factors contributing to workability, nor is it always representative of the practicability of the concrete. However it is used conveniently as control test and gives an indication of the uniformity of the concrete from batch to batch.

The thickness of metallic sheet for the mould should not be less than 1.67mm. Sometimes the mould is provided with suitable guides for lifting up. For tamping the concrete, a steel tamping rod of 16mm diameter, 0.6m long, with a bullet end, is used. Each layer is tamped 25 times with the tamping rod, taking care to distribute the strokes evenly over the cross-section. The variation of slump with concentration of sodium hydroxide solution is given in fig.5.5.

### **VEE-BEE Test**

This is a laboratory test measuring indirectly the workability of the concrete. Slump cone is placed inside a metal cylinder and the slump test is conducted in the cylinder. The electric vibrator is switched on and simultaneously stop watch is started. The vibration is continued till such a time as the conical shape of the concrete disappears and the concrete assumes a cylindrical shape. The time required for the shape of concrete to change from slump cone shape to cylindrical shape in seconds, is known as Vee-Bee degree. The variation of vee-bee time with molarities of NaOH is shown in figure-5.6.

## **EXPERIMENTAL RESULTS**

### **Mix proportions:**

### **Mix proportions of geopolymers concrete used in the manufacture of test cubes:**

Various mix proportions were considered.

#### **TABLE 4.1.1:**

#### **MIX – I COMPOSITION: ( NaOH-10 Molar)**

Alkaline solution (Na<sub>2</sub>SiO<sub>3</sub>+NaOH) /Fly ash =0.5

Na<sub>2</sub>SiO<sub>3</sub> : NaOH = 0.358 : 0.142

NaOH concentration = 10 molar

1 M of NaOH weight = 40 gms

10 M of NaOH weight= 400 gms

10 M of NaOH solution weight=

1000(water)+400(NaOH)= 1400 gms

Super plasticizer=(1.5% of weight of fly ash)

Water = 4% (wt of materials)

S.No.	Material	Kg Per cum
1	Combined aggregate (sand+20mm+6mm)=1.8+1.35+1.35	1800
2	Fly-ash	400
3	Sodium hydroxide (10M) solution	56.8
4	Sodium silicate solution	143.2

#### **TABLE 4.1.2:**

#### **MIX – II COMPOSITION: ( NaOH-12 Molar)**

Alkaline solution (Na<sub>2</sub>SiO<sub>3</sub>+NaOH) /Fly ash =0.5

Na<sub>2</sub>SiO<sub>3</sub> : NaOH= 0.358 : 0.142

NaOH concentration= 12 molar

1 M of NaOH weight= 40 gms

12 M of NaOH weight= 480 gms

12 M of NaOH solution weight=

1000(water)+480(NaOH)= 1480 gms

Super plasticizer= (1.5% of weight of fly ash)

Water =4% (wt of materials)

S.No.	Material	Kg Per cum
1	Combined aggregate (sand+20mm+6mm)=1.8+1.35+1.35	1800
2	Fly-ash	400
3	Sodium hydroxide (12M) solution	56.8
4	Sodium silicate solution	143.2

#### **TABLE 4.1.3:**

#### **MIX – III Composition: ( NaOH-14 Molar)**

Alkaline solution (Na<sub>2</sub>SiO<sub>3</sub>+NaOH) /Fly ash =0.5

Na<sub>2</sub>SiO<sub>3</sub> : NaOH= 0.358 : 0.142

NaOH concentration= 14 molar

1 M of NaOH weight= 40 gms

14 M of NaOH weight= 560 gms

14 M of NaOH solution weight  
 =1000(water)+560(NaOH)= 1560 gms  
 Super plasticizer = (1.5% of weight of fly ash)  
 Water =4% (wt of materials)

S.No.	Material	Kg Per cum
1	Combined aggregate (sand+20mm+6mm)=1.8+1.35+1.35	1800
2	Fly-ash	400
3	Sodium hydroxide (14M) solution	56.8
4	Sodium silicate solution	143.2

**TABLE 4.1.4:**

**MIX – IV Composition: ( NaOH-16 Molar)**

Alkaline solution (Na<sub>2</sub>SiO<sub>3</sub>+NaOH) /Fly ash =0.5

Na<sub>2</sub>SiO<sub>3</sub> : NaOH= 0.358 : 0.142

NaOH concentration= 16 molar

1 M of NaOH weight= 40 gms

16 M of NaOH weight= 640 gms

16 M of NaOH solution weight=

1000(water)+640(NaOH)= 1640 gms

Super plasticizer= (1.5% of weight of fly ash)

Water= 4% (wt of materials)

S.No.	Material	Kg Per cum
1	Combined aggregate (sand+20mm+6mm)=1.8+1.35+1.35	1800
2	Fly-ash	400
3	Sodium hydroxide (16M) solution	56.8
4	Sodium silicate solution	143.2

**Slump test results:**

Slump results are obtained by on an averaging the trail mixes for every 10M, 12M, 14M and 16 Molars. The variation of slump with the concentration of sodium hydroxide solution is given in the following table and shown in fig-5.5.

**TABLE 4.2: Slump test results**

S.No	Conc. Of NaOH in molarity	Slump (mm)
1	10 M	110
2	12 M	95
3	14 M	85
4	16 M	70

**VEE-BEE test results:**

Vee - bee time is taken for every trail mix and on an averaging the results with molarities of NaOH the final table values are given.

The variation of Vee-Bee time with concentration of sodium hydroxide solution is given in the following table and graph as shown in fig-5.6.

**TABLE 4.3: VEE-BEE test results**

S.No	Conc. Of NaOH in molarity	Vee - Bee Time(sec)
1	10 M	8.5
2	12 M	9.4
3	14 M	10.2
4	16 M	11.5

**Compressive strength test results:  
 (Materials used :-fly ash)**

**MIX- I:-**

**TABLE :- 4.4.1-**

Alkaline solution (Na<sub>2</sub>SiO<sub>3</sub>+NaOH) /Fly ash =0.5

Concentration of NaOH = 10 Molar

**Variation of compressive strength results with molarities of NaOH – 10M:**

S.No	Age in days	Concentration of NaOH In molarities	Curing temperature (24 hours)	Alkaline Solution + Flyash	Test Specimen Size in mm.	Compressive strength In N/mm <sup>2</sup>
1	7	10	60 °C	(0.5:1.0)	100x100x100	22.9
2	14	10	60 °C	(0.5:1.0)	100x100x100	23.4
3	21	10	60 °C	(0.5:1.0)	100x100x100	23.78
4	28	10	60 °C	(0.5:1.0)	100x100x100	24.4

**TABLE :- 4.4.2-**

Alkaline solution (Na<sub>2</sub>SiO<sub>3</sub>+NaOH) /Fly ash =0.5

Concentration of NaOH = 10 Molar

**Variation of compressive strength results with molarities of NaOH – 10M:**

S.No	Age in days	Concentration of NaOH In molarities	Curing	Alkaline Solution + Flyash	Test Specimen Size in mm.	Compressive strength In N/mm <sup>2</sup>
1	7	10	Water	(0.5:1.0)	100x100x100	23.56
2	14	10	Water	(0.5:1.0)	100x100x100	24.12
3	21	10	Water	(0.5:1.0)	100x100x100	24.38
4	28	10	Water	(0.5:1.0)	100x100x100	24.98

**TABLE 4.4.3:**

Alkaline solution (Na<sub>2</sub>SiO<sub>3</sub>+NaOH) /Fly ash =0.5

Concentration of NaOH = 12 Molar

**Variation of compressive strength results with molarities of NaOH – 12M:**

S.No	Age in days	Concentration of NaOH In molarities	Curing temperature (24 hours)	Alkaline Solution + Flyash	Test Specimen Size in mm.	Compressive strength In N/mm <sup>2</sup>
1	7	12	60 °C	(0.5:1.0)	100x100x100	24.23
2	14	12	60 °C	(0.5:1.0)	100x100x100	24.67
3	21	12	60 °C	(0.5:1.0)	100x100x100	24.91
4	28	12	60 °C	(0.5:1.0)	100x100x100	25.50

**TABLE 4.4.4:**

Alkaline solution (Na<sub>2</sub>SiO<sub>3</sub>+NaOH) /Fly ash =0.5

Concentration of NaOH = 12 Molar

**Variation of compressive strength results with molarities of NaOH – 12M:**

S.No	Age in days	Concentration of NaOH In molarities	Curing	Alkaline Solution + Flyash	Test Specimen Size in mm.	Compressive strength In N/mm <sup>2</sup>
1	7	12	Water	(0.5:1.0)	100x100x100	24.78
2	14	12	Water	(0.5:1.0)	100x100x100	25.20
3	21	12	Water	(0.5:1.0)	100x100x100	25.52
4	28	12	Water	(0.5:1.0)	100x100x100	26.10

**TABLE 4.4.5:**

Alkaline solution (Na<sub>2</sub>SiO<sub>3</sub>+NaOH) /Fly ash =0.5

Concentration of NaOH = 14 Molar

**Variation of compressive strength results with molarities of NaOH – 14M:**

S.No	Age in days	Concentration of NaOH In molarities	Curing temperature (24 hours)	Alkaline Solution + Flyash	Test Specimen Size in mm.	Compressive strength In N/mm <sup>2</sup>
1	7	14	60 °C	(0.5:1.0)	100x100x100	25.89
2	14	14	60 °C	(0.5:1.0)	100x100x100	26.30
3	21	14	60 °C	(0.5:1.0)	100x100x100	26.59
4	28	14	60 °C	(0.5:1.0)	100x100x100	26.94

**TABLE 4.4.6:**

Alkaline solution (Na<sub>2</sub>SiO<sub>3</sub>+NaOH) /Fly ash =0.5

Concentration of NaOH = 14 Molar

**Variation of compressive strength results with molarities of NaOH – 14M:**

S.No	Age in days	Concentration of NaOH In molarities	Curing	Alkaline Solution + Flyash	Test Specimen Size in mm.	Compressive strength In N/mm <sup>2</sup>
1	7	14	Water	(0.5:1.0)	100x100x100	26.58
2	14	14	Water	(0.5:1.0)	100x100x100	26.92
3	21	14	Water	(0.5:1.0)	100x100x100	27.12
4	28	14	Water	(0.5:1.0)	100x100x100	27.44

**TABLE 4.4.7:**

Alkaline solution (Na<sub>2</sub>SiO<sub>3</sub>+NaOH) /Fly ash =0.5

Concentration of NaOH = 16 Molar

**Variation of compressive strength results with molarities of NaOH – 16M:**

S.No	Age in days	Concentration of NaOH In molarities	Curing temperature (24 hours)	Alkaline Solution + Flyash	Test Specimen Size in mm.	Compressive strength In N/mm <sup>2</sup>
1	7	16	60 °C	(0.5:1.0)	100x100x100	26.94
2	14	16	60 °C	(0.5:1.0)	100x100x100	27.08
3	21	16	60 °C	(0.5:1.0)	100x100x100	27.28
4	28	16	60 °C	(0.5:1.0)	100x100x100	27.76

**TABLE 4.4.8:**

Alkaline solution (Na<sub>2</sub>SiO<sub>3</sub>+NaOH) /Fly ash =0.5

Concentration of NaOH = 16 Molar

**Variation of compressive strength results with molarities of NaOH – 16M:**

S.No	Age in days	Concentration of NaOH In molarities	Curing	Alkaline Solution + Flyash	Test Specimen Size in mm.	Compressive strength In N/mm <sup>2</sup>
1	7	16	Water	(0.5:1.0)	100x100x100	27.56
2	14	16	Water	(0.5:1.0)	100x100x100	27.68
3	21	16	Water	(0.5:1.0)	100x100x100	27.92
4	28	16	Water	(0.5:1.0)	100x100x100	28.32

#### **4.5 Materials :-Fly ash & Cement.**

In this trail mix two types of base materials are used that is fly ash and cement and the proportions of fly ash and cement are 90% fly ash and 10% cement is used to know the variation of compressive strength for 7,14,21 and 28 days. And in this mix some sample cubes are cured at 60 °C and some sample are cured in water for a period of 7, 14, 21 and 28 days. The cubes are tested and the results are shown below with molarity wise.

**TABLE 4.5.1:-**

Fly ash content -90% and cement content – 10%

**Variation of compressive strength results with molarities of NaOH – 10M:**

S.No	Age in days	Concentration of NaOH In molarities	Curing temperature (24 hours)	Alkaline Solution + Flyash	Test Specimen Size in mm.	Compressive strength In N/mm <sup>2</sup>
1	7	10	60 °C	(0.5:1.0)	100x100x100	23.27
2	14	10	60 °C	(0.5:1.0)	100x100x100	23.62
3	21	10	60 °C	(0.5:1.0)	100x100x100	24.65
4	28	10	60 °C	(0.5:1.0)	100x100x100	25.44

**TABLE 4.5.2:-**

Alkaline solution (Na<sub>2</sub>SiO<sub>3</sub>+NaOH) /Fly ash =0.5

Concentration of NaOH = 10 Molar

Fly ash content -90%;cement content –10%

**Variation of compressive strength results with molarities of NaOH – 10M:**

S.No	Age in days	Concentration of NaOH In molarities	Curing	Alkaline Solution + Flyash	Test Specimen Size in mm.	Compressive strength In N/mm <sup>2</sup>
1	7	10	Water	(0.5:1.0)	100x100x100	24.15
2	14	10	Water	(0.5:1.0)	100x100x100	24.77
3	21	10	Water	(0.5:1.0)	100x100x100	25.57
4	28	10	Water	(0.5:1.0)	100x100x100	26.60

**TABLE 4.5.3:-**

Concentration of NaOH = 12 Molar

**Variation of compressive strength results with molarities of NaOH – 12M:**

S.No	Age in days	Concentration of NaOH In molarities	Curing temperature (24 hours)	Alkaline Solution + Flyash	Test Specimen Size in mm.	Compressive strength In N/mm <sup>2</sup>
1	7	12	60 °C	(0.5:1.0)	100x100x100	24.41
2	14	12	60 °C	(0.5:1.0)	100x100x100	25.21
3	21	12	60 °C	(0.5:1.0)	100x100x100	26.21
4	28	12	60 °C	(0.5:1.0)	100x100x100	27.24

**TABLE 4.5.4:-**

Alkaline solution (Na<sub>2</sub>SiO<sub>3</sub>+NaOH) /Fly ash =0.5

Concentration of NaOH = 12 Molar

Fly ash content -90% ; cement content – 10%

**Variation of compressive strength results with molarities of NaOH – 12M:**

S.No	Age in days	Concentration of NaOH In molarities	Curing	Alkaline Solution + Flyash	Test Specimen Size in mm	Compressive strength In N/mm <sup>2</sup>
1	7	12	Water	(0.5:1.0)	100x100x100	25.08
2	14	12	Water	(0.5:1.0)	100x100x100	26.09
3	21	12	Water	(0.5:1.0)	100x100x100	27.06
4	28	12	Water	(0.5:1.0)	100x100x100	28.04

**TABLE 4.5.5:-**

Alkaline solution (Na<sub>2</sub>SiO<sub>3</sub>+NaOH) /Fly ash =0.5

Concentration of NaOH = 14 Molar  
 Fly ash content -90%;cement content –10%  
 Curing at 60 °C temperature

**Variation of compressive strength results with molarities of NaOH – 14M:**

S.No	Age in days	Concentration of NaOH In molarities	Curing temperature (24 hours)	Alkaline Solution + Flyash	Test Specimen Size in mm	Compressive strength In N/mm <sup>2</sup>
1	7	14	60 °C	(0.5:1.0)	100x100x100	25.66
2	14	14	60 °C	(0.5:1.0)	100x100x100	26.74
3	21	14	60 °C	(0.5:1.0)	100x100x100	27.78
4	28	14	60 °C	(0.5:1.0)	100x100x100	28.89

**TABLE 4.5.6:-**

Alkaline solution (Na<sub>2</sub>SiO<sub>3</sub>+NaOH) /Fly ash =0.5

Concentration of NaOH = 14 Molar  
 Fly ash content -90%;cement content –10%

**Variation of compressive strength results with molarities of NaOH – 14M:**

S.No	Age in days	Concentration of NaOH In molarities	Curing	Alkaline Solution + Flyash	Test Specimen Size in mm	Compressive strength In N/mm <sup>2</sup>
1	7	14	Water	(0.5:1.0)	100x100x100	26.07
2	14	14	Water	(0.5:1.0)	100x100x100	27.44
3	21	14	Water	(0.5:1.0)	100x100x100	28.31
4	28	14	Water	(0.5:1.0)	100x100x100	29.62

**TABLE 4.5.7:-**

Alkaline solution (Na<sub>2</sub>SiO<sub>3</sub>+NaOH) /Fly ash =0.5

Concentration of NaOH = 16 Molar  
 Fly ash content -90%;cement content –10%  
 Samples Cured at 60 °C temperature

**Variation of compressive strength results with molarities of NaOH – 16M:**

S.No	Age in days	Concentration of NaOH In molarities	Curing temperature (24 hours)	Alkaline Solution + Flyash	Test Specimen Size in mm	Compressive strength In N/mm <sup>2</sup>
1	7	16	60 °C	(0.5:1.0)	100x100x100	26.83
2	14	16	60 °C	(0.5:1.0)	100x100x100	28.28
3	21	16	60 °C	(0.5:1.0)	100x100x100	29.43
4	28	16	60 °C	(0.5:1.0)	100x100x100	30.11

**TABLE 4.5.8:-**

Alkaline solution (Na<sub>2</sub>SiO<sub>3</sub>+NaOH) /Fly ash =0.5

Concentration of NaOH = 16 Molar  
 Fly ash content -90%;cement content –10%

**Variation of compressive strength results with molarities of NaOH – 16M:**

S.No	Age in days	Concentration of NaOH In molarities	Curing	Alkaline Solution + Flyash	Test Specimen Size in mm	Compressive strength In N/mm <sup>2</sup>
1	7	16	Water	(0.5:1.0)	100x100x100	27.17
2	14	16	Water	(0.5:1.0)	100x100x100	28.83
3	21	16	Water	(0.5:1.0)	100x100x100	29.71
4	28	16	Water	(0.5:1.0)	100x100x100	31.03

The variation of compressive strength with age and with concentration of sodium hydroxide solution is shown in fig.5.1 to fig.5.38.

**FLEXURAL STRENGTH TEST RESULTS**

In this experiment work low calcium dry fly ash obtained from the silos of Ramagundam thermal power station. Fly ash was used as the base material. The procedure for concrete mix is same as above mentioned in cube tests.

The test specimen shall consist of size 50 x 10 x 10 cm .

- In the present experimental program, low-calcium dry fly-ash obtained from the silos at a local power station was used as the base material and small quantity of cement obtained from local available market is also used.
- Analytical grade sodium hydroxide in flakes form (NaOH of 98% purity) and sodium silicate solution (Na<sub>2</sub>O= 12.65%, SiO<sub>2</sub>=29.93% and water = 56.42% by mass), were used as the alkaline activators.
- To avoid the effect of unknown contaminants in the mixing water, the sodium hydroxide flakes were dissolved in distilled water. The activator solution (NaOH solution + Na<sub>2</sub>SiO<sub>3</sub>) was prepared one day prior to its use.

**Material calculations for 10 Molar beams.**

No of beams = 2 nos  
 Beam size =0.5x0.1x0.10x2 =0.01 m<sup>3</sup>  
 Fly ash = 4 kgs  
 Na<sub>2</sub>SiO<sub>3</sub> = 0.358 x 4= 1.432 kgs  
 NaOH = 0.142x4 = 0.568 kgs

Sand =  $1.8 \times 4 = 7.20$  kgs  
 20 mm aggregate =  $1.35 \times 4 = 5.40$  kgs  
 6 mm aggregate =  $1.35 \times 4 = 5.40$  kgs  
 Sp 430 = 1.5% wt of fly ash  
 Water = 4%

Additional water 200 ml is added for mix.  
 The flexural strength of the specimen is expressed as the modulus of rupture " $f_b$ "  
 The flexural strength of beam is given by following formulas.

$$1). f_b = \frac{p.l}{b.d^2}$$

$$2). f_b = \frac{3.p.a}{b.d^2}$$

where ' p ' is load at failure in kn corresponding to dial gauge reading at failure.

b = measured width in cm of the specimen  
 d = measured depth in cm of the specimen at the point of failure

l = length in cm on span on which specimen was supported

a = distance at which failure occurs.

If the failure occurs within the middle to 1/3 the formula ' 1 ' is used and if the failure occurs outside 1/3 distance then the formula ' 2 ' is used.

**Results :**

(1) Flexural strength of geo polymer concrete for 10 molar ( **only fly ash**)

$$f_b = \frac{p.l}{b.d^2}$$

for trail mix (1a) : dial gauge reading = 480 mm

$$f_b = \frac{11.60 \times 500 \times 1000}{100 \times 100^2} = 5.8 \text{ N/mm}^2.$$

for trail mix (1b) : dial gauge reading = 462 mm

$$f_b = \frac{11.10 \times 500 \times 1000}{100 \times 100^2} = 5.55 \text{ N/mm}^2.$$

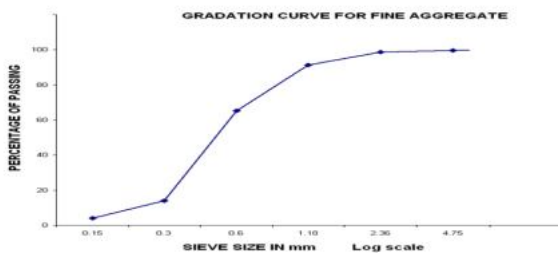


Fig.5.1. Graduation curve for fine aggregate

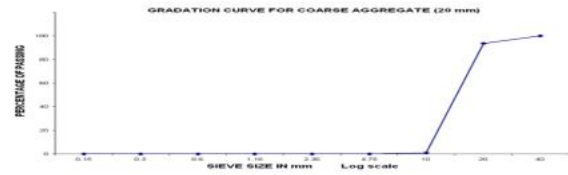


Fig. 5.2. Graduation curve for coarse aggregate (20mm)

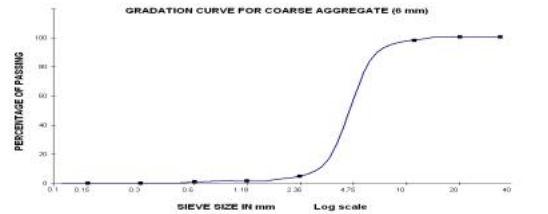


Fig. 5.3. Graduation curve for coarse aggregate (6mm)

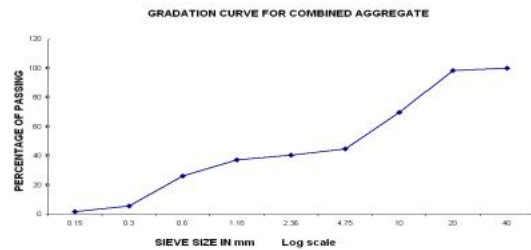


Fig. 5.4. Graduation curve for combined aggregate

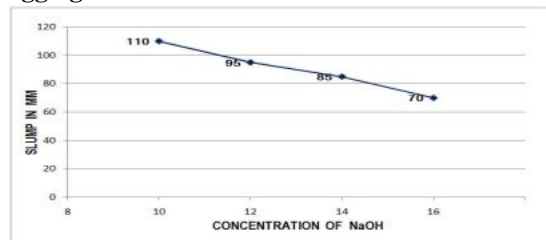


Fig. 5.5. Variation of slump with molarity of NaOH.

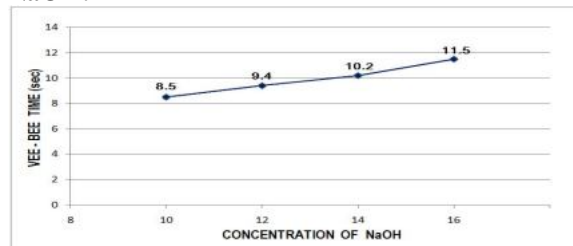


Fig. 5.6. Variation of VEE-BEE TIME(sec) with molarity of NaOH.

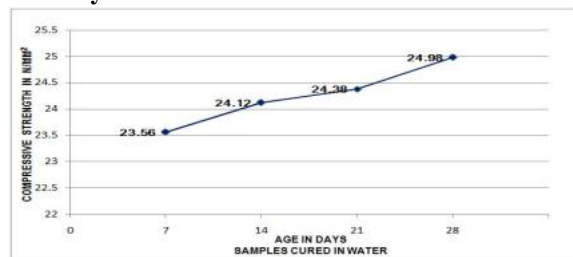


Fig.5.7. Variation of compressive strength with molarity of NaOH-10M.

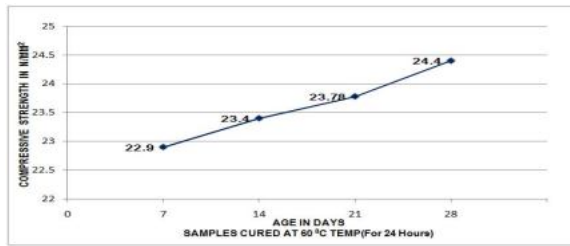


Fig-5.8. Variation of compressive strength with molarity of NaOH-10M.

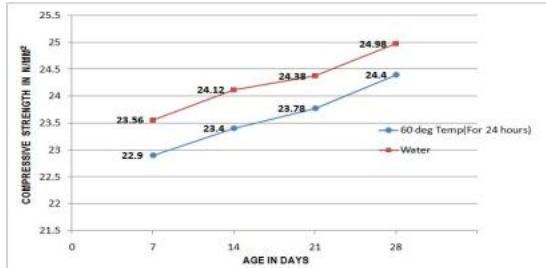


Fig-5.9. Variation of compressive strength with molarity of NaOH-10M.

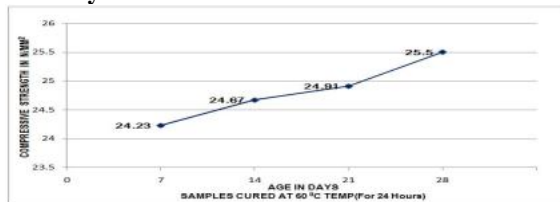


Fig-5.10. Variation of compressive strength with molarity of NaOH-12M.

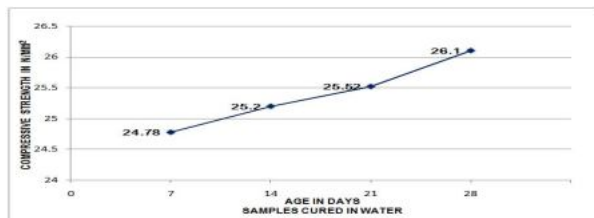


Fig-5.11. Variation of compressive strength with molarity of NaOH-12M.

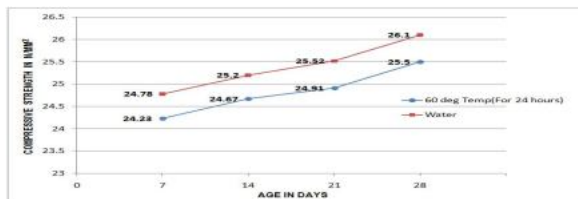


Fig-5.12. Variation of compressive strength with molarity of NaOH-12M.

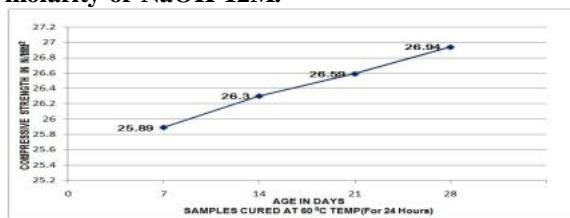


Fig-5.13. Variation of compressive strength with molarity of NaOH-14M.

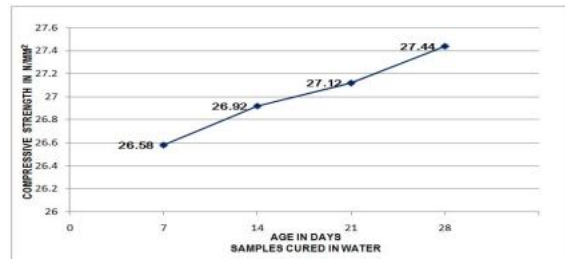


Fig-5.14. Variation of compressive strength with molarity of NaOH-14M.

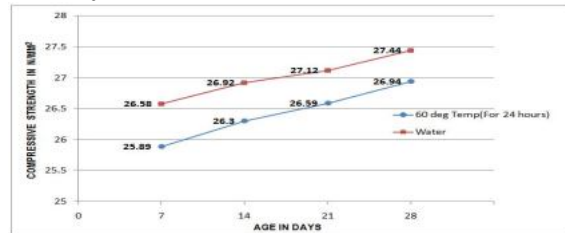


Fig-5.15. Variation of compressive strength with molarity of NaOH-14M.

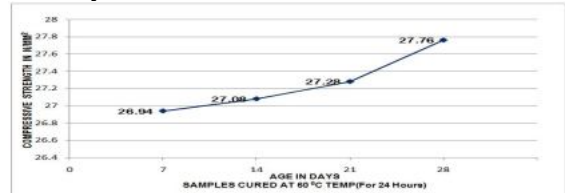


Fig-5.16. Variation of compressive strength with molarity of NaOH-16M.

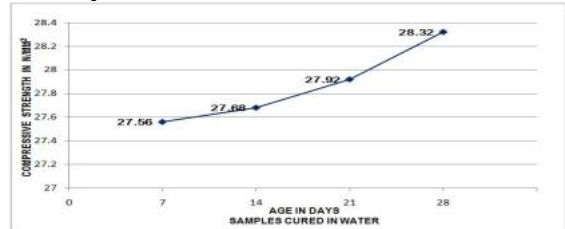


Fig-5.17. Variation of compressive strength with molarity of NaOH-16M.

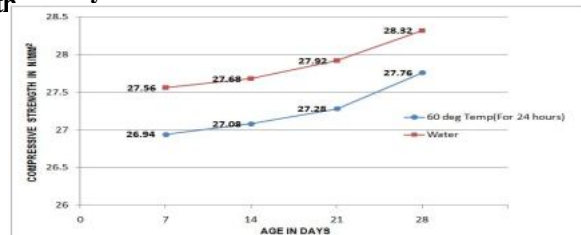


Fig-5.18. Variation of compressive strength with molarity of NaOH-16M.

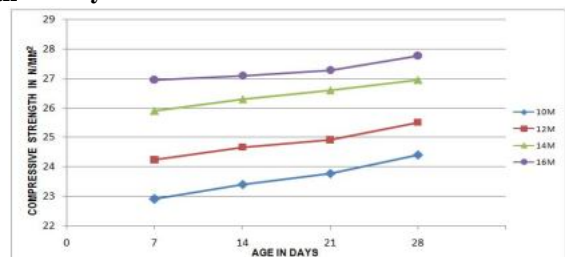


Fig-5.19. Variation of compressive strength with molarity of NaOH - 10M, 12M, 14M, 16M



(Samples Cured in 60°C Temperature for 24 Hours)

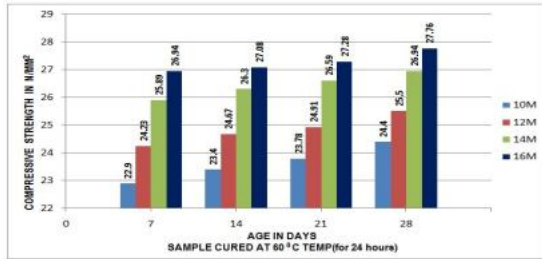


Fig-5.20. Variation of compressive strength with molarity of NaOH – 10 M,12M,14M,16M (Samples Cured in 60°C Temperature for 24 Hours)

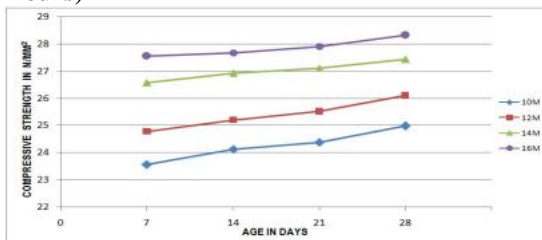


Fig-5.21. Variation of compressive strength with molarity of NaOH – 10 M,12M,14M,16M (Samples Cured in Water)

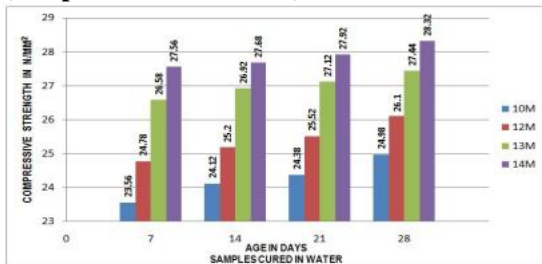


Fig-5.22. Variation of compressive strength with molarity of NaOH – 10 M,12M,14M,16M (Samples Cured in Water)

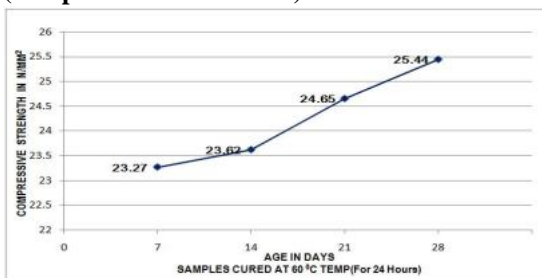


Fig-5.23. Variation of compressive strength with molarity of NaOH – 10 M (FLYASH -90% & CEMENT -10%).

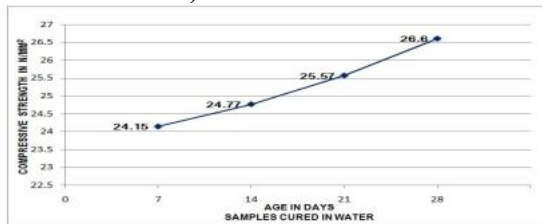


Fig 5.24. Variation of compressive strength with molarity of NaOH – 10 M (FLYASH -90% & CEMENT -10%).

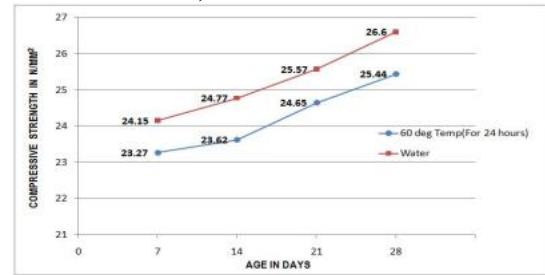


Fig-5.25. Variation of compressive strength with molarity of NaOH – 10 M (FLYASH -90% & CEMENT -10%).

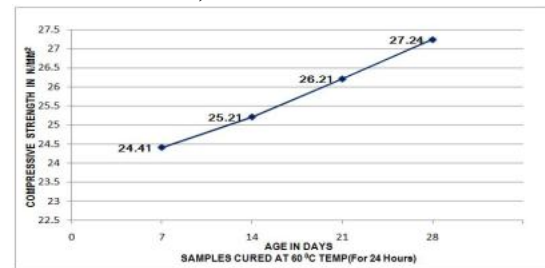


Fig-5.26. Variation of compressive strength with molarity of NaOH – 12 M (FLYASH -90% & CEMENT -10%).

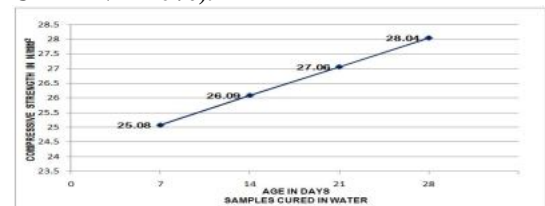


Fig-5.27. Variation of compressive strength with molarity of NaOH – 12 M (FLYASH -90% & CEMENT -10%).

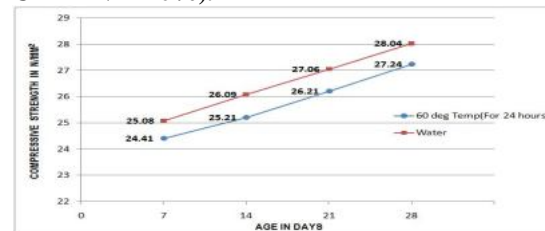


Fig-5.28. Variation of compressive strength with molarity of NaOH – 12 M (FLYASH -90% & CEMENT -10%).

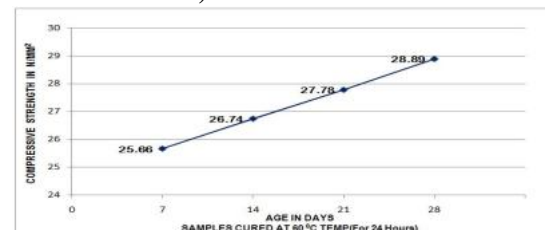


Fig-5.29. Variation of compressive strength with molarity of NaOH – 14 M (FLYASH -90% & CEMENT -10%).

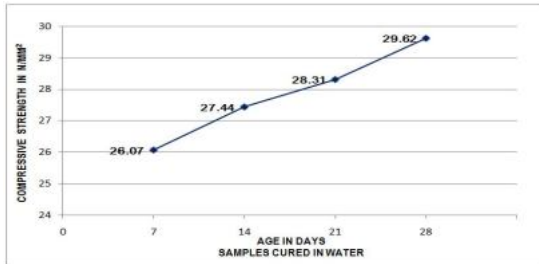


Fig-5.30. Variation of compressive strength with molarity of NaOH – 14 M (FLYASH -90% & CEMENT -10%).

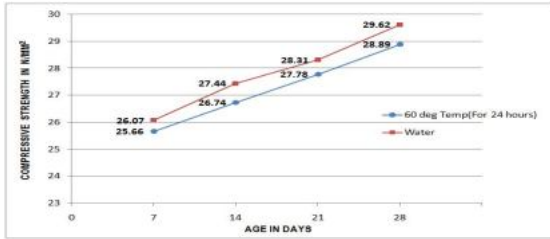


Fig-5.31. Variation of compressive strength with molarity of NaOH – 14 M (FLYASH -90% & CEMENT -10%).

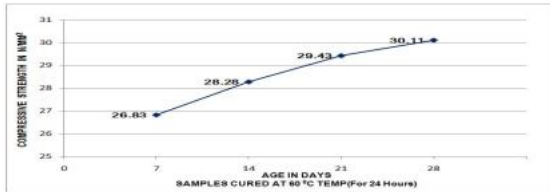


Fig-5.32. Variation of compressive strength with molarity of NaOH – 16 M (FLYASH -90% & CEMENT -10%).

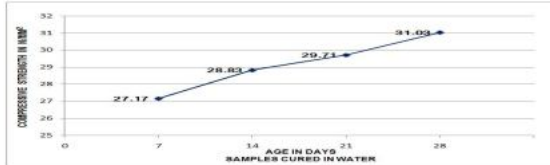


Fig-5.33. Variation of compressive strength with molarity of NaOH – 16 M (FLYASH -90% & CEMENT -10%).

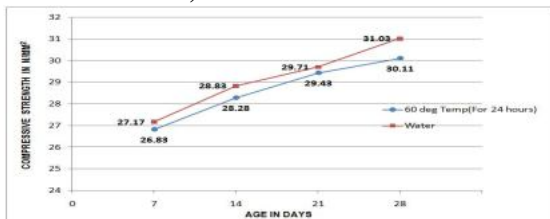


Fig-5.34. Variation of compressive strength with molarity of NaOH – 16 M (FLYASH -90% & CEMENT -10%).

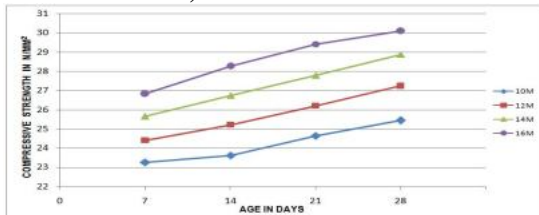


Fig-5.35. Variation of compressive strength with molarity of NaOH – 10M,12M,14,16 M (FLYASH -90% & CEMENT -10%). (Samples Cured at 60°C Temperature for 24 Hours)

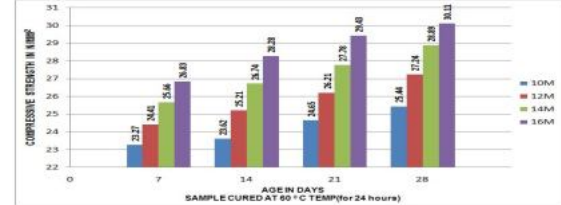


Fig-5.36. Variation of compressive strength with molarity of NaOH – 10M,12M,14,16 M (FLYASH -90% & CEMENT -10%). (Samples Cured at 60°C Temperature for 24 Hours)

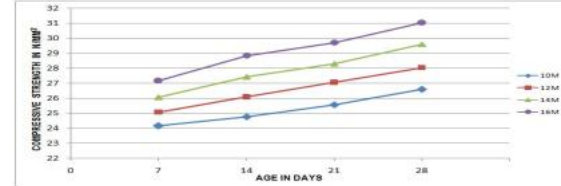


Fig-5.37. Variation of compressive strength with molarity of NaOH – 10M,12M,14,16 M (FLYASH -90% & CEMENT -10%) (Samples Cured in Water)

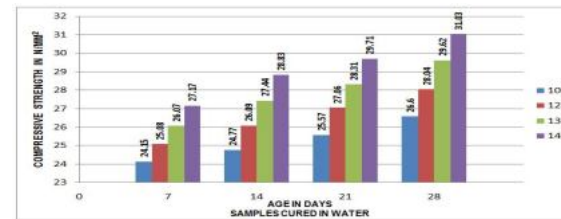


Fig-5.38. Variation of compressive strength with molarity of NaOH – 10M,12M,14,16 M (FLYASH -90% & CEMENT -10%) (Samples Cured in Water)

## DISCUSSIONS

### Effect of parameters:

Table 6.1 to table 6.3 gives the composition of four different mixes and the 7,14,21,28 day compressive strengths of 100×100×100mm some of the test cubes cured at 60°C and some are cured in water for a period of 7,14,21 and 28 days. In table 6.1 to table 6.3, the second column gives the concentration of the sodium hydroxide solution in terms of molarity (M). The third, fourth, fifth and sixth columns give the mean 7, 14, 21, 28 day compressive strengths of test cube.

- Compressive strength increases with molarity in the range of 10 M to 16 M.
- Compressive strength increases with age, though the variation is lesser than that in the case of ordinary concrete.
- Flexural strength of 50x10x10 cm test beams cured at 60°C.

In this test, results are also increasing with molarity in range 10 M to 12 M

**TABLE 6.1:**  
**Compressive Strength text results when samples are cured at 60<sup>0</sup> C temperature for 24 hours with 100% fly ash.**

Mixture	Concentration of NaOH liquid in molarity	7 day-compressive strength after curing (MPa)	14 day-compressive strength after curing (MPa)	21 day-compressive strength after curing (MPa)	28 day-compressive strength after curing (MPa)
A	10	22.90	23.40	23.78	24.40
B	12	24.23	24.67	24.91	25.50
C	14	25.89	26.30	26.59	26.94
D	16	26.94	27.08	27.28	27.76

**TABLE 6.2:**  
**Compressive Strength text results when samples are cured in water with 100% fly ash.**

Mixture	Concentration of NaOH liquid in molarity	7 day-compressive strength after curing (MPa)	14 day-compressive strength after curing (MPa)	21 day-compressive strength after curing (MPa)	28 day-compressive strength after curing (MPa)
A	10	23.56	24.12	24.38	24.98
B	12	24.78	25.20	25.52	26.10
C	14	26.58	26.92	27.12	27.44
D	16	27.56	27.68	27.92	28.32

**TABLE 6.3:**  
**Compressive Strength text results when samples are cured at 60<sup>0</sup> C temperature for 24 hours with 90% fly ash and 10% Cement.**

Mixture	Concentration of NaOH liquid in molarity	7 day-compressive strength after curing (MPa)	14 day-compressive strength after curing (MPa)	21 day-compressive strength after curing (MPa)	28 day-compressive strength after curing (MPa)
A	10	23.27	23.62	24.65	25.44
B	12	24.41	25.21	26.21	27.24
C	14	25.66	26.74	27.78	28.89
D	16	26.83	28.28	29.43	30.11

**TABLE 6.4:**  
**Compressive Strength text results when samples are cured in water with 90% fly ash and 10% Cement.**

Mixture	Concentration of NaOH liquid in molarity	7 day-compressive strength after curing (MPa)	14 day-compressive strength after curing (MPa)	21 day-compressive strength after curing (MPa)	28 day-compressive strength after curing (MPa)
A	10	24.15	24.77	25.77	26.60
B	12	25.08	26.09	27.06	28.04
C	14	26.07	27.44	28.31	29.62
D	16	27.17	28.83	29.71	31.03

**TABLE 6.5 :**

**Flexural strength text results at 28 days with 100% fly ash.**

Mixture	Concentration of NaOH liquid in molarities	Average flexural strength in (Mpa)
A	10	5.675
B	12	6.575

**TABLE 6.6 :**  
**Flexural strength text results at 28 days with 90% fly ash and 10% Cement.**

Mixture	Concentration of NaOH liquid in molarities	Average flexural strength in (Mpa)
A	10	5.975
B	12	6.80

### 6.2 Concentration of sodium hydroxide:

The only difference between the mixes is the concentration of sodium hydroxide measured in molarity. Mixes with high concentration of NaOH yield higher compressive strengths.

### 6.3 Curing time:

Longer curing time improved the polymerization process resulting in higher compressive strength. The results indicate that a longer curing time at 60°C does not produce weaker materials. However, the increase in compressive strength beyond 48 hours of curing time is not significant.

### 6.4 Handling time:

Due to lack of a suitable method to determine the initial setting time of geopolymer concrete, the setting time of fresh concrete could not be measured. The laboratory experience however, showed that the fresh concrete could be handled up to 120 minutes after mixing without any sign of setting and degradation in the compressive strength.

### 6.5 Water content in the mix:

The water content in the mix was an important factor which influenced the properties of geopolymer binders. To study the effect of water content on the compressive strength of geopolymer concrete, several tests were performed. The quantity of the high-range water reducing

admixture was fixed at 1.5% of the mass of fly-ash.

#### **Age of concrete:**

To the study the effect of age on geopolymer concrete, specimens were tested at the end of 7, 14, 21, 28 days. Because the chemical reaction of the geopolymer paste is a fast polymerization process, the compressive strength does not vary much with the age of concrete when cured for 24 hours. This observation is in contrast with the well known behavior of OPC concrete, which undergoes a hydration process and gains strength over time.

#### **6.7 Unit weight:**

The unit weight of geopolymer concrete primarily depends on the unit weights of the aggregates used in the mixes. Because the type of the aggregates in all mixes did not vary, the unit weight of the concrete mixes varied only marginally between 2280 kg/m<sup>3</sup> and 2400 kg/m<sup>3</sup>.

#### **6.8 Applications of geopolymer concrete:**

Conventional methods, similar to those used in case of OPC concrete, have been used for mixing and placing of geopolymer concrete. Different mixes have been manufactured successfully with a compressive strength in the range of 20 to 80 MPa and slump in the range of 70 to 110 mm, depending on the molarity of NaOH and the mass of extra water added to the mix.

#### **CONCLUSIONS**

- This project presented the development of geopolymer concrete. The binder in this concrete, the geopolymer paste, is formed by activating by-product materials such as low-calcium fly-ash that are rich in silica (SiO<sub>2</sub>) and alumina (Al<sub>2</sub>O<sub>3</sub>).
- In the experimental work, the fly-ash from a local power station (RTPS) was used as source material. A combination of sodium silicate and sodium hydroxide solutions was used as activator. The

geopolymer paste binds the loose coarse and fine aggregate and any un-reacted materials to form the geopolymer concrete. Based on the experimental work reported in this project, the following conclusions are given.

- Higher concentrations of sodium hydroxide (in the range of 10 to 16 M) solution results in a higher compressive strength and Flexural strength of geopolymer concrete.
- The geo-polymer concrete gains strength rapidly when cured in an oven at 60°C for 24 hours, due to the accelerated polymerization process.
- There is a slight increase in the compressive strength with age of the concrete.
- The addition of high-range water reducing admixture, up to approximately 2% of fly-ash by mass, improved the workability of fresh geopolymer concrete with very little effect on the compressive strength of the hardened concrete.
- Flexural strength of geo polymer concrete gains strength rapidly when cured in an oven at 60 °C .

#### **FUTURE RESEARCH NEEDS AND SUGGESTIONS FOR FUTURE WORK**

1. As in the case of ordinary Portland cement concrete, the properties of constituent materials in the geopolymer concrete mixes will influence the physical properties of the hardened concrete. It is therefore necessary to collect experimental data on various properties and use this data to formulate appropriate codes of practice.
2. Future research work has to be done using wider range of molarity of sodium hydroxide solution.
3. The effect of different ratios of sodium silicate to sodium hydroxide solutions, on the overall performance of the geopolymer concrete has to be studied.

4. Durability tests need to be conducted on the geopolymer concrete to assess its performance over time.
5. Future research should also focus on the fundamental science of geopolymers to determine the mechanism of chemical reaction during setting and hardening.

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