AN EXPERIMENTAL INVESTIGATION ON GEOPOLYMER CONCRETE

Submitted in partial fulfilment of the requirements

For the degree, of

Bachelor of Engineering

By

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CERTIFICATE

This is to certify that the project entitled "**An Experimental Investigation on Geopolymer Concrete**" is bonafide work of **Mr. Tungekar Ruh-ul-Ameen (13CE62), Mr. Gupta Sonu Jiyaram (13CE61), Mr. Ansari Waseem (14DCE69), Ms Khan Rameeza (14DCE7)**, submitted to the University of Mumbai in partial fulfilment of the requirements for the award of the degree of **Bachelor of Engineering.**

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DECLARATION

We declare that this written submission represents our ideas in our own words and where other ideas or words have been included; we have adequately cited and referred the original sources. We also declare that we have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in our submissions. We understand that any violation of the above will cause for disciplinary action by the institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

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ABSTRACT

Increase in emission of carbon dioxide due to different industrial and non-industrial activities are posing a severe threat to global atmosphere. Cement industry contributes significantly in emission of carbon dioxide gas during its production. On the other hand, industrial by-products such as GGBS, fly ash, etc. poses a serious waste disposal problems thus affecting the economy of the town or nation leading to global environmental impact. Geopolymer concrete is a solution to this problem. Geopolymer is a class of aluminosilicate binding material synthesized by thermal activation of solid aluminosilicate base material such as GGBS and fly ash. Geopolymer concrete is produced due to alkalination of materials rich in aluminium and silicon with an alkali solution, an aqueous solution of sodium hydroxide and sodium silicate. Alkali solution was varied in different molar concentration as 16 M, 18M, 20M and 22 M with hydroxide to silicate ratio of 2.5. Two different set of concrete specimens were casted which were viz. fly ash based only and GGBS together with fly ash in the proportion to 70:30. All the specimens were cured at 60 °C in oven and accelerated curing tank for 3 days and atmospheric curing in lab till 28^{th} day. It was observed that, oven dried curing showed a slight higher strength than steam cured and it was a successful.

Keywords – geopolymer, aluminosilicates, molar concentration, alkalination, geopolymerisation.

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CHAPTER 1

INTRODUCTION

1.1 General

Concrete is the most widely used construction material in the world and is second only to water as the most utilised substance on the planet. It is obtained by mixing cementing materials, water, aggregates and SCM's if necessary and sometimes admixtures. The mixture when placed in forms and allowed to cure, hardens into rock like mass known as concrete.

Cement is one of the most important building material as of now. The term cement is generic that can be applied for many organic and inorganic materials. However, the most widely used and versatile material is Portland cement. The invention of Portland bought about a landmark change and provided a satisfactory answer to mankind's quest for a strong and durable binder for constructions.

Concrete, in broad sense, is any product or mass made from cementing medium. Generally, this medium is the result of reaction between water and cement. But, in these days this definition could cover a wide range of products. Concrete is made up of different types of cement as well as pozzolan, blast furnace slag, fly ash, micro silica, alcofines and other SCM's and can we normally cures, steam cured, dry heat cured, vacuum treated, shock vibrated, extruded and sprayed.

1.2 Concrete and Environment

The trading of carbon dioxide (CO_2) emissions is a critical factor for the industries, including the cement industries, as the greenhouse effect created by the emissions is considered to produce an increase in the global temperature that may result in climate changes. The production of cement is increasing about 3% annually. The production of one ton of cement liberates about one ton of CO_2 to the atmosphere, as the result of de-carbonation of limestone in the kiln during manufacturing of cement and the combustion of fossil fuels. The contribution of Portland cement production worldwide to the greenhouse gas emission is estimated to be about 1.35 billion tons annually or about 7% of the total greenhouse gas emissions to the earth's atmosphere.

The concrete industry has recognized these issues. For example, the U.S. Concrete Industry has developed plans to address these issues in 'Vision 2030: A Vision for the U.S. Concrete Industry'. The document states that 'concrete technologists are faced with the challenge of leading future development in a way that protects environmental quality while projecting concrete as a construction material of choice. Public concern will be responsibly addressed regarding climate change resulting from the increased concentration of global warming gases.

In India, the cement production has increased from 6.44% to 282.79 million tonnes over FY 2016. As per 12th five-year plan, production is expected to reach 407 million tonnes for FY 2017. In August 2016, cement production has increased by 3.1% as compared in July 2016 that increased by 1.4%.

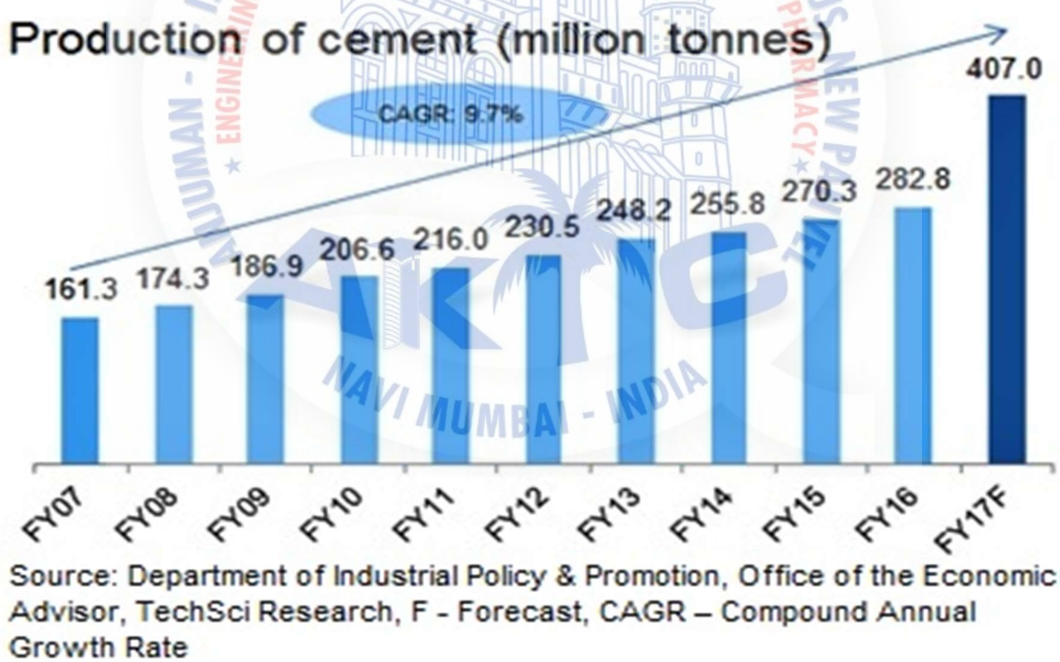

FIG :1.1 CEMENT PRODUCTION IN INDIA.

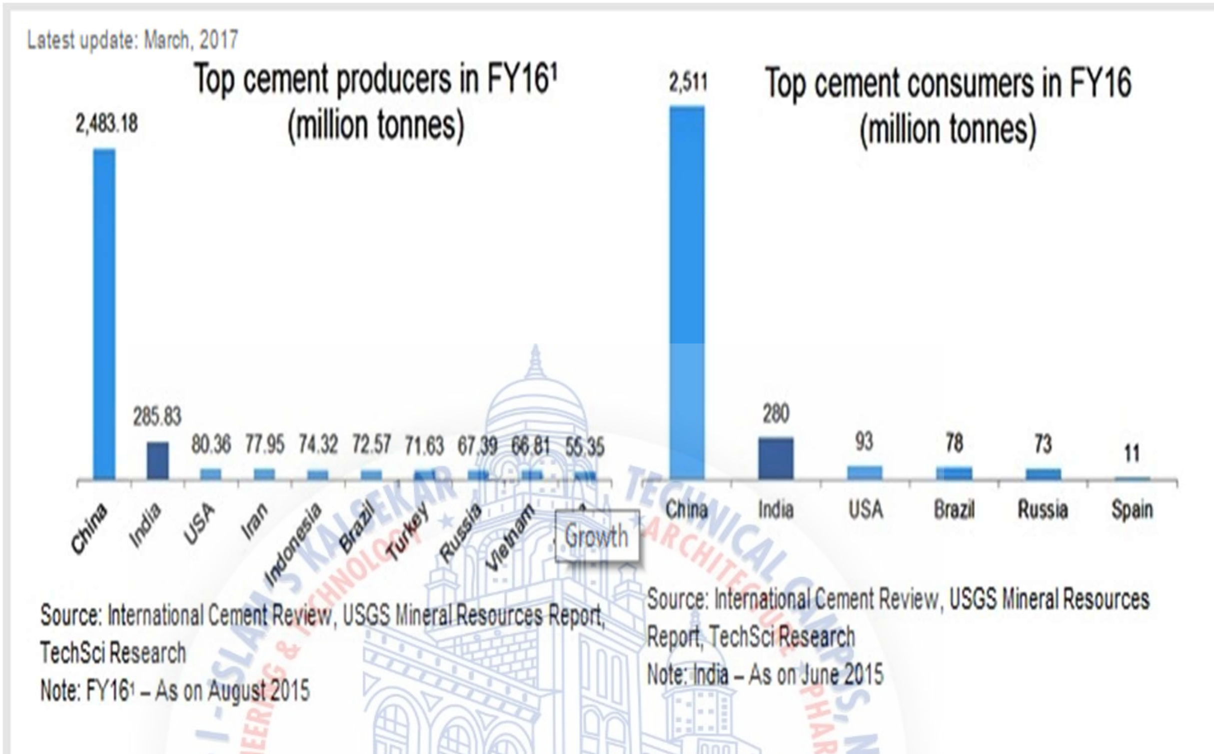

FIG :1.2 TOP CEMENT PRODUCERS IN THE WORLD.

As discussed earlier, 1 tonne of cement production liberates 1 tonne of chemical carbon dioxide gas. Hence from the above charts, due to high cement production and emission of gas, the global carbon footprint will also increase. Therefore, many initiative have been taken worldwide to eliminate the use of Portland Cement in concrete and use sustainable materials in concrete to make durable and eco-friendly concrete.

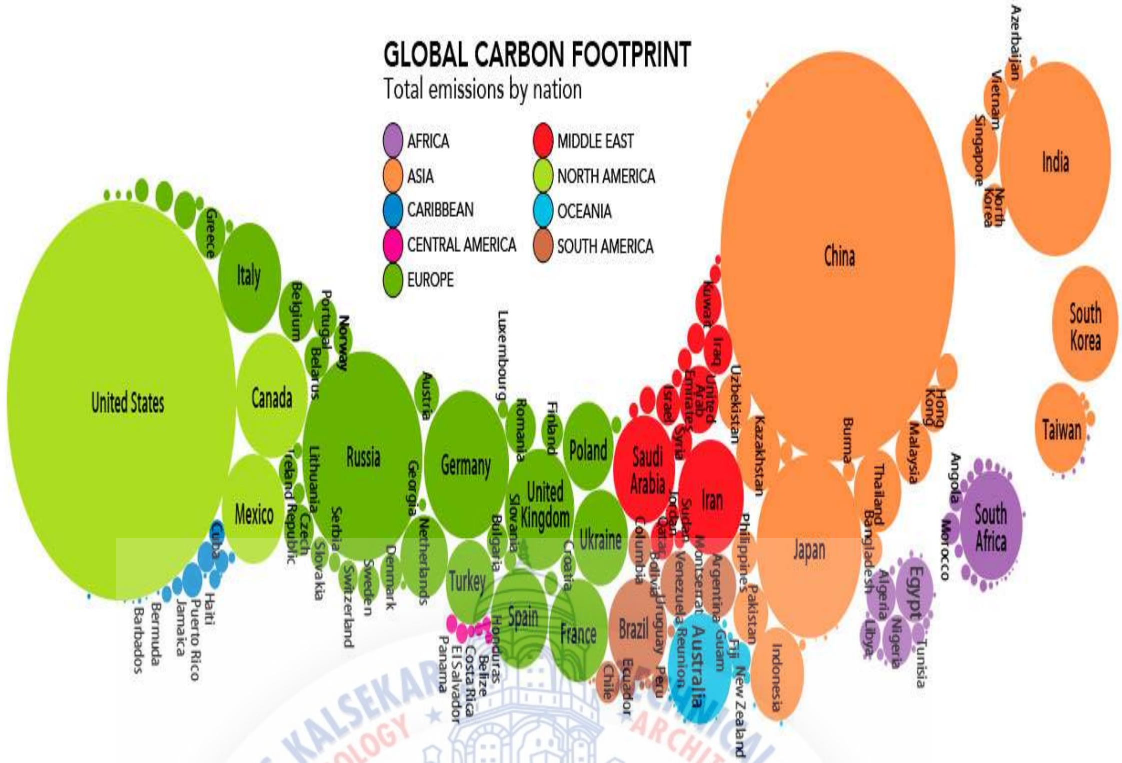

FIG:1.3 GLOBAL CARBON FOOTPRINT

Therefore, to reduce the carbon footprint, we are eliminating Portland cement and replacing by mineral admixtures and SCM's. The details of the same shall be explained in forth coming chapters.

1.3 Types of Concrete

Since history, development of concrete has made a new phase in industry. Following are the types of concrete

1. According to Indian standard Classification
   - Ordinary concrete M10 – M20
   - Standard concrete M25 – M60
   - High strength and high performance concrete M65 – M100

2. As per development in concrete and construction industry
   - GGBS or Slag based concrete
   - Light weight concrete
   - High density concrete
   - High volume fly ash concrete

- Silica fume or alcofine concrete
- Ternary blend concrete
- Coloured concrete
- Pervious concrete
- Foam concrete
- Floating concrete
- Self-compacting concrete
- Fibre reinforced concrete
- Water proof concrete
- Temperature controlled concrete
- Green concrete or sustainable concrete or geo-polymer concrete

3. As per Concrete Mixes
   - Nominal concrete
   - Design mix concrete

1.4 Background of Geopolymer

Geo-polymer chemistry was first developed by Prof. Joseph Davidovits, a French chemist in the year 1972 at the Cordi-Geopolymere private research laboratory, Saint Quentin, France. In June 1998, first European conference was held on “soft mineralogy” at university of technology of Compiegne by geo-polymer institute. The second conference was held in June July 1999 in Saint Quentin, France which welcomed 32 research papers presented to 100 scientists from over 12 countries. Third conference was help in Australia in 2002 in Melbourne university with an aim of “turn potential into profit”. Properties and uses of GPC are being explored in many scientific and industrial disciplines, modern inorganic chemistry, physical chemistry, colloidal chemistry, minerology and geology and in all types of engineering technologies.

A major catastrophic fire took place at a night club in France which claimed the lives of many people. The entire interior of the night club was decorated with polyurethane and paper meshes for architectural appearances which proved to be the cause of spreading of fire across the entire night club within no time. Thus, Prof Joseph Davidovits made a statement saying “a material has to good in appearance as well as fire resistant. Nature states, selected inorganic materials are fire resistant so I developed inorganic polymer.” The product so obtained was inorganic and was a cross linked structure and he coined the word “geo-polymer.”

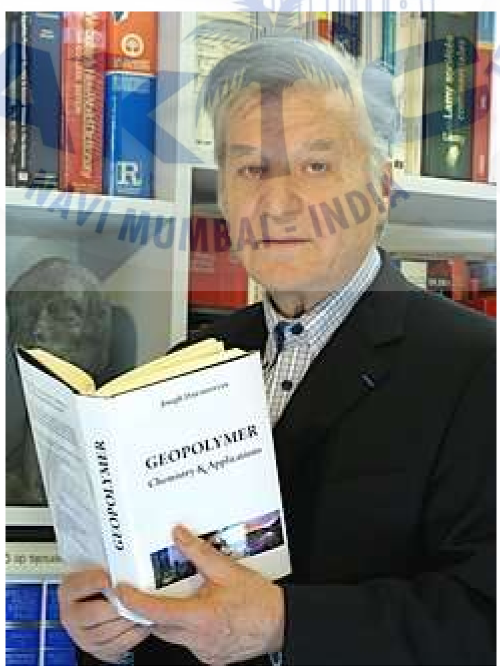

FIG :1.4 PROF JOSEPH DAVIDOVITS

1.5 Aim and Objectives of present study

1. To study the effect of molarity of sodium hydroxide on mechanical properties of hardened concrete.
2. To study the effect of curing methods on mechanical properties of concrete.
3. To study the gain of strength of geo-polymer concrete in 1,3,7,28 days after curing.
4. To carry out the cost analysis of geo-polymer concrete with conventional Portland cement concrete.

1.6 Methodology

1. Study of literature and collection of data for the same
2. Procurement of materials
3. Visual inspection of materials
4. Laboratory test on materials
5. Mix design calculations
6. Trial mixes
7. Correction of mix design after trials if any
8. Final casting of cube moulds and cylinder moulds whose dimensions confirm to IS.
9. Testing of cubes and collection of result data
10. Interpretation of results and discussions
11. Concluding remarks.

CHAPTER 2

LITERATURE REVIEW

2.1 General.

Although strength is the first and biggest parameter which an engineer sees in his concrete. Other than strength, mechanical properties such as split tensile strength, elastic modulus and flexural strength along with shrinkage, creep, etc. plays a key role in durability of concrete. These can be worked out by good quality control on concrete but a challenge in geo-polymer concrete is the compatibility and suitability of those materials with each other.

2.2 Review of equations and other criteria

1. Testing of cubes for compressive strength

Although the cube strength of concrete does not represent the actual strength of concrete in the structure, it is an important test to consider while establishing quality control measures. Cube strength tests are a good indicator of the potential strength of the mix and is a good measure of variance on the strength achieved on site.

Strength or compressive strength of concrete is defined as per IS 456:2000 as follows

- Characteristic compressive strength of a cube measuring 150mm x 150mm x 150mm cube at the end of 28 days
- Characteristic compressive strength of mortar measuring 100mm x 100mm x 100mm at the end of 28 days.

Some points to remember while testing cubes for compressive strength.

- At least three samples per batch of concrete are cast to monitor strength development over time to give good statically validity of the test result.

- Cube are casted in accordance with the relevant standards and care is taken to achieve proper compaction of concrete as influence of voids and honeycombing due to improper compaction can result in false values.
- Rate of loading maintained not more than $14 N/mm^2$
- Measured results must follow certain acceptance criteria need to be referred to for correctly accepting and rejecting the measured results.
- The acceptance criteria according to IS 456:2000 states that – the mean strength determined for any group of four consecutive test result should comply with following condition…

For mixes M15

Mean strength $\geq fm + 0.825 \times s.d$

$\geq fm + 3 N/mm^2$

For mixes M20 and above

Mean strength $\geq fm + 0.825 \times s.d$

$\geq fm + 4 N/mm^2$

2. **Split tensile strength of concrete**

 i As per IS 456:2000, clause 6.2.2

$$E = 0.7 \sqrt{fck} \quad \text{.......................... (1)}$$

 ii As per ACI 318-95

$$E = 0.94\sqrt{fck} \quad \text{............................ (2)}$$

2.3 Review of Literature

1. **Joseph Davidovits et al (1978)** explained about geo-polymer chemistry and their production along with the correct scientific definition, concept and chemical structure.

2. **Shankar H Sanni and B Khadiranaikar et al, (2000)** prepared the alkali solution with sodium silicate to sodium hydroxide ratio varying as 2, 2.5, 3, 3.5 for all grades of geo-polymer concrete mixes. Sodium hydroxide of 8 M concentration

was prepared and superplasticizer dosage of 1.5% by mass of fly ash was adopted. The chemical admixture i.e. superplasticizer (HRWRA) labelled as "CONMIX SP - 430". The geopolymer concrete specimens were kept in mould for 48 hours and then demoulded and kept in curing for 24 hours at 60° C. 5 specimens each of cube and cylinder and each of grade M30, M40, M50 and M60 was prepared.

3. **Joseph Davidovits et al (2002)** illustrated 30 applications of geo-polymer concrete based on Si:Al ratio which attracted interests of 100 scientific research papers from 12 countries.

4. **D. Hardjito and B.V. Ranjan (2004)** studied the properties of low calcium fly ash based geo-polymer concrete. They varied the concentration of sodium hydroxide from 8M to 16M with difference of 2M each. Proper well graded aggregates were used i.e. 20mm, 14mm and 7mm in proper propositions. Naphthalene sulphonate super plasticizer was used labelled as "RHEOBULD 100". The specimens were wrapped and kept in curing along with mould and cured after a period of 1 day for 24 hours at 60°C.

5. **R. Anuradha, V. Shreevidya, Venkatashubram and B.V.Ranjan (2005)** developed a mix design of geopolymer concrete in accordance with the IS method with some modification. They modified the equation which is used to calculate the quantity of coarse and fine aggregates based on total volume of concrete with percentage air entrainment and specific gravity of the aggregates. The sodium hydroxide concentration was varied from 10M to 14M. Various graphs were developed viz. "compressive strength v/s fly ash content", "compressive strength v/s alkali solution to fly ash ratio" and "compressive strength v/s percentage in sand."

6. **Madeshwaran, Gopalakrishan.N (2007)** produced geopolymer concrete using both fly ash and GGBS in varying proportion and ratios. They even used 100% GGBS in production of geo-polymer concrete. The sodium hydroxide concentration varied from 3M to 7M with alkali solution to geopolymer solids ratio as 0.65.

7. **Committee of concrete institute, Australia (2011)** gave a brief explanation and correct practise for geo-polymer concrete production. They not only used sodium system. But also, potassium system as reagents (activators). They studied the effect of different curing methods and techniques on geo-polymer concrete which includes ambient atmospheric curing, dry heat curing, steam curing and wet curing along with the effect of curing temperature and curing time. They studied the mechanical properties of hardened concrete such as split tensile strength, modulus of rupture and developed their own empirical equations for the same derived from ACI codes.

2.4 Concluding remarks

After a thorough study of previous works and literatures, we conclude the following points.

- Molar concentration of sodium hydroxide plays a key role in compressive strength of concrete.
- With some modifications in the equation of IS code, geopolymer mix can be designed.
- On developing various mix design by adding various trial contents of sand and other cementitious materials, their optimum quantity as well as its effect on geopolymer concrete can be determined.
- The ultimate aim to develop such a concrete is to reduce global carbon dioxide emissions and move towards a sustainable development.
- Geopolymer binders is not limited to use in geopolymer concrete, but in variety of applications depending upon its Si : Al ratio.
- Geopolymeric materials are fire and heat resistant, which serves the main aim of developing this inorganic geopolymer.

CHAPTER 3

GEO-POLYMER INVENTORIES

3.1 General

Inventories is nothing but materials, materials used in the production of geo-polymer concrete. The materials are similar to that used in high strength and high performance concrete depending upon its use and necessity.

Use of mineral admixture (pozzolans) as a partial replacement of cement in concrete is well accepted practice in Indian Concrete Industry as well as in the rest of the world. The most widely used mineral admixtures in India is fly ash and GGBS. Although other products such as silica fume, Metakaolin, Rice Husk Ash and natural pozzolan are sometimes utilized, their use is very limited either due to high cost or due to non-availability of materials.

Some of these mineral admixtures are waste products of different power and thermal plants, thus pose a serious waste disposal problem and high amount of finance is required to dispose to them. Hence, by using them in concrete as a partial or total replacement of cement in concrete, can enhance its mechanical concrete as compared to just using OPC. Now a days PPC and PSC are used widely in construction industry.

A brief description of all the constituent materials which are and can be used to make geo-polymer concrete are displayed below. They include.

1. PFA
2. GGBS
3. Alkali solutions or CLS
4. Coarse and fine aggregates

6. Water
7. SCM's

1. PFA

The first reference to the idea of utilizing coal fly ash in concrete was by McMillan and Powers in 1934 and in subsequent research (Davis et al., 1935, 1937). In the late 1940s, UK research was carried out (Fulton and Marshall, 1956) which led to the construction of the Lednock, Clatworthy and Lubreoch Dams during the 1950s with fly ash as a partial cementitious material.

Fly ash, the most widely used mineral admixture in concrete, is a by-product of combustion of pulverised fuel coal in electric furnace power generating plants at 1250° C to 1600° C. Upon ignition in the furnace, most of the volatile matter and carbon in the coal are burned off. During combustion, the mineral impurities of coal (such as clay, feldspar, quartz and shale) fuse in suspension and are carried away from the combustion chamber by the exhaust gases. In the process, the fused material cools and solidifies into spherical glassy particles called 'FLY ASH'.

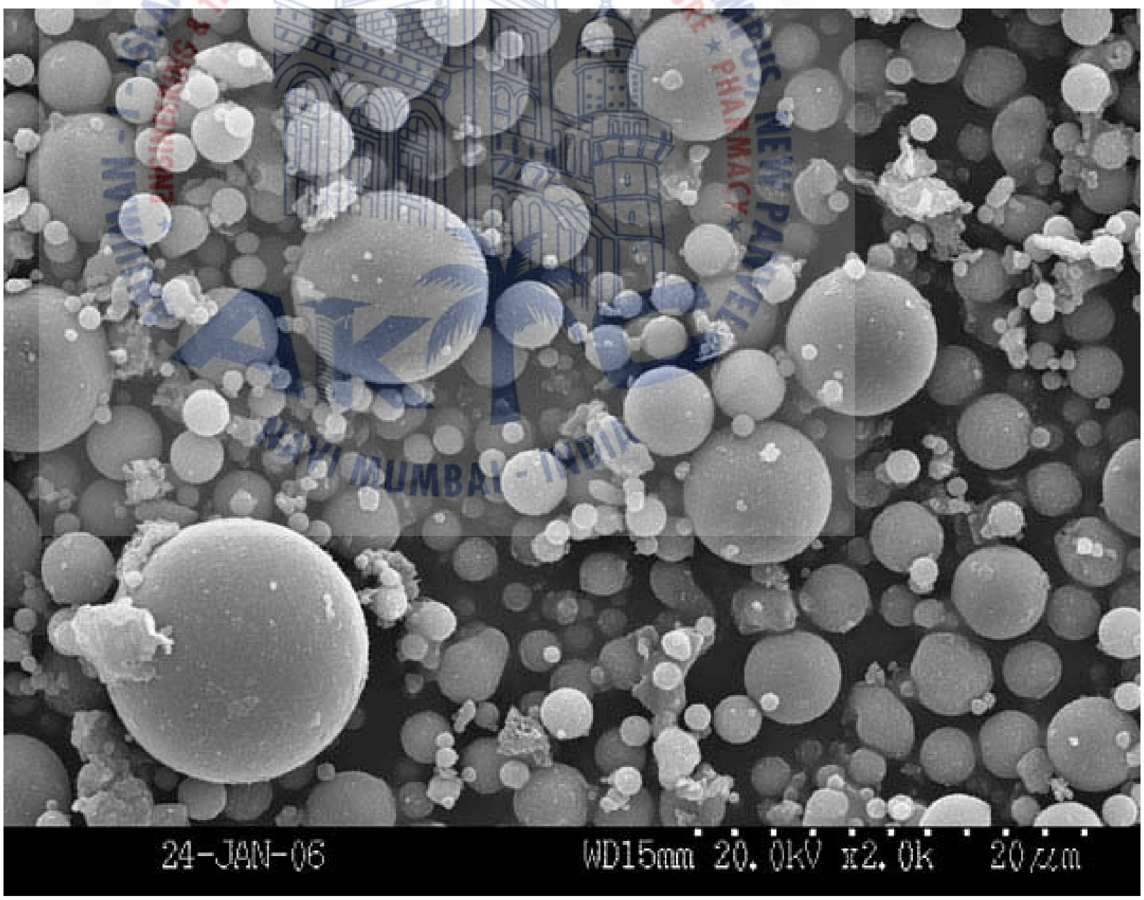

FIG 3.1: SCANNING ELECTRON MICROSCOPE (SEM) IMAGE OF FLY ASH PARTICLES MAGNIFIED 1000X.

The particle sizes in fly ash vary from less than 1µm to more than 100µm with the typical size measuring less than 20µm. Only 10 to 30% of the particles by mass are larger than 45µm. The relative density of fly ash normally ranges between 1.9 and 2.2 and the colour is generally grey.

FIG 3.2: FLY ASH AVALIABLE IN MARKET

There are two types of fly ash, according to the classification in ASTM 618, Class F and Class C. Class F ash is the true pozzolanic material, silica (as SiO2) being the most important constituent, and alumina and iron oxide are also active. Class C ash also contains appreciable amounts of calcium compounds and may have some minor hydraulic cementing value in the absence of cement. IS 3812 - Part 1 classifies fly ash as siliceous pulverized fuel ash and calcareous pulverised fuel ash i.e. class F and class C respectively as mentioned above which was classified by ASTM. Both classes of fly ash are commonly used as pozzolanic admixtures for general purpose concrete, though availability of Class C fly ash is less in India.

Class f materials are generally low calcium (less than 10% CaO) fly ashes with carbon contents usually less than 5%, but some may have as high as 10%. Class C materials are often high calcium (10% to 30% CaO) fly ashes with carbon contents less than 2%.

Class F fly ash was procured from ACC RMC near Taloja MIDC road, Lodha palava city for our geo-polymer concrete. As it was obtained from RMC, we assume it to be as per specifications of IS. The typical details of fly ash requirements according to Indian standards are given overleaf.

The use of fly ash in concrete is facilitated in two ways i.e. using pre-blended cement or separately mixed with OPC. Here we are using in proportion with GGBS as it is a concrete without cement.

TABLE 3.1: CHEMICAL REQUIREMENTS OF FLY ASH AS PER IS 3812 PART 1

Sr. No	Chemical characteristics	SPF (%)	CPFA (%)
1	$SiO_2 + Al_2O_3 + Fe_2O_3$	> 70	> 50
2	SiO_2	> 35	> 25
3	Reactive SiO_2	> 20	> 20
4	MgO	< 5	< 5
5	SO3	< 3	< 5
6	Alkali as Na_2O equivalent	< 1.5	< 1.5
7	Total chlorides Cl	< 0.05	< 0.05
8	LOI	< 5	< 5

TABLE 3.2: PHYSICAL REQUIREMENTS OF FLY ASH AS PER IS 3812 PART 1

Sr. No	Physical characteristics	SPFA AND CPFA
1	Specific surface	>320 m^2/kg
2	Sieve residue on 45µm	<34 %
3	Lime reactivity	>4.5 N/mm^2
4	Compressive strength at 28 days	>80% of plain cement mortar in N/mm^2
5	soundness	0.8 %

2. GGBS

Blast furnace slag is produced as a by-product during the manufacture of iron as a blast furnace. It results from the fusion of limestone flux with ash from coke and siliceous and aluminous residue remaining after the reduction and separation of iron from the ore. Slag is rapidly cooled with water to form a glassy disordered structure. If the slag is allowed to cool too slowly this allows a crystalline well-ordered structure to form which is stable and non-reactive. The properties of cementitious and pozzolana materials depend on their chemical composition, their physical state, and their fineness. This is particularly the case with blast-furnace slag. Since it is a by-product of the production of iron, its composition may differ from different sources but is likely to be reasonably consistent from a given source.

However, to develop satisfactory properties it is essential that the molten slag be rapidly chilled (by quenching with water) as it leaves the furnace. This causes the slag to granulate, that is, break up, into sand-sized particles. More important it causes the slag to be in a glassy or amorphous state in which it is much more reactive than if allowed to develop a crystalline state by slow cooling. In the latter state, it is suitable as a concrete aggregate but not as a cementitious material. It is important to note that the unground granulated material does not make a good fine aggregate because often the grains are weak, fluffy conglomerates rather than solid particles. To use as a cementitious material, the granulated slag must be ground as fine or finer than cement. The fineness of grind will (along with the chemical composition and extent of glassiness) determine how rapidly the slag will react in concrete.

In north America 20 to 30% GGBS has been used as a partial replacement of cement which increases the mechanical properties of concrete. Now a day 50% GGBS as a partial replacement of cement is being used. In our college, AIKTC, new Panvel, 5% GGBS as a partial replacement of cement has been used for design of high strength concrete.

In our project on geo-polymer modified concrete, we are not using OPC. This is completely replaced by GGBS and fly ash to produce green concrete. The GGBS reactivity is being discussed in later chapters.

The chemical composition of slag will vary depending on the source of the raw materials and the blast furnace conditions. The major oxides exist within the slag in the form of a network of calcium, silicon, aluminium and magnesium ions in disordered combination with oxygen. the oxide composition of GGBS is tabulated below.

TABLE 3.3: OXIDE COMPOSITION OF GGBS AND PORTLAND CEMENT

Oxide composition (%)	Portland cement	GGBS
CaO	64	40
SiO_2	21	36
Al_2O_3	6	10
Fe_2O_3	3	0.5
MgO	1.5	8.0
SO_3	2	0.2
K_2O	0.8	0.7
Na_2O	0.5	0.4

TABLE 3.4: PROPERTIES OF GGBS FOR USE IN CONCRETE

Property	Standards	Requirements
Glass content	IS 12089:1987	>85%
Blaine's fineness	BS EN 15167:2006	>275 m3/kg
Compressive strength	BS EN 15167:2006	7 days > 12MPa 28 days > 32.5MPa
Initial setting time	BS EN 15167:2006	Not less than OPC
Soundness	BS EN 15167:2006	<10mm

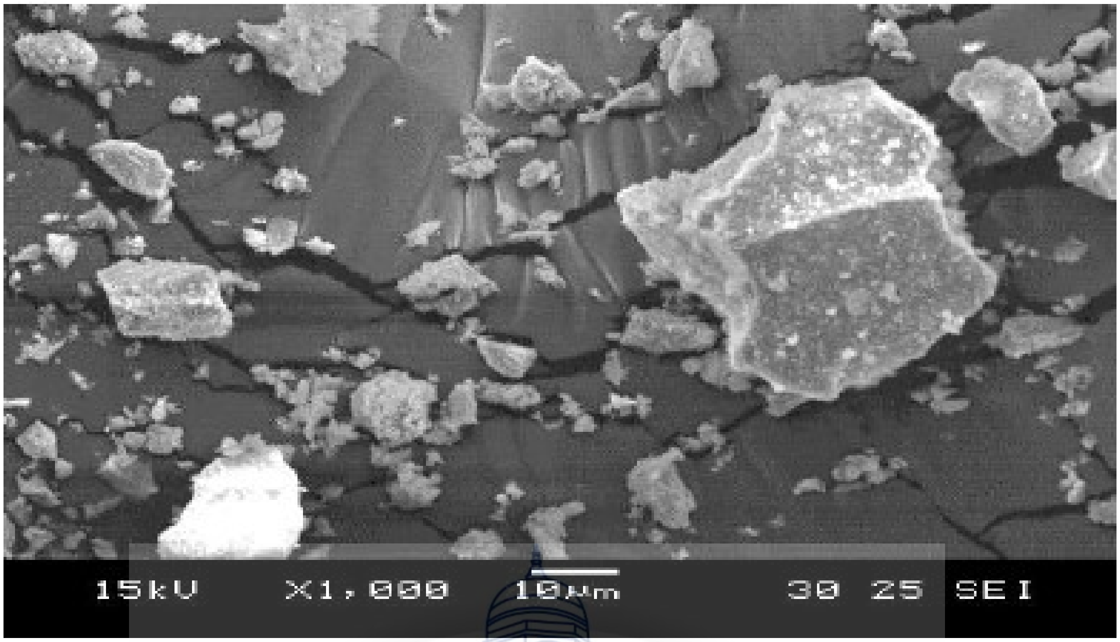

FIG 3.3: SEM OF GGBS

FIG 3.4: AVALIABLE GGBS IN MARKET.

GGBS is used on a large scale in concrete due to its stability than fly ash. Following points throws a light on the preferred use of GGBS over fly ash which are briefed overleaf.

- To use as a cementitious material, the granulated slag must be ground as fine or finer than cement. The fineness of grind will (along with the chemical composition and extent of glassiness) determine how rapidly the slag will react in concrete.
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Applications of GGBS are as follows.

- All types of residential, commercial and industrial complexes.
- Dams and other mass concrete works
- Water retaining structure.
- Concrete roads and flyover
- All civil structural works
- Idea for using in marine construction
- Precast concrete product
- Foundation and pile construction
- Increased flexibility to meet individual requirement in RMC.

Advantages of GGBS

- Reduction in heat of hydration and thermal cracks.
- Permeability and surplus lime released out of OPC to form into secondary hydrated minerology.
- Pore and grain refinement due to secondary hydrated minerology, thus contributing for permeability and enrichment of transition zones.
- For the alkalination and production of 100% green durable concrete.

3. **Alkali solutions and catalyst liquid system.**

The alkali solution is used for alkalination of GGBS thus leading to polymerization which results in geopolymer binder. Sodium hydroxide and sodium silicate is used as mediums to form alkali solutions. Sodium hydroxide and sodium silicate was purchased from T A corporations, Chembur. Different concentrations of sodium hydroxide solution were prepared in the Lab. Sodium silicate of 40% concentration and required grade was added to sodium hydroxide solution and the alkali solution was prepared.

This solution was prepared 1 day prior to be used and consumed within 36 hours.

The solution was prepared and kept covered at room temperature for gel formation.

FIG 3.5: SODIUM HYDROXIDE PELLETS IN LAB.

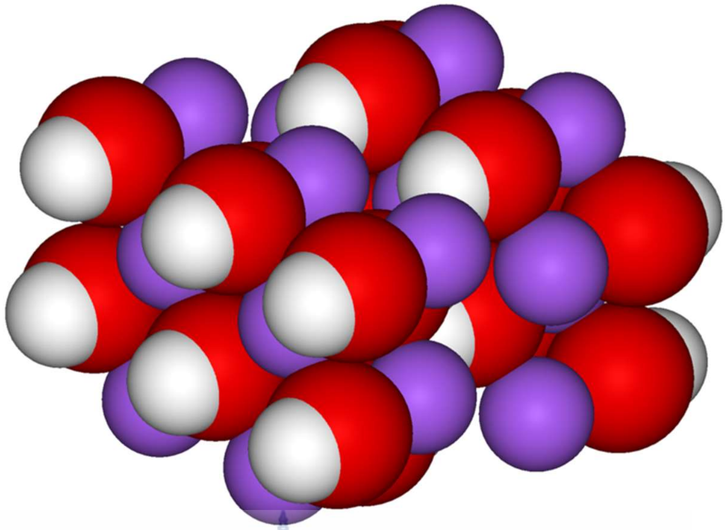


FIG 3.6: CRYSTALLOGRAPHY OF SODIUM HYDROXIDE PELLETS. (MOLECULAR PACKING)

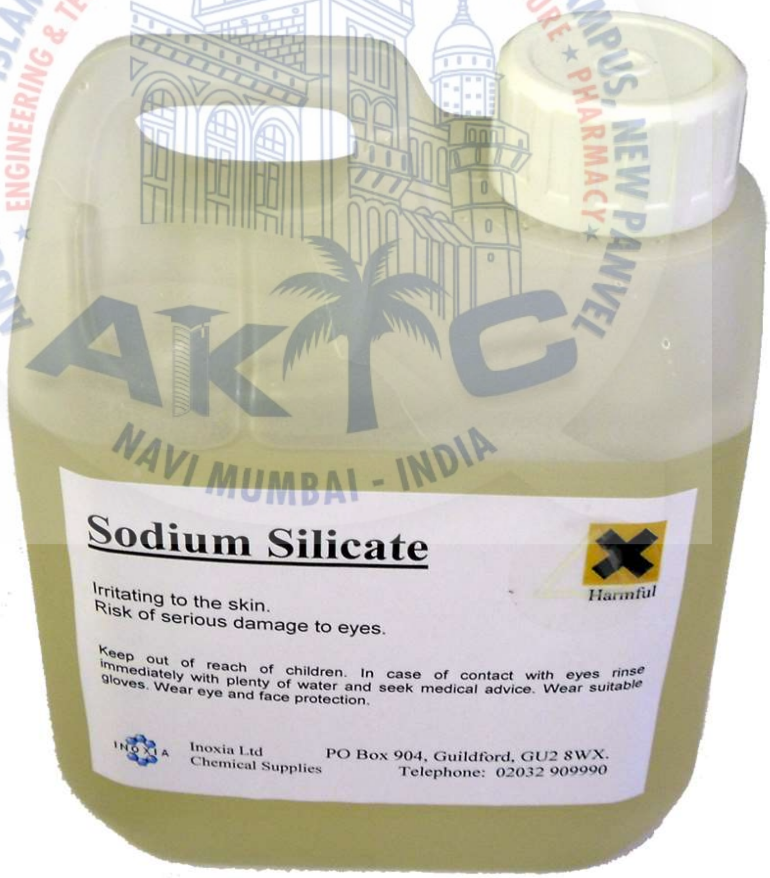


FIG 3.7: SODIUM SILICATE SOLUTION.

4. **Coarse aggregates (metal 1 and metal 2 aggregates)**
Aggregates provide about 75% of the concrete volume making it a very important constituent. They should meet certain requirements with respect to grading, shape, size and strength. Though they are considered inert, they exhibit certain reactivity which is popularly known as AAR (alkali aggregate reactivity or reaction). Since our geo-polymer concrete is highly alkaline due to sodium hydroxide hence AAR marks significance importance.

Here metal 1 and metal 2 coarse aggregates were procured from local contractor working on our college site. Various lab tests are conducted on these aggregates to ensure that they are well graded along with other properties essential for in corporating into mix design of concrete.

Fig 3.8: CA METAL 1 AGGREGATE

FIG 3.9: CA METAL 2 AGGREGATES

Another classification of aggregates are bulleted below which include

- Classification based on source
- Classification based on weight
- Classification based on shape
- Classification based on geology
- Artificial aggregates

Most concretes contain aggregates of maximum size 40mm or 20mm and grading going down to 150 microns or even smaller. At times, maximum aggregate size of 10mm is also used. For massive work or large unreinforced pours, MSA of 150mm or above is used. In and around Mumbai crushed downgraded aggregates are generally screened through rotating screens having a rounded mesh of 1 to 0.5 inch in diameter. Hence crushed aggregates are available with maximum size of 30mm and 15mm respectively. Economical concrete is produced by using as large as MAS as possible as this reduces the amount of cement required in concrete due to reduction of surface area per unit weight of the aggregates. It is therefore recommended to use as large as MAS as possible (depending upon the condition of concreting).

The limitations of MAS can be due to following reasons.

- The maximum dimensions of the concrete section to be casted should not be less than about four times the MAS.
- The concrete cover to be embedded steel generally should not be less than the MAS or better still it should be 5mm more than the MAS.
- For densely reinforced concrete members, MAS is generally restricted to 5mm less than the minimum clear distance between the main bars.

Coarse aggregate is the predominant constituent of concrete. Hence, naturally, properties and characteristics of fresh and hardened concrete ae significantly affected by the properties of coarse aggregate. Of course, characteristics of concrete are also affected by the properties of other constituent materials like cement, fine aggregates, chemical and mineral admixtures, SCM’s etc. in addition to this, concrete performance is also affected by proportionating of constituent materials, method of mixing, transporting, placing, compaction and curing.

TABLE 3.5: PROPERTIES OF COARSE AGGREGATE AND ITS INFLUENCE ON CONCRETE PROPERTIES.

Properties	Influence on concrete performance
Specific gravity / porosity	Strength / absorption and density of concrete
Chemical stability	Durability, AAR
Surface texture	Bond grip
Gradation of particle size distribution	Water demand (strength), cohesion, bleeding and segregation, cement consumption and low void ratio
MAS	water demand, cement consumption and strength
Deleterious materials	Water demand, bond, cohesion and durability, workability, setting and hardening of concrete.
Shape	Water demand, packing.

5. **Fine aggregates**

Fine aggregates are finer in size less than 4.75mm. its size ranges from 4.75mm to 150 microns. A fraction finer than 150 microns is considered as dust or silt. Due to development in construction and infrastructure, fine aggregates are available in various categories like manufactured sand - famously known as M-Sand, river or natural sand, Gujarat sand, etc. Gujarat sand was procured from a local contractor from our college site.

FIG 3.10: GUJARAT SAND

Fineness of aggregate play a key role. It is very important to know the fineness of aggregate as they significantly influence the water demand of the concrete mix or in other words strength. Fine aggregates are classified in four zones. While zone 1 represents coarsest sand, zone 4 represents finest sand. Zone 2 and zone 3 represents medium fineness. When finer fines of fine aggregate particles, generally 600 microns passing, are in high percentage, the surface area of aggregate increase per unit weight. Larger surface area will require more cement paste to bind the aggregate particles together. Due to increase in surface area of aggregates, mix will require more water.

For selection of proportion of fine aggregates, the method given by DoE is adopted. From the percentage passing through 600-micron sieve, Zone of sand is determined.

Fine aggregate requirement should be such that coarse and fine aggregates combined should produce minimum voids. This should necessitate minimum cement paste requirement. The properties of coarse and fine aggregates will vary from place to place depending upon particle size distribution of locally available materials. The efforts should be directed to arrive at the optimum ratio to coarse aggregate to arrive at the best particle packing of aggregate.

Gradation of fine aggregate is also required and an important parameter in designing pumpable concrete. Due to gap gradation of fine aggregates, concrete becomes less cohesive and homogenous ad attain a little adhesively and hence results in choking of the pump, thus affecting the project.

6. **Water**

Water is the most critical but probably the cheapest constituents of concrete. Water requirement of fresh concrete is the water content in kg or litres per cubic meter of concrete to bring the mix to specified consistency. However, the maximum water to binder ratio required is specified as per IS 456:2000 clause 6.1.2 and 8.2.4.1 and 9.1.2, table 5.

In general, portable water can be used for mixing and curing of concrete. Algae in mixing water causes marked reduction in strength of concrete. Water used in mixing of concrete should not have Ph 6. Presence of vegetable oil in water reduces the strength of concrete particularly at the early ages. As per IS 456:2000 sea water is not used for mixing concrete. Seawater has adverse effects like high risk of corrosion of reinforced steel, possible effloresce and dampness on concrete surfaces and increased AAR.

Sea water used for mixing concrete can be used for curing subjected that the capillary pores of concrete gets totally blocked and sea water contains material harmful for concrete in permissible limits.

TABLE 3.6: PERMISSIBLE LIMITS FOR SOLIDS PRESENT IN WATER AS PER IS 456:2000

Material	Relevant IS code	Permissible limit (ppm)
Organic	IS 3025 (pt 18)	200 mg/l
Inorganic	IS 3025 (pt 18)	3000 mg/l
Sulphates (as SO_3)	IS 3025 (pt 24)	400 mg/l
Chlorides (as Cl)	IS 3025 (pt32)	2000 mg/l for PCC 500 mg/l for RCC
Suspended particles	IS 3025 (pt 17)	2000 mg/l

Water used for mixing concrete was tap water of AIKTC campus. Water was tested for Ph and chloride content in environmental engineering lab. Water tested was safe for use in concrete.

7. **SCM's**

SCM's known as supplementary cementitious materials are widely used in concrete in today's construction world. Other than GGBS and PFA, many other materials are available which are used in concrete to improve its characteristics both in fresh and hardened state. Some of the SCM's used in high strength and high performance concrete are mentioned below.

- Silica fume
- Metakaolin
- Volcanic tuffs and pumicates
- Surkhi
- Rice husk ash
- Allcofines and microfine
- Siliceous and aluminous materials, etc.

8. Chemical Admixtures

Admixtures are chemical compounds in concrete; other than hydraulic cement, water and aggregates and mineral additives that are added to concrete mix immediately before or during mixing to modify one or more of the specific properties of concrete in fresh or hardened state. These days concrete is being used for wide varieties of purposes to make it suitable in different conditions. In these conditions, ordinary concrete may fail to exhibit the required quality performance or durability. In such cases, admixture is used to modify the properties of ordinary concrete so as to make it more suitable for any situation. Some of the admixtures are listed below

- Plasticizers
- Superplasticizers
- Retarders or retarding plasticizers
- Accelerators and accelerating plasticizers
- Air entraining admixtures
- Pozzolanic or mineral admixtures
- Damp proofing and water proofing admixtures
- Air detraining admixtures
- Air entraining admixtures
- Alkali aggregate expansive inhibiting admixtures
- Workability admixtures
- Corrosion inhibiting admixtures
- Bonding admixtures

Now a day due to advancement in construction many modified admixtures are available now a day. "CONMIX SP 1080" was procured from RadheKrishna chemicals. Malad west. It is an Sulphonated Naphthalene Formaldehyde (SNF) based superplasticizer also known as High Range Water Reducing Admixture (HRWRA).

The compatibility of admixture has to be supervised before using it in concrete. Especially in geo-polymer concrete which consist of a very strong alkali like sodium hydroxide. Hence IS gives a chart based on the requirements of a chemical admixture.

TABLE 3.7: PHYSICAL REQUIREMENTS OF CHEMICAL ADMIXTURES AS PER IS 9103

Sr no	Requirements	Accelerating admixtures	Retarding Admixtures	Water Reducing admixtures	Air entraining Admixtures	Superplasticizer	
						normal	Retarding
1	Water content % of control sample (max)	-	-	95	-	80	80
2	Slump	-	-	-	-	Not more than 15mm below that of control mix concrete	
3	Setting time (hours)						
	• Initial max	-3	+3	+/- 1	-		+4
	• Initial min	-1	+1			+1.5	+1
	• Final max	-2	+3	+/-1	-	+1.5	+3
	• Final min	-1	+1				
4	Compressive strength (%) of control samples, min						
	• 1 day					140	
	• 3 days	125	90	110	90	125	125
	• 7 days	100	90	110	90	125	125
	• 28 days	100	90	110	90	115	115
	• 6 months	90	90	100	90	100	100
	• 1 year	60	90	100	90	100	100

5	Flexural strength % of control sample, min • 3 days • 7 days • 28 days	 110 100 90	 9 90 90	 100 100 100	 90 90 90	 110 100 100	 110 100 100
6	Length change % increase over control sample, min • 28 days • 6 months • 1 year	 0.010 0.010 0.010	 0.010 0.010 0.010	 0.010 0.010 0.010	 0.010 0.010 0.010	 0.010 0.010 0.010	 0.010 0.010 0.010
7	Bleeding % increase over control sample	5	5	5	5	5	5
8	Loss of workability	-	-	-	-	At 45 min, slump should not be less than 15 mins	At 2 hours. Slump not be less than 15 min of control mix
9	Air % max over control	-	-	-	-	1.5	1.5

CONMIX SP1030 is basically a high range water reducing super plasticizer admixture. It drastically reduces the amount of water required to achieve the same workability of concrete at a nominal dosage. It enhances the strength and durability of concrete. It produces extremely workable and flowing concrete without loss of strength and with reduced w/c ratio. It can be used in mass concrete work, precast concrete work, structural R.C.C construction, congested reinforcement areas, heavy industrial construction etc.

FIG 15: CONMIX SP 1030

details of this admixture are given below.

- **Technical data**
  - ✓ Appearance: Brown Liquid
  - ✓ Main Base: Sulphonated Naphthalene Formaldehyde
  - ✓ pH: 7-8
  - ✓ Chloride Content: Nil
  - ✓ Sp. Density: 1.2 at room temperature
  - ✓ Shelf Life: 12 months in original packing
- **Dosage**
  - ✓ CONMIX SP1030 can be used in all types of concrete depending upon the desired properties of strength and flowability. It can be used in various applications at different dosage rates per bag of cement. It is to be added to the gauging water (water to be mixed in concrete). It is suitable for use with all types of ordinary Portland cements and other pozzolonic materials such as PFA, GGBFS and silica fume.

- ✓ For high strength, water reduced concrete the normal dosage range is from 400ml-800ml/per bag of cementitious material, including PFA, GGBFS and microsilica. For high workability concrete the normal dosage range is from 350ml -1000ml/per bag of cement. For normal water reduced and flowable concrete a lower dosage of 100-250ml can be used. Still the user should take field trials to evaluate the appropriate dosage according to his individual requirement.
- ✓ Over dosage should generally be avoided. It can give undesired results such as delay in setting time or segregation or reduction in strengths.
- ✓ Precaution: It should not be added to dry cement. It should always be added to the gauging water or directly to the wet mix.

➢ **Advantages**

- ✓ High water reduction of 15-30 % is possible depending upon dosage
- ✓ Higher increase in strength at early ages without increase in cement content
- ✓ Increased workability, flowability & pumpability of concrete
- ✓ Easier placing, better compaction and finishing
- ✓ Improves slump and reduces permeability
- ✓ Significant cement saving without reduction in strength

➢ **Uses**

- ✓ In production of high strength flowable concrete
- ✓ To achieve high water reduction and better workability in normal strength concrete
- ✓ In areas of congested reinforcement
- ✓ In high strength, precast concrete

CHAPTER 4

GEO-POLYMER CHEMISTRY

4.1 General

A geopolymer is essentially a mineral chemical compound or mixture of compounds consisting of repeating units. For example, silico-oxide (-Si-O-Si-O-), silico-aluminate (-Si-O-Al-O), ferro-silico-aluminate (-Fe-O-Si-O-Al-O-) or alumino-phospate (-Al-O-P-O) created through a process of geo-polymerization.

Geopolymer is a Nano material. Geopolymer cement is a new kind of cement which uses a different chemistry to that found in traditional Ordinary Portland Cement (OPC). A geopolymer is made by activating amorphous alumino-silicate materials, such as fly ash and slag, with alkali-based chemicals such as sodium hydroxide and sodium silicate. Geopolymer cement does not need to contain OPC to work. Geopolymers have been known to be useful binders in concrete for over 60 years, but have recently developed rapidly in Australia due to the fact they have a CO2 footprint which is approximately 80% lower than OPC cement.

Geo-polymer cement, high alkali (K-Ca)-Poly(Sialate-Siloxo) cement, results from an inorganic polycondensation reaction, so called geo-polymerization yielding 3D zeolitic frameworks. Davidovits (1988, 1994) proposed that an alkaline liquid could be used to react with the silicon (Si) and the aluminium (Al) in a source material of geological origin or in by-product materials such as fly ash, ggbs rice-husk ash, etc. to produce binders. Because the chemical reaction that takes place in this case is a polymerization process, he coined the term geopolymer to represent these binders.

Geopolymers are members of the family of inorganic polymers. The chemical composition of the geopolymer material is similar to natural zeolitic materials, but the microstructure is amorphous. The polymerization process involves a substantially fast chemical reaction under alkaline conditions on silicon–aluminium minerals that results in a three-dimensional polymeric chain and ring structure consisting of Si–O–Al–O bonds (Davidovits, 1994).

Geo-polymerization is the process of combining many small molecules known as oligomers into covalently bonded network. The geo-chemical synthesis is carried out through oligomers (dimers, trimers, tetramers, pentamers) which provide the actual unit structure of three-dimensional macromolecular edifice

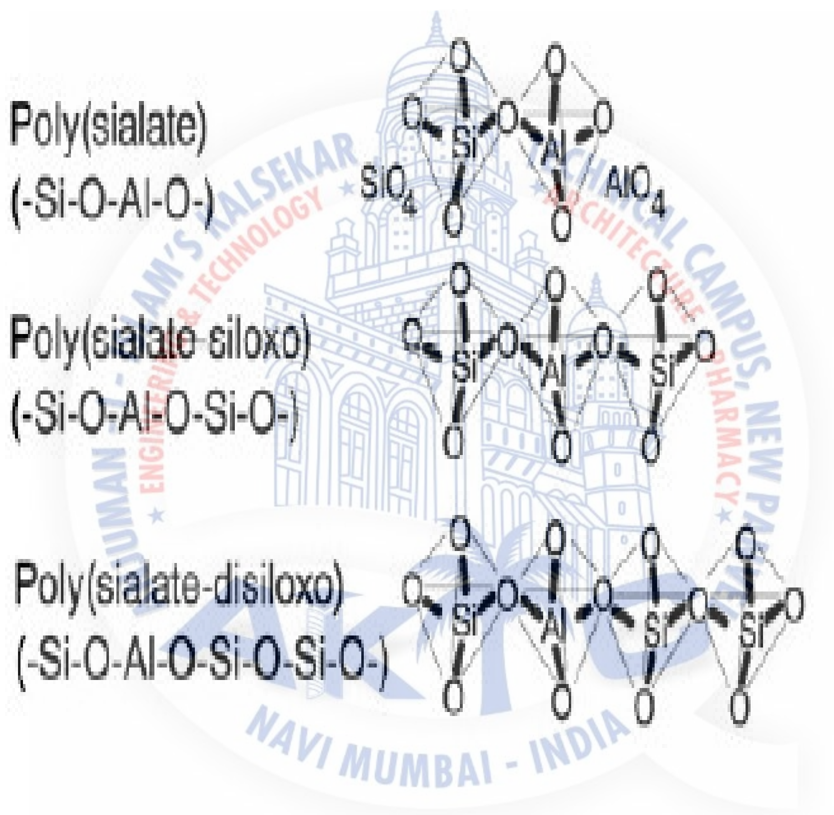


FIG :4.1 CHEMICAL STRUCTURE OF GEOPOLYMERIC REACTANTS

$$\underset{\text{(Si–Al materials)}}{n(Si_2O_5Al_2O_2)} + 2nSiO_2 + 4nH_2O + NaOH \text{ or } KOH \rightarrow Na^+, K^+ + \underset{\text{(geopolymer precursor)}}{n(OH)_3\text{–Si–O–}\underset{\substack{| \\ (OH)_2}}{Al^-}\text{–O–Si–}(OH)_3}$$

$$n(OH)_3\text{–Si–O–}\underset{\substack{| \\ (OH)_2}}{Al^-}\text{–O–Si–}(OH)_3 + NaOH \text{ or } KOH \rightarrow \underset{\text{(geopolymer backbone)}}{(Na^+, K^+)\text{–}(\underset{\substack{| \\ O \\ |}}{\overset{|}{Si}}\text{–O–}\underset{\substack{| \\ O \\ |}}{\overset{|}{Al^-}}\text{–O–}\underset{\substack{| \\ O \\ |}}{\overset{|}{Si}}\text{–O–})} + 4nH_2O$$

FIG :4.2 FORMATION OF GEOPOLYMER MATRIX

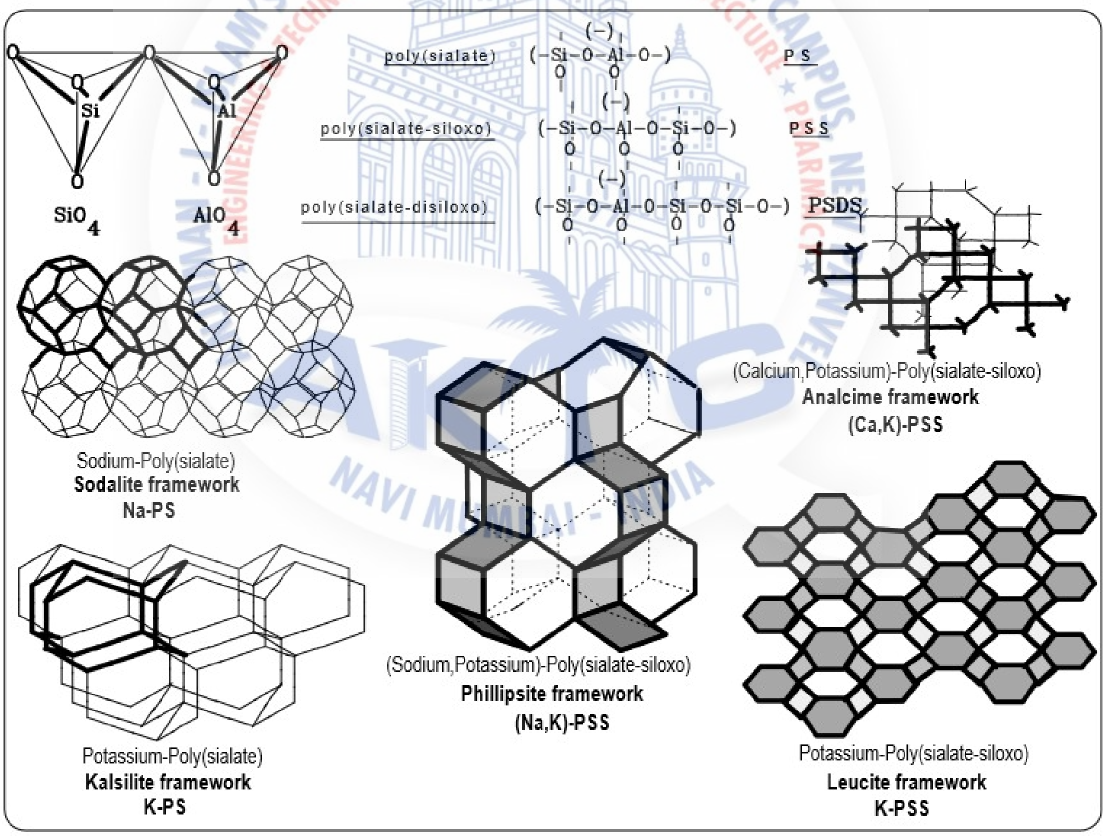


FIG :4.3 COMPUTER MOLECULAR GRAPHICS OF POLYMERIC M_n –(-Si-O-Al-O-)$_n$ POLY(SIALATE) M_n –(-Si-O-Al-O-Si-O-)$_n$ POLY(SIALATE-SILOXO) AND RELATED FRAMEWORKS.

4.2 Polymerization chemistry

Polymer means many. Hence, a polymer comprises of many molecules and bonds linked with each other to form a cross linked structure. Many macro molecules built up by linking together large number of small molecules which is n called polymer. Here, geo-polymers are made, hence geopolymer. As per the nomenclature of polymers, geopolymers are cross linked copolymer or cross linked hetropolymer.

Geopolymer is a polyfunctional polymer (tetra-functional) as Si and Al forms four covalent bonds through an oxygen atom resulting in the formation of 3-D network. It is a kind of thermosetting polymer and a type of amorphous alumino-silicate cementitous material.

The number of bonding sites in monomer is referred to its functionality. The movements of individual molecules is prevented by strong cross links.

Geopolymer cement is a binding system that hardens at room temperature, unlike that of coventional portland cement.

Geopolymer can be synthesized by polycondensation reaction of geopolymeric precursor and alkali polysilicates known as geopolymerisation process. It involves hetrogenous chemical reaction between solid aluminosilicates oxides and alkali metal silicates solution at highly alkaline conditions and mild temperatures. Geopolymerisation depends upon the valency of Si and Al (i.e. 4 - fold or 6 - fold).

Alkaline liquid or system is used to activate the source materials like silicon and aluminium in GGBS to start the polymerisation process. The polymerisation process involves a substantially fast chemical reaction under alkaline condition on Si-Al minerals, that results in a threedimensional polymeric chain and ring structure consisting of Si-O-Al-O bonds.

$$M_n\,[-(SiO_2)_z-AlO_2]_n\,.\,wH_2O$$

FIG 4.4: BASIC POLYMERISATION PROCESS

The chemical reaction may comprise of the following steps

- Dissolution of Si and Al atoms from the source material through the action of hydroxide ions.
- Transportation or orientation or condensation of precursor ions into monomers.
- Setting or polycondensation/polymerisation of monomers into polymeric structure

A geopolymer can take one of the three basic forms

- Poly (sialate), which has [-Si-O-Al-O-] as the repeating unit.
- Poly (sialate-siloxo), which has [-Si-O-Al-O-Si-O-] as the repeating unit.
- Poly (sialate-disiloxo), which has [-Si-O-Al-O-Si-O-Si-O-] as the repeating unit.

4.3 GGBS based polyerization

X-Ray micrography of GGBS shows a very complex structure. GGBS contains ghelenite (aluminosilicate of Ca^{2+}) and akerminite (magnesiumsilicate of Ca^{2+}), both are solid solutions of melilite. Melilite is a type of crystalisation substance. Both these materials react under an alkaline medium, typically called as alkalination of GGBS.

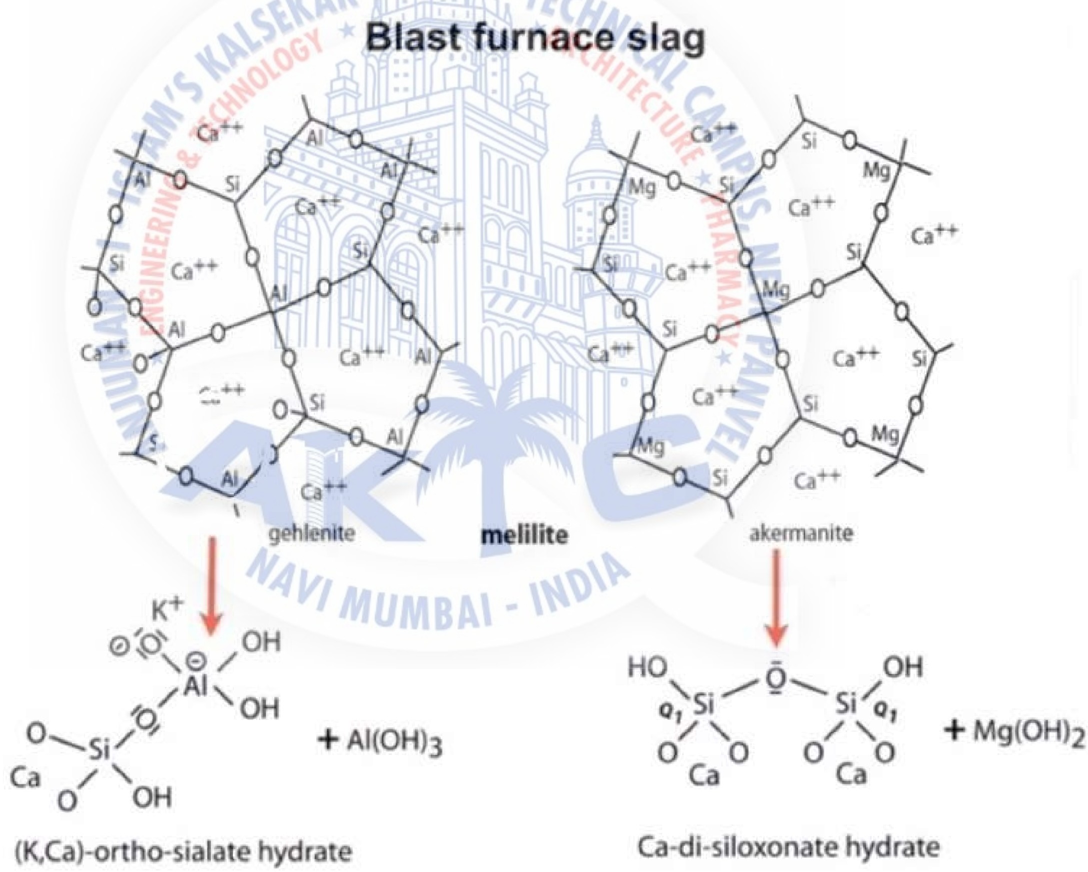


FIG 4.5: FORMATION OF INTERMEDIATE PRODUCT AS A RESULT OF ALKALINATION WITH GGBS

The intermediate by products like aluminium hydroxide and magnesium hydroxide are generated which gets consumed in the reaction. The calcium ions trapped inside and those which are freely avaliable serves the same purpose like that of calcium compounds in cement. The second intermediate product Calcium di siloxonate hydrate serves as a partial binder like that of C-S-H during cement hydration. This will again polymerise and form a cross linked matrix called geopolymer matrix.

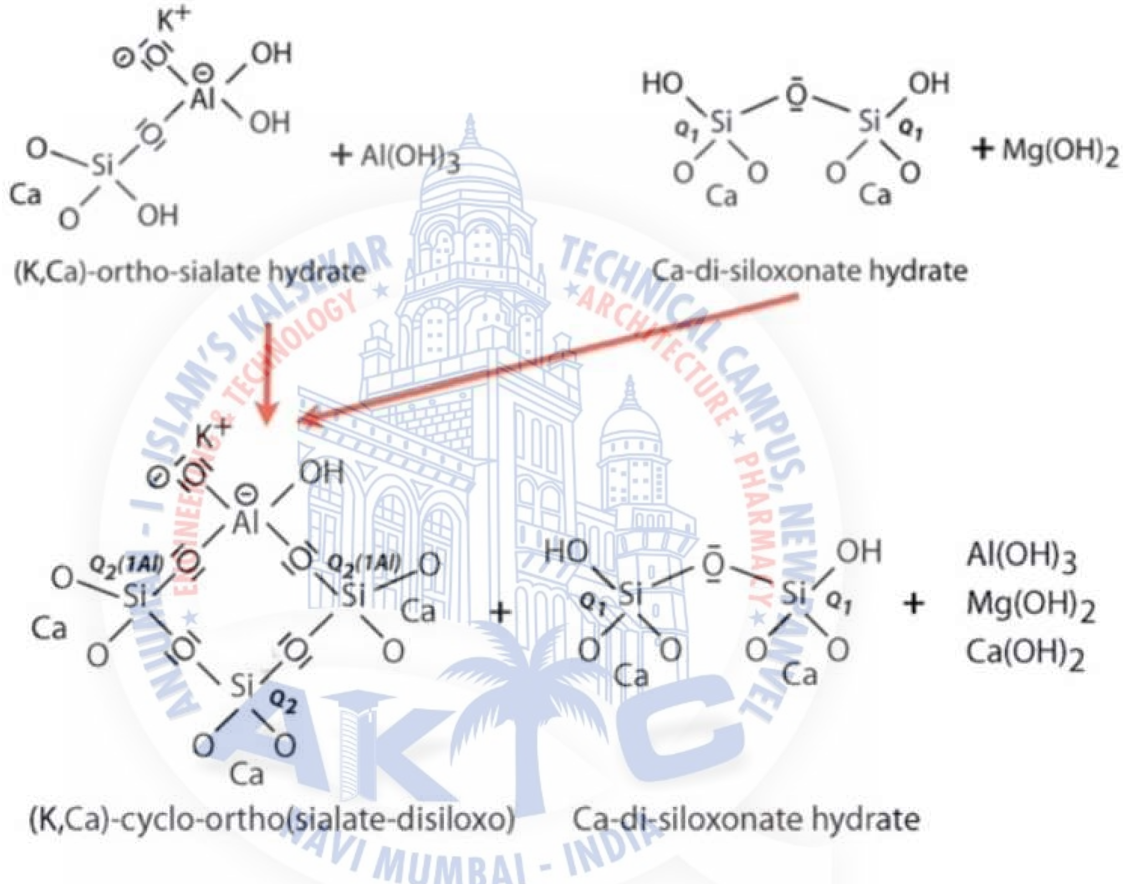


FIG 4.6: 2ND STAGE POLYRISATION RESULTING IN MORE STRONGER COMPOUNDS AND BINDERS.

The intermediate products viz. calciu ortho sialate hydrate and calcium di siloxonate hydrate react and combine to form calcium cyclo ortho sialate disiloxo and calcium di silixonat hydrate along with hydroxides of calcium, aluminium and magnesium as precipitates. The calcium di siloxonate hydrate formed in this stage of polymerisation results in more stronger binder like that of C-S-H formed due to hydration of cement paste after initial setting time. The calcium hydroxide formed during polymerisation reacts with excess sodium hydroxide present and thus form C-(Na)S-H gel resulting in the formation of inorganic polymer. The reaction mechanism of calcium hydroxide with an alkali is shown below

GGBS + Water + $Ca(OH)_2$ + NaOH / KOH = C(Na,K)-S-H gel

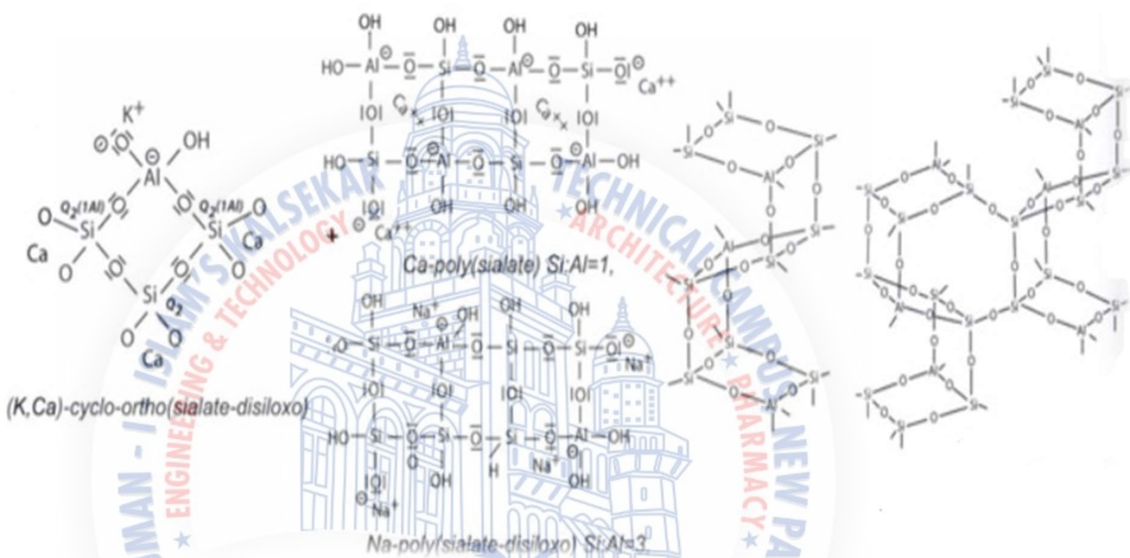


FIG 4.7: FINAL STAGE POLYCONDENSATION RESULTING IN FORMATION OF 3D CROSS LINKED POLYMERIC CHAIN.

As calcium cyclo ortho sialate disiloxo is unstable, it tries to form covalent bondings with the species of its same nature. Thus it undergoes polycondensation with metakaolin and forms calcium poly sialate disiloxo and sodium poly sialate disiloxo which immediately combines and reacts together to form a stable 3D polymeric chain known as a result of alkalination of GGBS in presence of strong alklais.
The aluminosilicate kaolinite at 100 to 150 ° C and polycondenses into hydrated sodalite or hydrosilicate or hydrosaodalite.

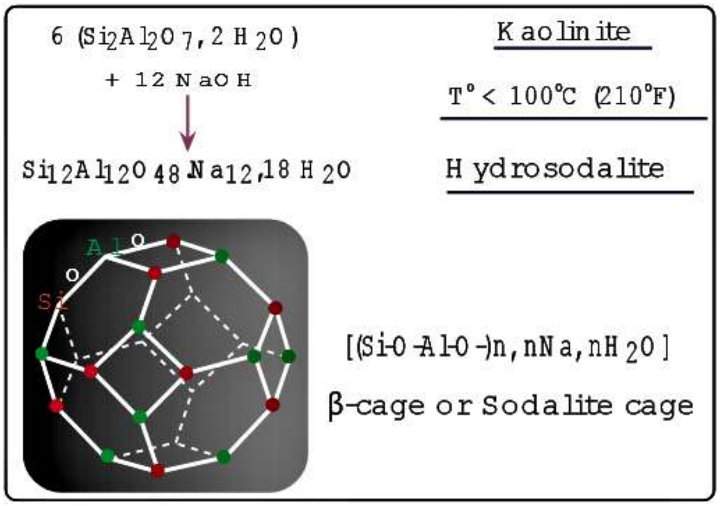


FIG 4.8: CAGE OF GEOPOLYMER PRECUSER ON INITIAL ALKALINATION.

The conclusion and overall scenerio remains similar. Hydration of cement paste results in the formation of C-S-H gel which is responsible for binding the coarse aggregates, fine aggregates and other loose materials. Alkalination of GGBS to form inorganic polymeric chain results in the formation of similar C-S-H edifice along with alkalis which is responsible for binding the aggregates and the loose materials in concrete.

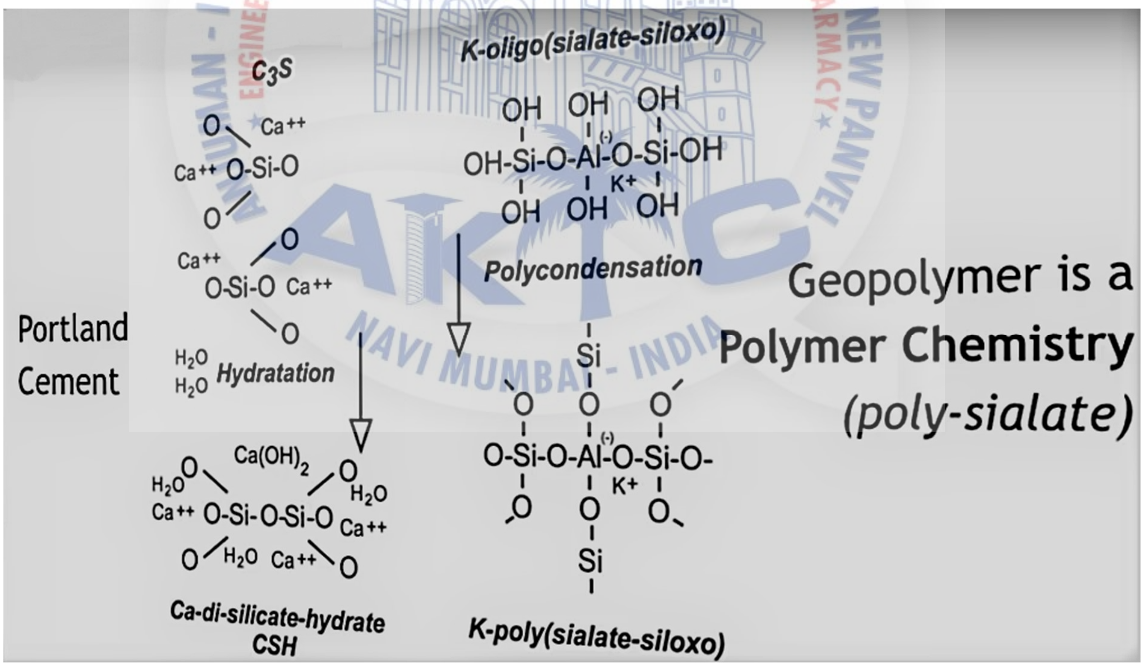


FIG : 4.9 REACTION MECHANISM OF PORTLAND CEMENT V/S GEOPOLYMERISATION

Here, the only difference between reaction mechanism of portland cement and geopolymer binder is the initial reactants. In case of portland cement, cement reacts with water to form a hydrating gel i.e C-S-H binder. It is an exothermic reaction and sets in the initial setting time. In case of geopolymer binders, alkalination of GGBS with strong alkali like NaOH or KOH reacts to form intermediate products which polycondenses to form calcium polysialate siloxo i.e. C-S-H binder. This process is not exothermic, but the initial making of sodium hydroxide solution is exothermic depending upon its molar concentration. Setting time of geopolymer binder depends upon the concentration of alkalination. Initial setting time is greater as copared to portland cement.

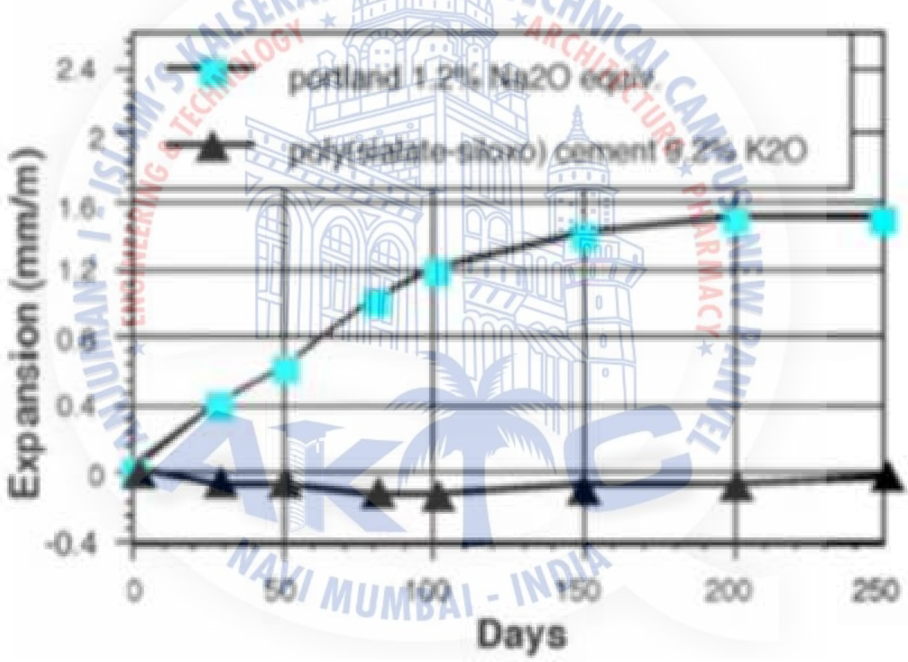


FIG 4.10: ALKALI AGGREGATE REACTIVITY OF PORTLAND CEMENT V/S GEOPOLYMER CONCRETE.

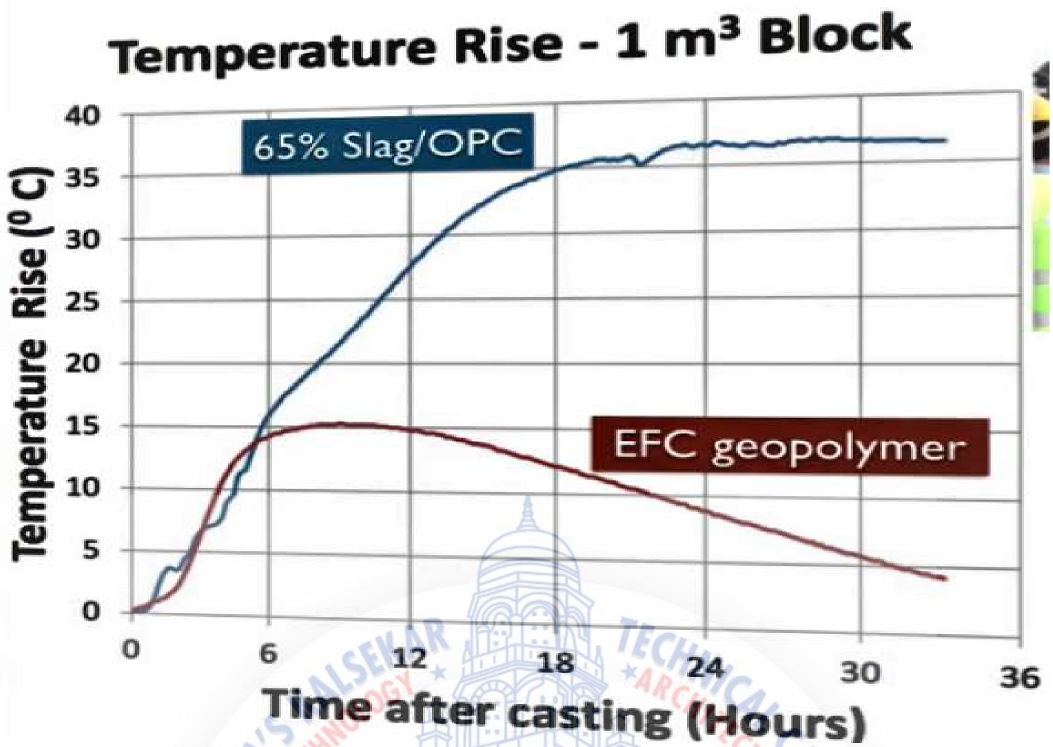


FIG 4.11: HEAT OF HYDRATION OF PORTLAND CEMENT V/S GEOPOLYMER CONCRETE BINDER

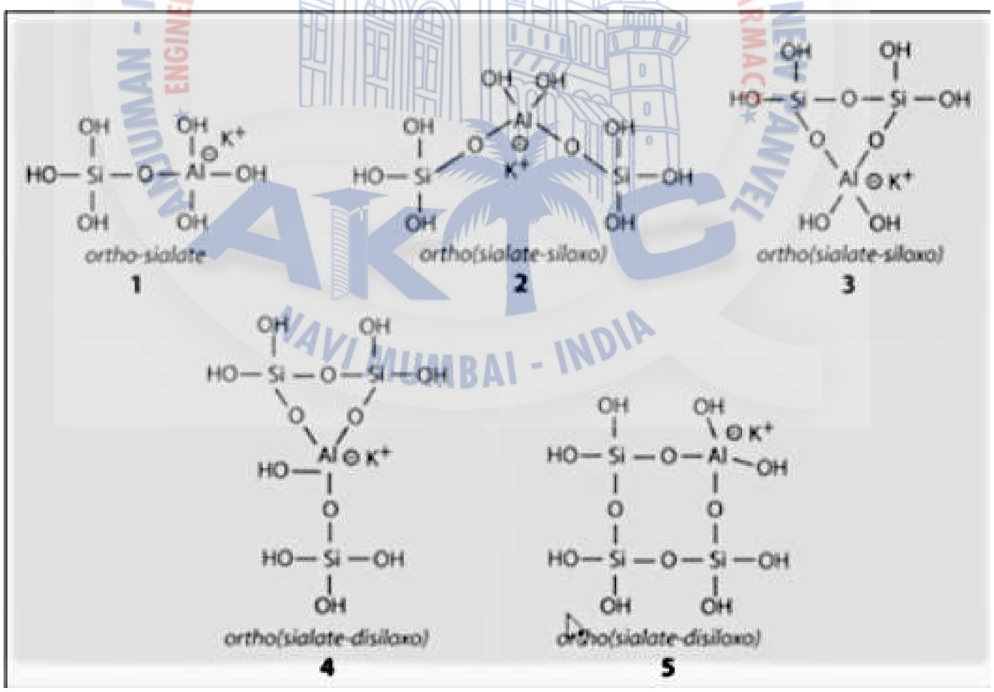


FIG 4.12: INITIAL REACTANT PRECUSERS OF GEOPOLYMER FORMED DURING INITIAL ALKALINATION.

Fly ash added along with GGBS also participates in the polymerisation process and as a result forms a filler paste in the voids formed with GGBS. Geopolymer miscelle is the smallest of the filler material which fill the voids in the concrete, thereby improving its strength.

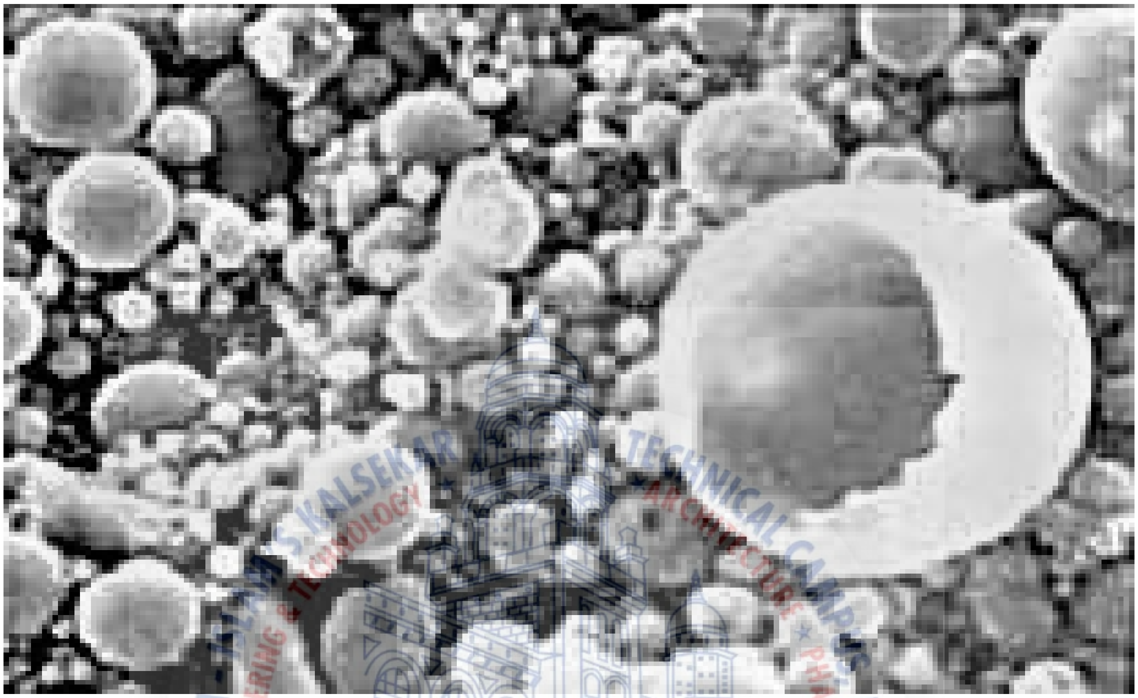


FIG 4.13: SEM OF UNREACTED FLY ASH

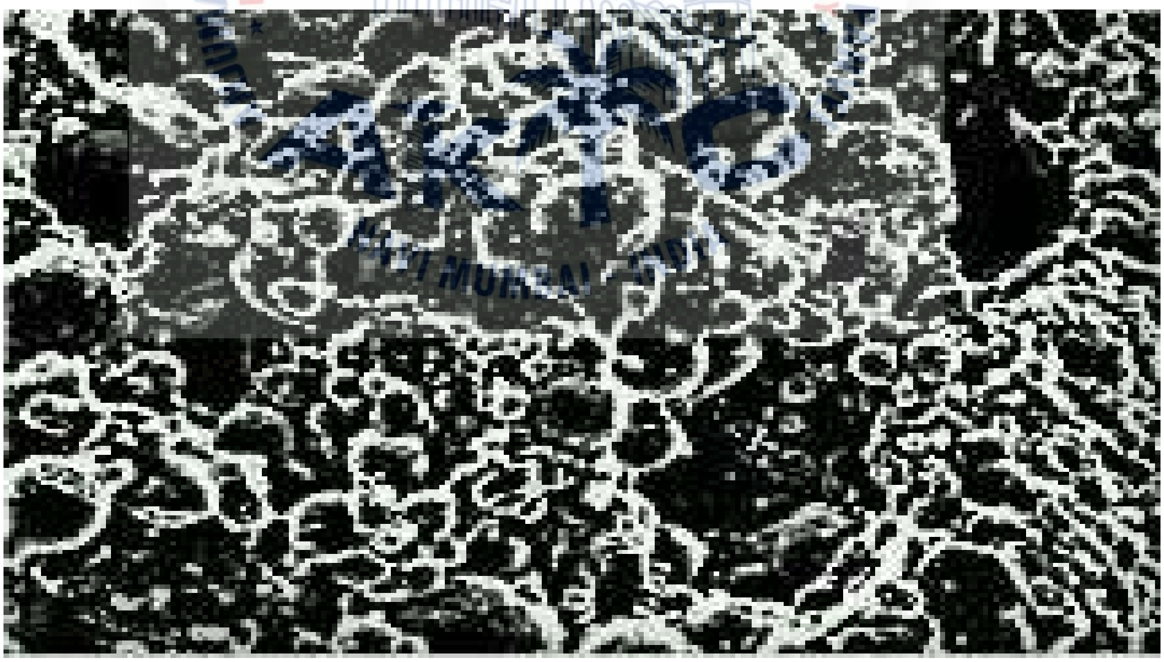


FIG 4.14: SEM OF FLY ASH ON ALKALINATION

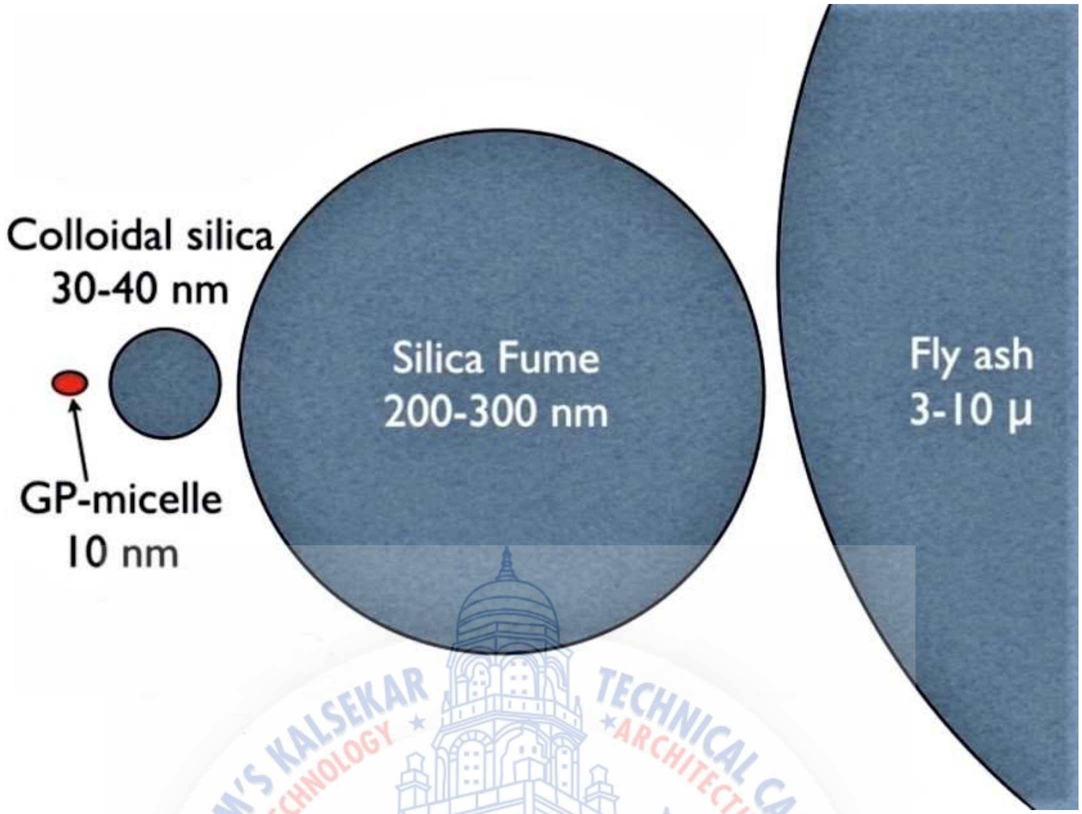


FIG 4.15: COMPARISION OF PARTICLE SIZE OF FLT ASH, SILICA FUME AND GEOPOLYMER MICELLE.

Correct steps and correct method in makiing of geopolymer concrete depends upon the ratio of silicon and aluminium. Si:Al. The ratio promotes the bonding of the source materials and its application. Following post shows the same.

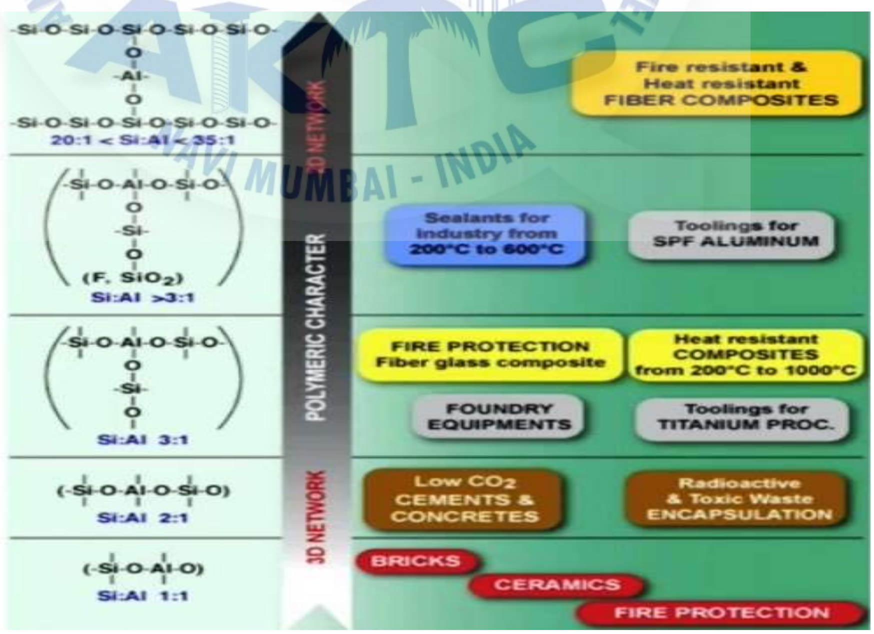


FIG 4.16: RATIO OF Si:Al AND ITS APPLICATION

CHAPTER 5

EXPERIMENTAL PROGRAMME

5.1 WBS of the project

WBS i.e work breakdown structure is a typical schedule which splits and divides the work into different stages so that it can be carried out smoothly and effeciently. Following flowchart shows the WBS of our geopolymer concrete production.

WBS is an important tool for smooth functioning of the project. It helps to achieve economy of the project. Wether it is big projects or small, industrial or non industrial, R & D type or conventional, large scale or small scale, WBS is required for its timely completion and with optimum cost.

We have adopted WBS for our project in order to make it successful and economical.

There are two reasons for adopting it here in this project…

- Geopolymer concrete is a new technology, latest research, a trial and error basis
- Quality in economy.

Typical WBS of our project is illustrated overleaf.

materials procurement

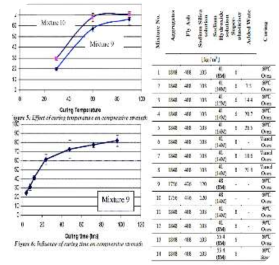
- GGBS
- Fly Ash
- Sand
- Coarse aggregate
- sodium hydroxide
- sodium silicate
- chemical admixtures

Laboratory Tests

- Sieve analysis
- aggregatre imapct and crushing test
- bulkage
- DLBD
- Water Absorption.
- Specific gravity
- elongation and flakiness test.

Alkaline solution preparation

- preparation of sodium hydroxide aqueous solution
- mixing of sodium hydroxide with sodium silicate to produce alkali solution.



Batching and Casting of Cubes

- weigh batching
- dry mixing
- addition of alkaline solution and admixture.
- wet mixing
- test on fresh concrete - slump cone, compaction factor and cohesiveness
- compactionhi ng.

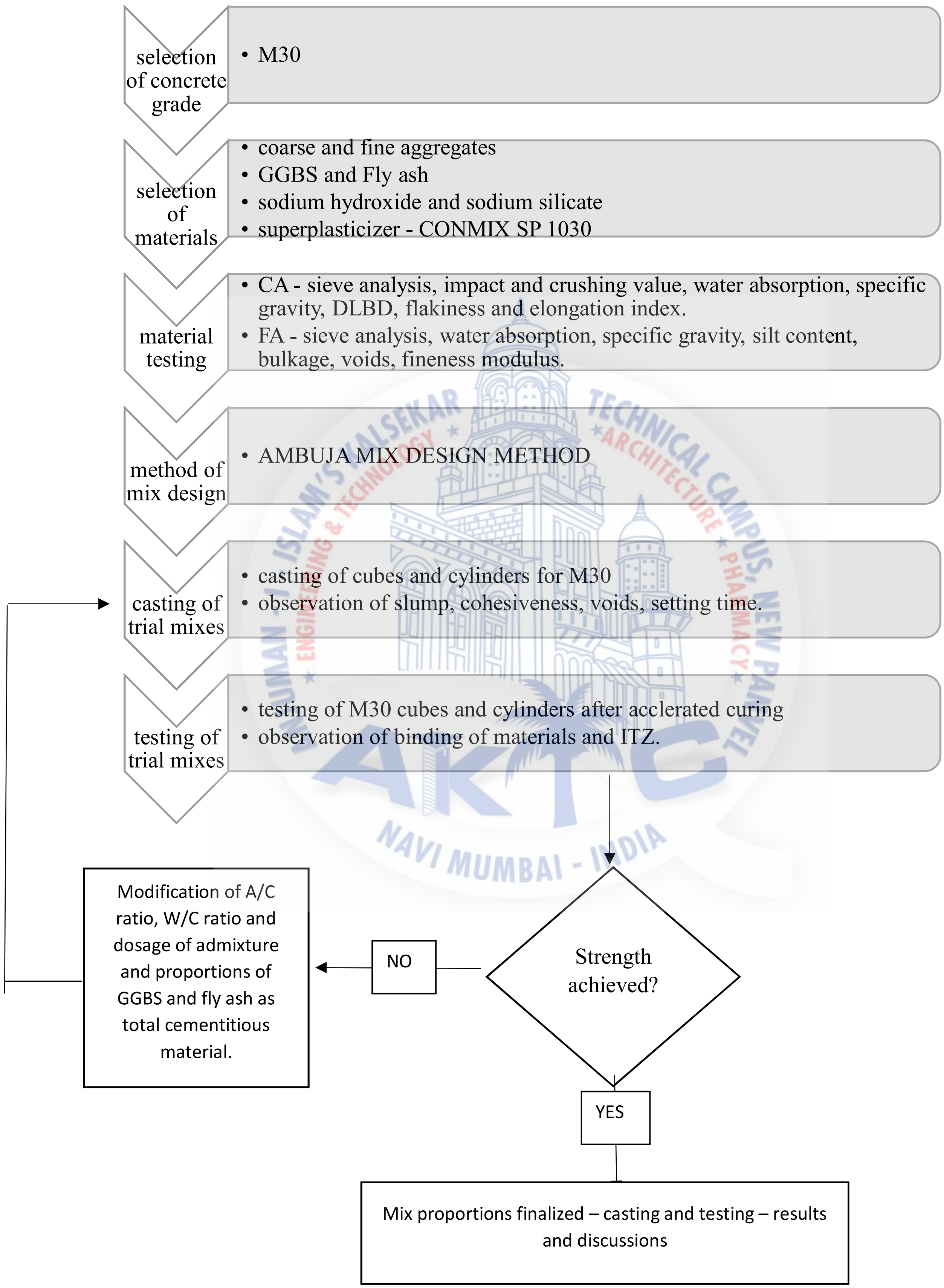
Post casting tasks.

- test on hardened concrete - compressive strength, split tensile test, rebound hammer.
- curing - accelerated steam curing and dry oven curing.

Results and Discussions

- intepretatio n and comparisio n of results.
- display of the same.

5.2 Experimental flowsheet



5.3 Laboratory tests

Lab tests are done on coarse and fine aggregates. These tests are essential to achieve control on quality.

Lab test on coarse aggregates include

- Sieve analysis
- Impact test on aggregate
- DLBD
- Water absorption
- Visual inspection
- Specific gravity
- Crushing strength
- Flakiness and elongation index
- Persentage voids
- Angularity number

Lab test on fine aggregate include

- Sieve analysis
- Silt content
- Bulkage
- Fineness modulus
- Visual inspection
- Specific gravity

Mix design of concrete cannot be done without carrying out these test. Such tests ensures quality control on concrete and correct steps in making concrete. Other than this, handling, placing, transporting also plays a key role in achieving good and economical concrete, a concrete with specified and selected strength.

To perform a correct tests on materials, proper sampling of materials is necessary. Usually aggregates are sampled in quarters and quatering the quarter by selecting diagonal quarters.

IS 2386 (part 1 to 8), IS 2430 were used in the testing of coarse aggregates.

5.3.1 Lab test on coarse aggregates

5.3.1.1 sieve analysis

- Job – lab tests
- Type – CA II
- Physical inspection – sieve analysis
- DLBD – 1.43 kg/l
- Source – Panvel
- Specific gravity – 2.70

TABLE 5.1: SIEVE ANALYSIS OF C.A 20mm DOWN AGGREGATE

IS sieves	% weight retained	Cumulative % weight retained	Cumulative % passing	Remarks
40mm	0	0	100	
20mm	8.91	8.91	91.09	MAS = 20mm
16mm	57.1	66.01	33.99	
10mm	33	99.01	0.99	
4.75mm	0.99	100	0	
2.36mm	0	0	0	

TABLE 5.2: SIEVE ANALYSIS OF C.A 10mm DOWN AGGREGATE

IS sieves	% weight retained	Cumulative % weight retained	Cumulative % passing	Remarks
20mm	0	0	100	MAS = 20mm
16mm	0.8	0.8	99.2	
10mm	24.2	25	75	
4.75mm	73.85	98.85	1.15	Fines present
2.36mm	1.1	99.95	0.05	
Pan	0.05	100	0	

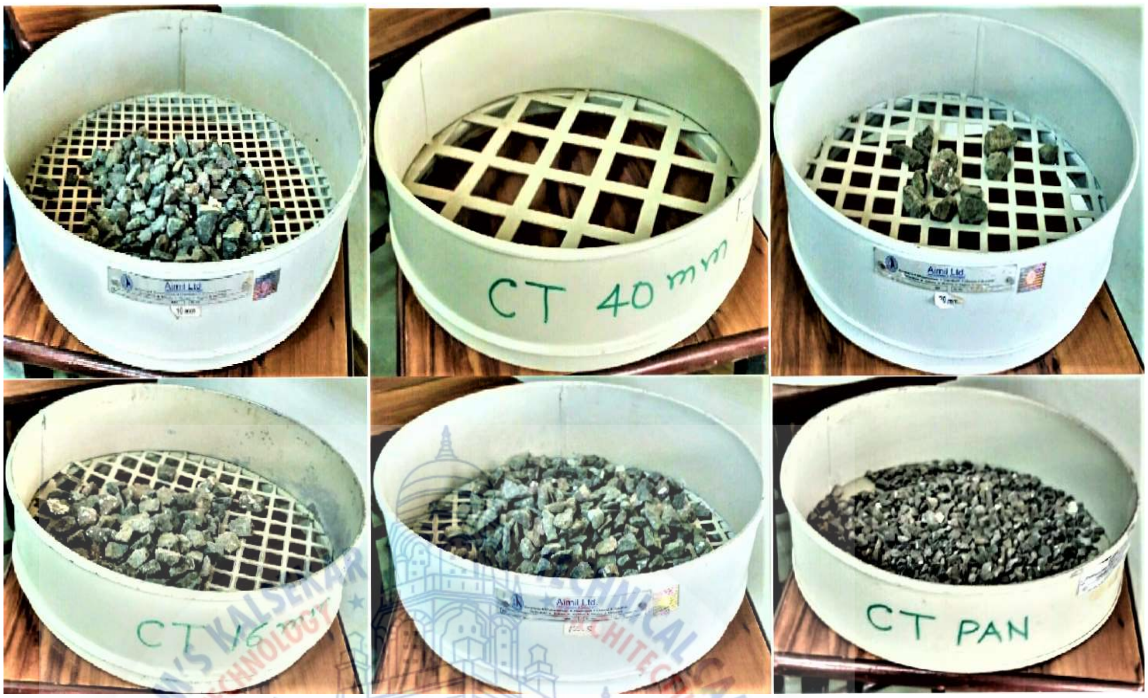


FIG 5.1: SIEVE ANALYSIS OF CA I AND II

5.3.1.2 Aggregate impact value

- Total weight of dry sample = 0.33
- Weight of aggregate passing 2.36mm IS sieve = 0.05
- Aggregate impact value = $\frac{0.05}{0.33} \times 100 = 15.152$

TABLE 5.3: TOUGHNESS OF AGGREGATE BASED ON AGGREGATE IMPACT VALUE

Aggregate impact value (%)	Aggregate quality	results
<10	Exceptionally strong	
10 – 20	Strong	✓
20 – 30	Satisfactory	
>35	weak	

5.3.1.3 Dry Loose Bulk Density (DLBD)

- A = weight of aggregates retained on each sieve
- B = empty weight of cylinder
- V = volume of cylinder

$$\text{DLBD} = \frac{A+B}{V} = 1.43 \text{ kg/l}$$

5.3.1.4 Percentage voids in aggregates

- G = specific gravity of coarse aggregates
- γ = DLBD

$$e = \frac{G-\gamma}{G} \times 100 = 45.28\%$$

5.3.2 Lab tests on fine aggregate

5.3.2.1 Bulking of fine aggregates

- y = mark of sand level after mixing in water

$$\%\text{ bulking} = \frac{200}{y} - 1 = 2.67\%$$

On determination of sand bulkage, necessary changes and adjustments need to be done in the mix design calculation.

FIG 5.2: BULKING OF FINE AGGREGATE

5.3.2.2 Determination of clay and fine silt content

- A = total volume of sample
- B = volume of silt

Percentage impurities = $\frac{B}{A} \times 100 = \frac{5}{96} \times 100 = 5.2\%$

Here % impurities is 5.2% < 6%. Hence there is no need to wash the entire lot of sand for the use. If the silt content increases above the permissible limits, sand has to be washed before use.

FIG 5.3: SILT CONTENT AND IMPURITIES IN FINE AGGREGATES.

5.3.2.3 Sieve analysis

TABLE 5.4: SIEVE ANALYSIS OF FINE AGGREGATES.

IS Sieves	% weight retained	Cumulative % weight retained	% weight passing	Remarks
4.75mm	0.5	0.5	99.5	0.5 % oversize
2.36mm	6.5	7	93.5	
1.18mm	27	34	73	
600 micron	32.5	66.5	67.5	Zone 3, 68 %
300 micron	21.5	88	78.5	
150 micron	7	95	93	
Pan	5	100	95	

FIG 5.4: GRADATION OF SAND AFTER SIEVE ANALYSIS.

5.4 Concrete Mix Design and Proportionating

5.4.1 Definition

Concrete mix design is a scientific approach of choosing economic proportion from various available materials to obtain cohesive concrete of desired workability to meet specified strength and durability standards.

It is the process of selecting suitable ingredients of concrete and determining their relative proportions with the object of producing concrete and certain minimum strength and durability as economically as possible. There are various method of mix designs available. These methods can only give guidelines to the site engineer to workout the various parameters of concrete mix and it may or may not be necessary to make minor adjustments thereafter. Before commencing the concrete mix design, it is necessary to study the specifications of concrete and also to have enough information of environment around the structure, the size and cross section of the structure, reinforcement details, method proposed to be adopted for batching, mixing, transporting, placing and compacting of concrete. Here our geopolymer concrete mix design is done by ABMUJA METHOD with some necessary modifications and changes.

5.4.2 Objectives of Mix Design

- To achieve a specified compressive strength for a specified grade.
- For ensuring required workability
- For achieving durability
- To economise concrete production.

5.4.3 Methods of Concrete Mix Design

Other than ambuja method, standard mix design methods are as follows

- IS method
- ACI method
- DoE method
- Maximum density method
- Minimum voids method
- Fineness modulus method
- Road research laboratory method
- Fineness modulus method

5.4.4 Mix Design Calculation worksheets.

TABLE 5.5: GEO-POLYMER CONCRETE MIX DESIGN WORKSHEET

Sr no	Requirements	Specimen data
1 a	Specified minimum strength	M30
b	Durability requirements	
	• Exposure	Moderate
	• Maximum w/c ratio	0.45
	• Maximum aggregate size	20 mm
	• Minimum cementitious content	320 kg/m^3
	• Minimum concrete grade	M30
c	Required workability Slump	Medium 75 – 100 mm
d	Fine aggregates	
	• Type	Gujarat sand
	• Passing 600 micron IS sieve (%) pure sand	67.5 %
	• Zone	3
	• Percentage retained 4.75mm sieve	0.5
	• Specific gravity	2.64
	• DLBD	1.43 kg/l
	• Bulkage	2.67 %
e	Coarse aggregate	
	• Type	Crushed and angular. Gravel type.
	• Percentage passing 20mm IS sieve CA II	91.01
	• Maximum aggregate size MAS	20 mm
	• Percentage passing 4.75mm IS sieve	21%
	• Specific gravity	2.70
	• DLBD CA I CA II	1.15 0.79
2	Target mean strength	
	• Standard deviation (s)	5 + 1 = 6

	• Value of t	1.65
	• Fm	39.9 N/mm^2
3	Proportion of fine aggregates	
	• MAS	20 mm
	• Slump	75 – 100 mm
	• Free w/c	0.45
	• Percentage passing 600 micron As available Pure sand	 67.5% 68%
	• Proportion of fine aggregate (average)	33 %
4	Proportion of coarse aggregate	
	• CA I	23 %
	• CA II	44 %
5	Correction in aggregate proportion	
a	Aggregate proportion before correction	
	• FA (sand without oversize)	33 %
	• CA I	23 %
	• CA II	44 %
b	Correction due to coarse aggregate in fine aggregates	
	• Percentage passing 4.75mm IS sieve	99.5 %
	• Percentage proportion of fine aggregates before correction	33 %
	• Percentage proportion of fine aggregates after correction CA I CA II	 23 % 44 %
c	Correction due to fines in coarse aggregates	
	• Percentage passing 4.75mm IS sieve	1.15 %
	• Percentage proportion after correction	30 %
	• Percentage proportion of coarse aggregates CA I	 26 %

	CA II	44 %
6	A/C ratio	
	• MAS	20 mm
	• Type of aggregate FA CA I CA II	 Gujarat sand Crushed rock Gravel
	• Degree of workability	Medium
	• Zone	3
	• Adopted w/c ratio	0.45
	• Aggregates value FA CA I and II	 4.55 3.4
	• Aggregate proportion FA CA I + CA II	 30 % 70 %
	• Correction for specific gravity	8.05
	• Correction for flakiness	0.95
	• Final A/C ratio	3.8
7	Calculation of geo-polymer constituents	
	• Calculation of NaOH pellets to be mixed in 1L of water.	16 M = 16 X 40 = 640g 18 M = 18 X 40 = 720g 20 M = 20 X 40 = 800g 22 M = 22 X 40 = 880g
	• Sodium silicate to sodium hydroxide solution	2.5
	• Sodium hydroxide content in aqueous solution	16 M = 1640 g 18 M = 1720 g 20M = 1800 g 22 M = 1880g
	• Sodium silicate content	16 M = 4100g 18 M = 4300g 20 M = 4500g 22 M = 4700g

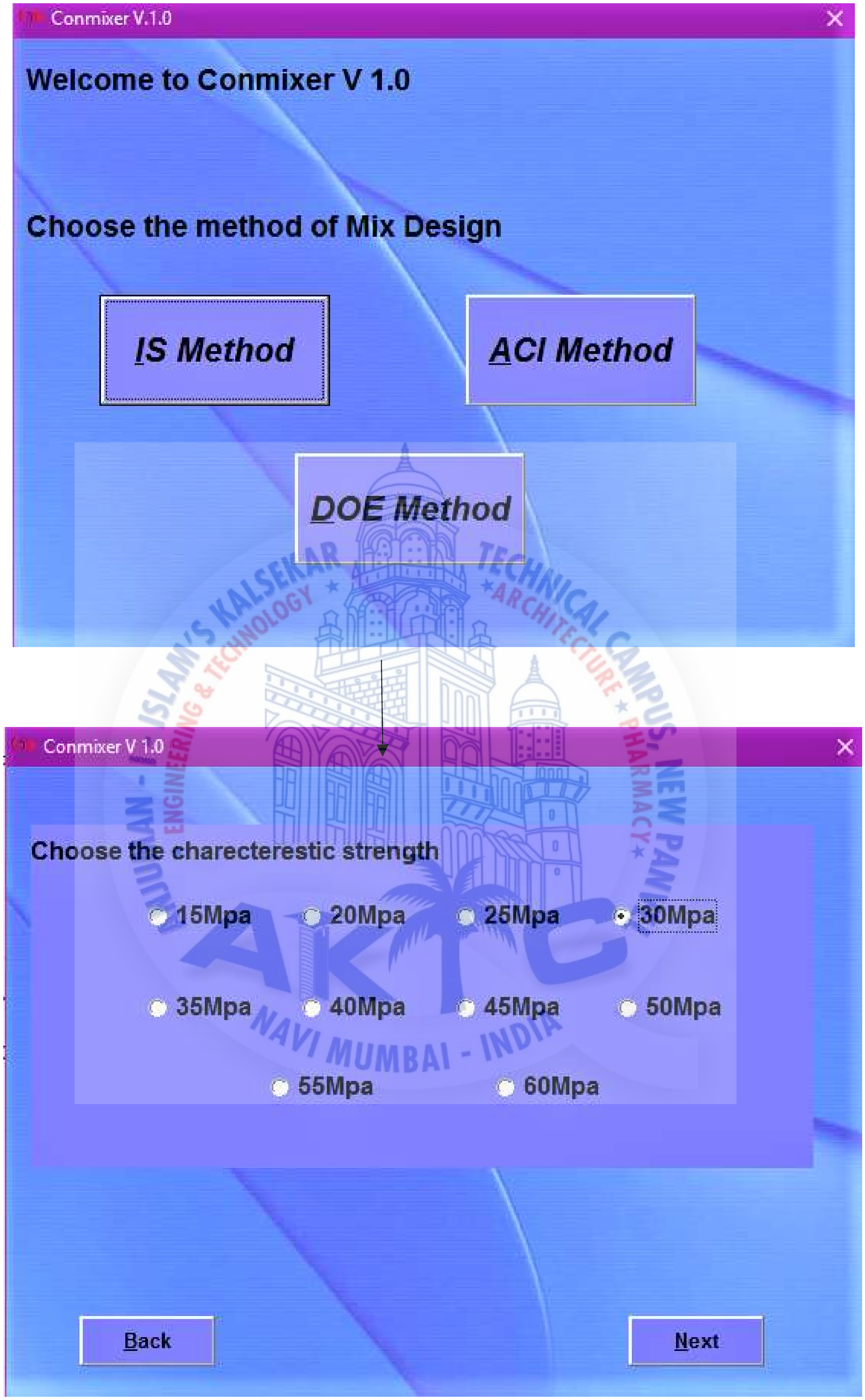
8	Final w/c ratio	0.45
9	Weigh batching	
	• Cementitious content	457.14 kg/m^3
	• Water content	205.72 kg/m^3
	• Fine aggregate	520.98 kg/m^3
	• Coarse aggregate CA I CA II Total	 451.52 kg/m^3 764.11 kg/m^3 1215 kg/m^3
10	Results of trial mixes	
	• Workability Targeted Achieved Remarks	 75 – 100 mm 178 mm average Highly workable – accepted
	• Compaction factor	0.99
	• Cohesiveness	Very good
	• Average weight of cubes	8.52
	• Density of concrete	2400 kg/m^3
	• Cementitious content of mix	457.14 kg/m^3
	• Minimum cementitious content	320 kg/m^3
	• Durability conditions	Satisfied
11	Proportions	1 : 1.14 : 2.66 (adopted)

5.4.5 mix design of conventional cement concrete.

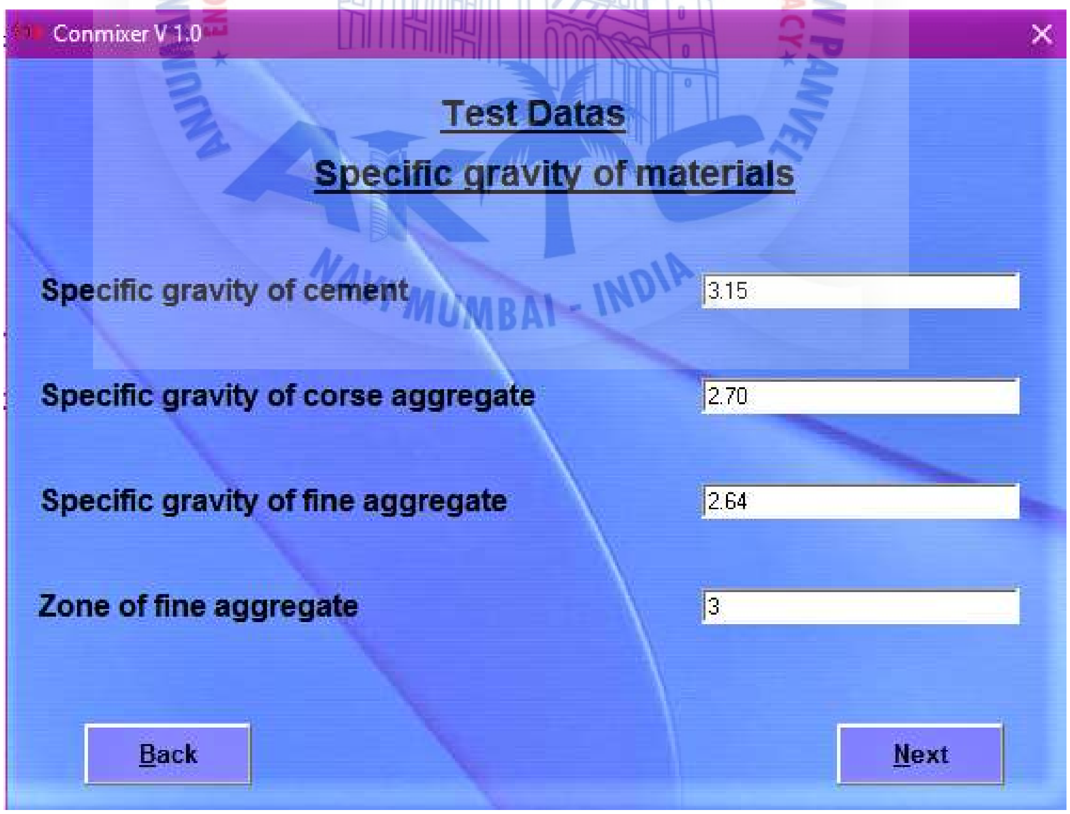
Mix design of conventional cement concrete is done to compare two parameters

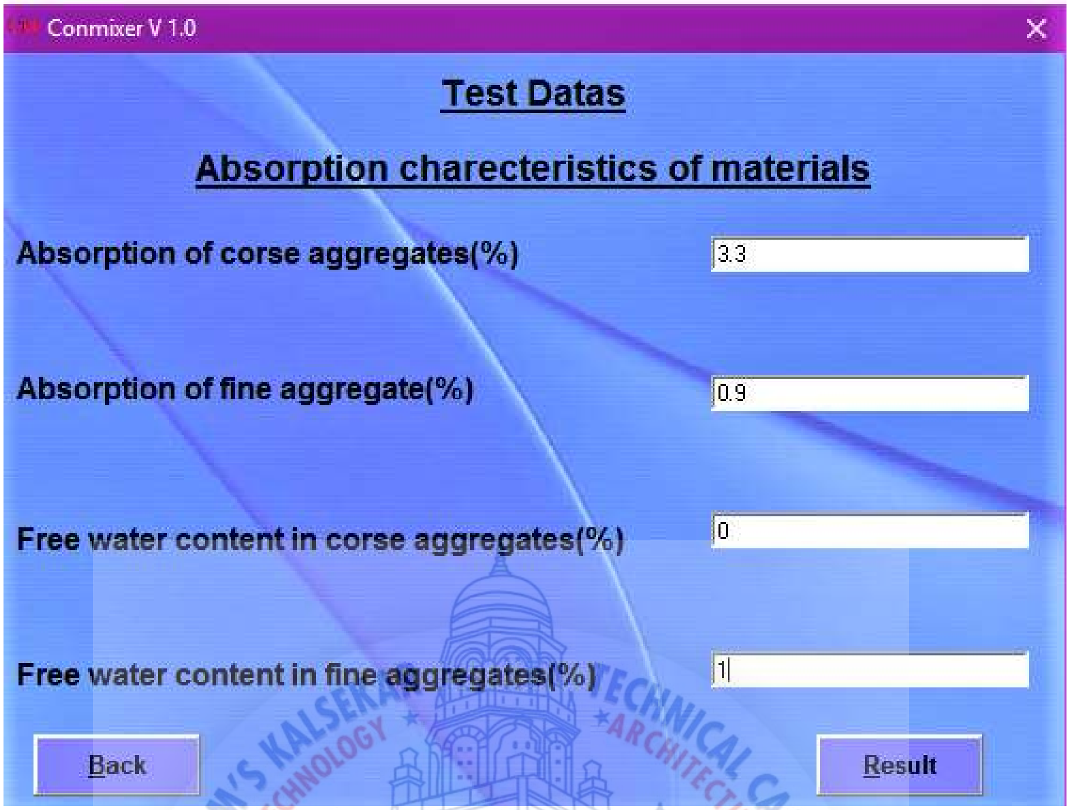
- Cost and economy of both the concrete mixes per meter cube of concrete
- Strength of concrete after 28 days immersed curing and 1 day accelerated curing.

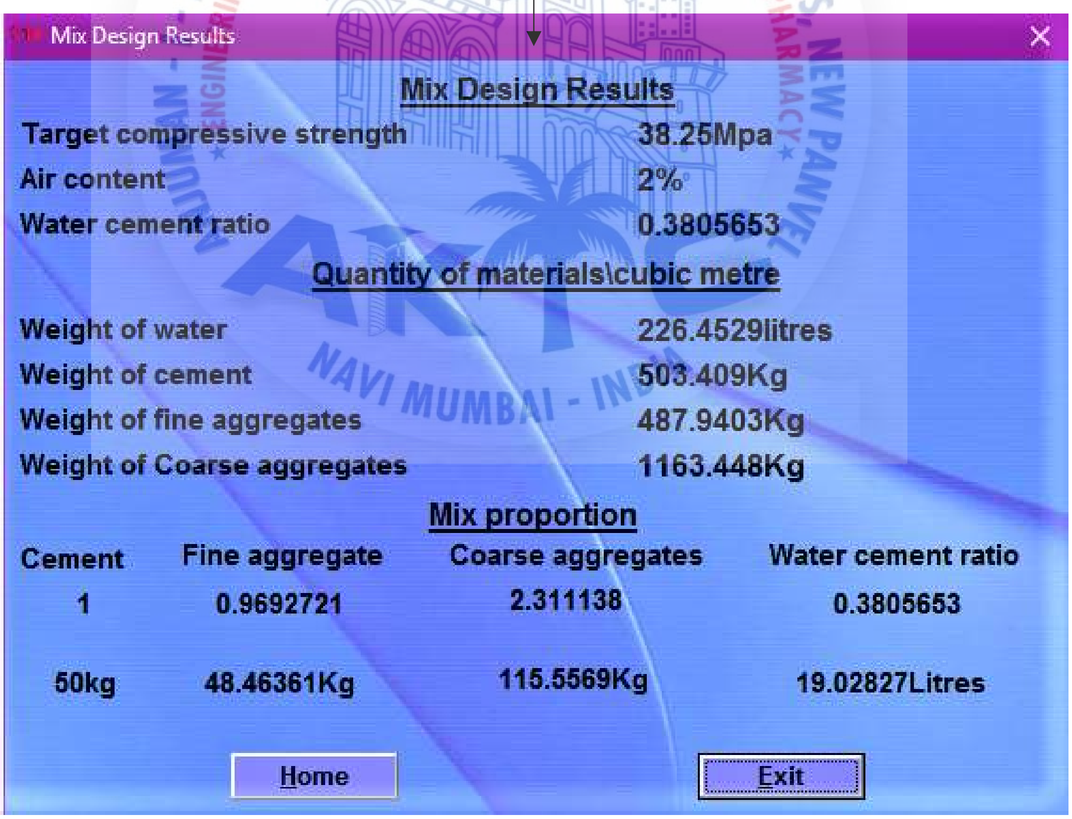
The cement concrete mix design is carried out on concrete mix design software – CONMIXER V 1.0. Mix design on this software is done by 3 methods viz. IS method, ACI method and DoE method. We are adopting IS method.


Conmixer V.1.0
Welcome to Conmixer V 1.0
Choose the method of Mix Design
IS Method
ACI Method
DOE Method
Conmixer V 1.0
Choose the charecterestic strength
15Mpa
20Mpa
25Mpa
30Mpa
35Mpa
40Mpa
45Mpa
50Mpa
55Mpa
60Mpa
Back
Next


Conmixer V1.0
Design Stipulations
Maximum Size of Aggregates
10mm
20mm
40mm
Shape of aggregates
Angular
Rounded
Degree of Quality control
Verygood
Exposure condition
Moderate
Desired Workability(Compaction factor)
.9
Back
Next


Conmixer V 1.0
Test Datas
Specific gravity of materials
Specific gravity of cement
3.15
Specific gravity of corse aggregate
2.70
Specific gravity of fine aggregate
2.64
Zone of fine aggregate
3
Back
Next


Conmixer V 1.0
Test Datas
Absorption charecteristics of materials
Absorption of corse aggregates(%)
3.3
Absorption of fine aggregate(%)
0.9
Free water content in corse aggregates(%)
0
Free water content in fine aggregates(%)
1
Back
Result


Mix Design Results
Mix Design Results
Target compressive strength 38.25Mpa
Air content 2%
Water cement ratio 0.3805653
Quantity of materials\cubic metre
Weight of water 226.4529litres
Weight of cement 503.409Kg
Weight of fine aggregates 487.9403Kg
Weight of Coarse aggregates 1163.448Kg
Mix proportion
Cement Fine aggregate Coarse aggregates Water cement ratio
1 0.9692721 2.311138 0.3805653
50kg 48.46361Kg 115.5569Kg 19.02827Litres
Home
Exit

5.5 Methodology

After procurement and testing on materials, casting of concrete is now on its way. Here, step by step procedure is bulleted below explaining about the mixing and casting of concrete with necessary precautions. They include the following..

- Finalised mix proportions for M30 grade of concrete
- The geopolymer hardener or alkali solution was prepared in the laboratory by mixing sodium hydroxide and sodium silicate in the required proportion as mentioned in the mix design worksheet. The alkali solution was prepared 1 day prior to casting.
- All the apparatus and equipment's were made ready for casting. They include pan mixer, slump cone apparatus, compaction factor apparatus, tamping rod, buckets, trays, dry and wet cloths, travels, etc.
- After weigh batching, materials are introduced in pan mixer with a sequence. GGBS along with 50% of prepared solution was introduced in the mixer so that alkalination could start. Fly ash together with coarse and fine aggregates were introduced in the mixer and mixing was continued for 2 minutes. The remaining alkali solution was then again added to the mix. Water was added after the alkali solution and superplasticizer was introduced. The wet mixing continued for another 4 minutes until a homogenous mix was achieved.
- Immediately after the mixing was over, it was observed that the concrete was getting more cohesive due to the polymeric chain formation. Slump cone test and compaction factor test was performed to test its workability.
- 150 x 150 x 150 mm cubes and 150 x 300 mm cylinders were thinly coated with oil to prevent adhesion of concrete with inner walls of cubes and cylinders.
- Concrete was poured in 3 layers as per specifications and compacted. In case of cubes each layer was compacted 32 times with 4 along the edges, 4 along diagonals and 4 along midways in both axes. However, in case of cylinders, each layer was compacted 12 times, with 6 along the edges and 6 along both the axes.
- All the cubes were kept on vibrating table and vibrated for 2 minutes to let all the entrapped air escape. concrete was kept in moulds until it gained sufficient hardness to be demoulded. The demoulded concrete was wrapped in plastic bags and kept for accelerated steam curing at 60° C. other specimens were kept for hot air oven dry curing at 60° C. Specimens were kept for curing continuously for 3 days and after that left for ambient atmospheric curing till 28th day.

5.6 Observations during casting

During casting and handling of geo-polymer concrete, a lot of new parameters were observed.

- The targeted workability was 75 to 100 mm slump but we achieved 180 mm slump. This could be due to the excess water liberated from the aqueous solution of silicates and hydroxides along with the addition of superplasticizer.
- Colour of geopolymer concrete was quite typical. Due to use of GGBS and fly ash, it was brownish white to white with some shades of musk.
- Due to polymerisation process, the mix was getting difficult to handle.
- During demoulding, it was observed that the setting time of geopolymer concrete is much higher as compared to cement concrete say about days. Due to this, the demoulding of 3 specimens had spoiled edges.
- Adopting the method of pond curing is not applicable. As cement is not present, there is no concept of hydration. Moreover, geopolymer binder and slurry gets washed away solely on immersing it in water.
- Touching the mix by bear hands has adverse effects. The high concentration of silicates in its polymerisation stage can cause severe burns on skin.

5.7 Tests on Fresh Concrete

Following tests were performed on fresh concrete

- Slump cone test
- Compaction factor test
- Cohesiveness test

Each test was performed in lab following all the specifications. Compaction factor test gives more accurate results. Slump cone test revealed that concrete was flowable and pumpable. Slump range was 180 mm average, while compaction factor test gave a compaction factor of 0.9. when cohesive test was performed, concrete was thrown up in air for certain height and allowed to drop on floor under the action of gravity. On falling on the floor, concrete did not disperse, moreover no extra slurry was generated around the concrete ball.

FIG 5.5: PREPARATION OF ALKALINE SOLUTION

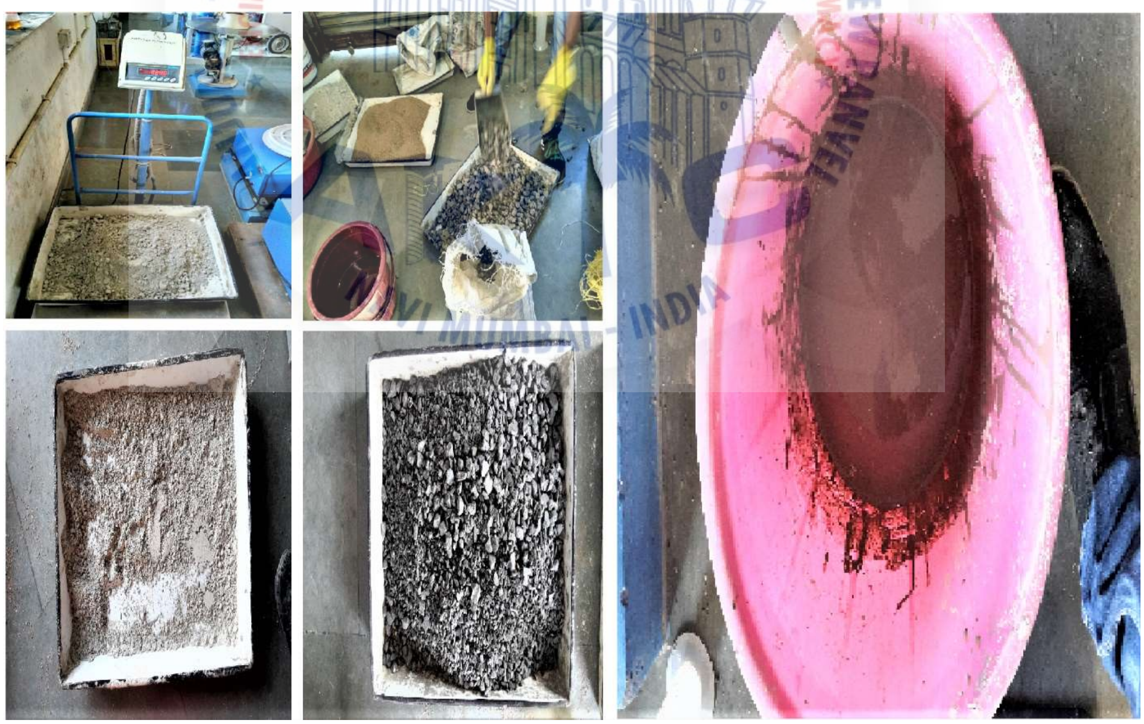


FIG 5.6: BATCHING OF CONCRETE MATERIALS.

FIG 5.7: WET AND DRY MIX OF CONCRETE IN MIXER (PAN STATIONARY)

FIG 5.8: WET AND DRY MIXING OF CONCRETE IN PAN MIXER

FIG 5.9: ADDITION OF ALKAI SOLUTION AND SUPERPLASTICIZER IN CONCRETE MIX AND FINAL MIXING.

FIG 5.10: SLUMP CONE TESTING ON FRESH CONCRETE

FIG 5.11: COMPACTION FACTOR TEST

FIG 5.12: CHECK FOR CHOSIVITY OF FRESH CONCRETE.

FIG 5.13: PLACING AND COMPACTION OF CONCRETE IN CUBE MOULDS.

FIG 5.14: COMPACTION AND PLACING OF CONCRETE IN CYLINDER MOULDS.

5.8 Curing of Concrete

Curing of geopolymer specimens was adopted by two methods

- Accelerated steam curing method (warm water method)
- Dry oven curing method

After demoulding the specimens, they were wrapped in plastic bags so that evaporation of excess moisture due to heat and gaining of condensed water of the tank is avoided. The extra 6 cubes were kept only in steam curing with moulds, covered with plastic sheets on top. both curing methods was continued for 3 days at 60 °C. after 3 days the specimens were left for open atmospheric curing for testing at 28 days.

FIG 5.15: CURING OF GEOPOLYMER CONCRETE SPECIMENS

FIG 5.16: DEMOULDED GEOPOLYMER CONCRETE SPECEMENS

5.9 Testing of Hardened Concrete

Test on hardened concrete is done by two types

- Compressive strength
- Split tensile strength

Testing is done with the specifications confirming to IS 516, IS 9013 and IS 14858. Cube compressive strength of 1, 3, 7, 28 days are obtained. Split tensile strength of 28 days is obtained. On testing all the parameters were kept in mind. Specimens were taken out, stripped and kept to cool at room temperature. After testing, various failure pattern was observed to study the kind of failure, reasons for such kind of failure, effects and causes of the same and its preventive measures.

Photographs and other parameters were noted during failure of specimens for future research and investigation which is beyond the scope of this project.

Overleaf illustrated pictures show the failure of cube and cylindrical specimens.

FIG 5.17: COMPRESSION TEST ON SPECIMENS

FIG 5.18: COMPRESION TEST

FIG 5.19: FAILURE PATTERN OF CUBES AFTER TESTING

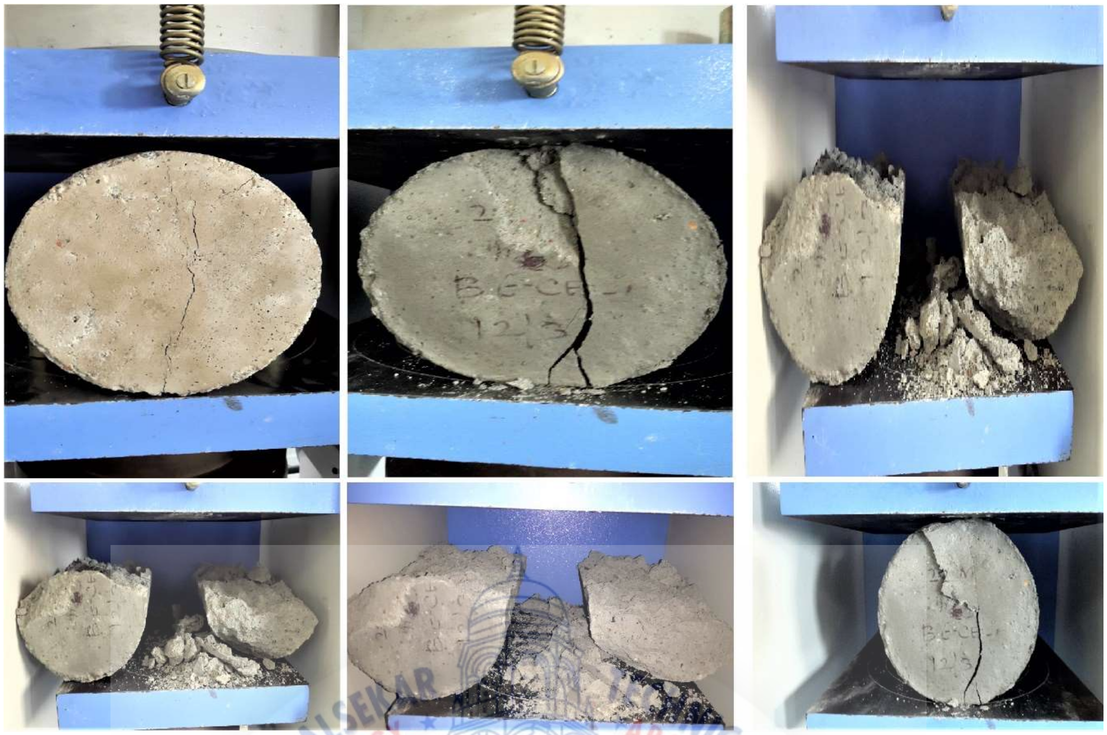


FIG 5.20: SPLIT TENSILE STRENGTH OF CYLINDER

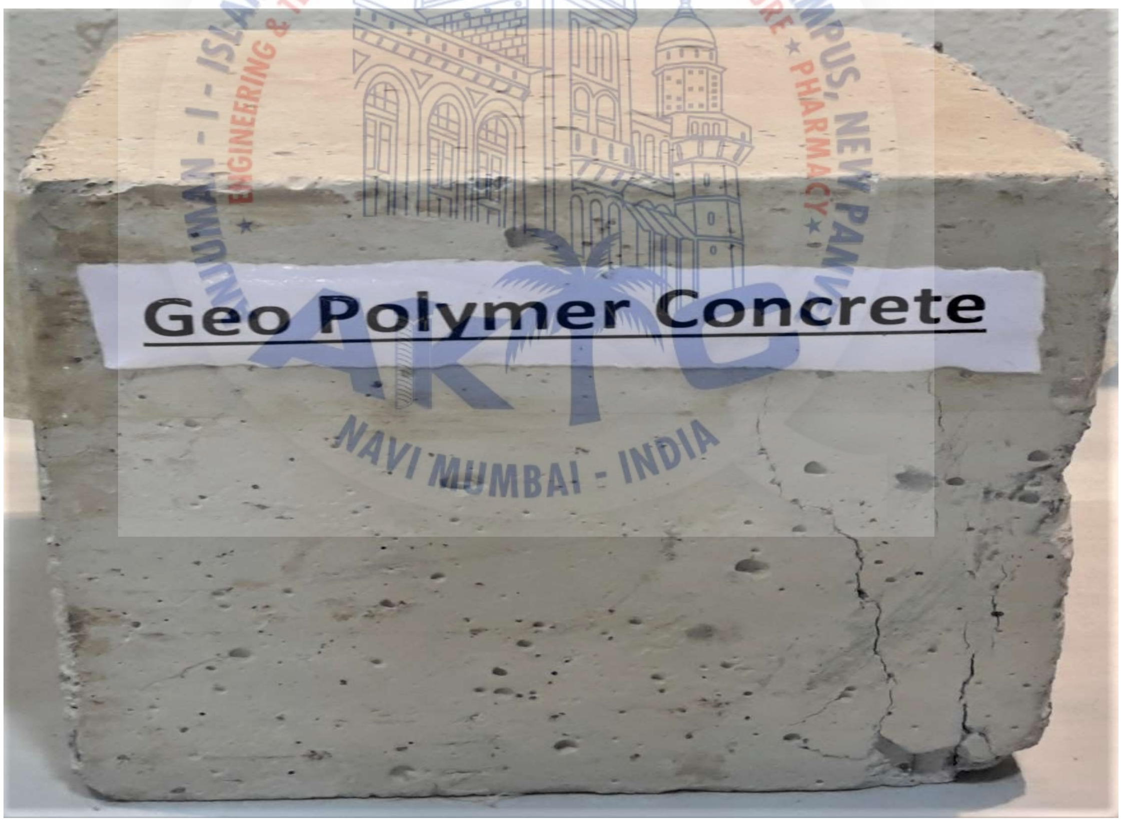


FIG 5.21: GEOPOLYMER CONCRETE SPECIMEN OF ACC THANE COMPLEX - CENTER OF EXCELLENCE

CHAPTER 6

RESULTS AND DISCUSSIONS

6.1 General

This chapter briefly describes the test results of the present study. It is cement free concrete replacing the content of cement totally by fly ash and GGBS. Here, alkalination of GGBS with alkali solutions varying in different molar concentrations on the effect of strength of concrete is studied. Tabulated charts and graphical results are illustrated in this chapter.

6.2 Compressive strength

Compressive strength of geopolymer concrete specimens was determined at 1, 3, 7 and 28 days, following all the IS specifications. Testing was carried out in accordance with IS 516, IS 1199, IS 9013, IS 10086 and IS 14858. Results of accelerated steam cured and oven dry cured concrete was compared and concluded. 100% fly ash concrete and concrete produced using GGBS and PFA was compared.

In the past studies, comparison of molar concentrations and compressive strength was studied and limited to 14 M concentration of NaOH solution. Here, in the present study, molar concentrations of NaOH was varied between 16 M and 22 M. The results of the same are illustrated below in a graphical representation.

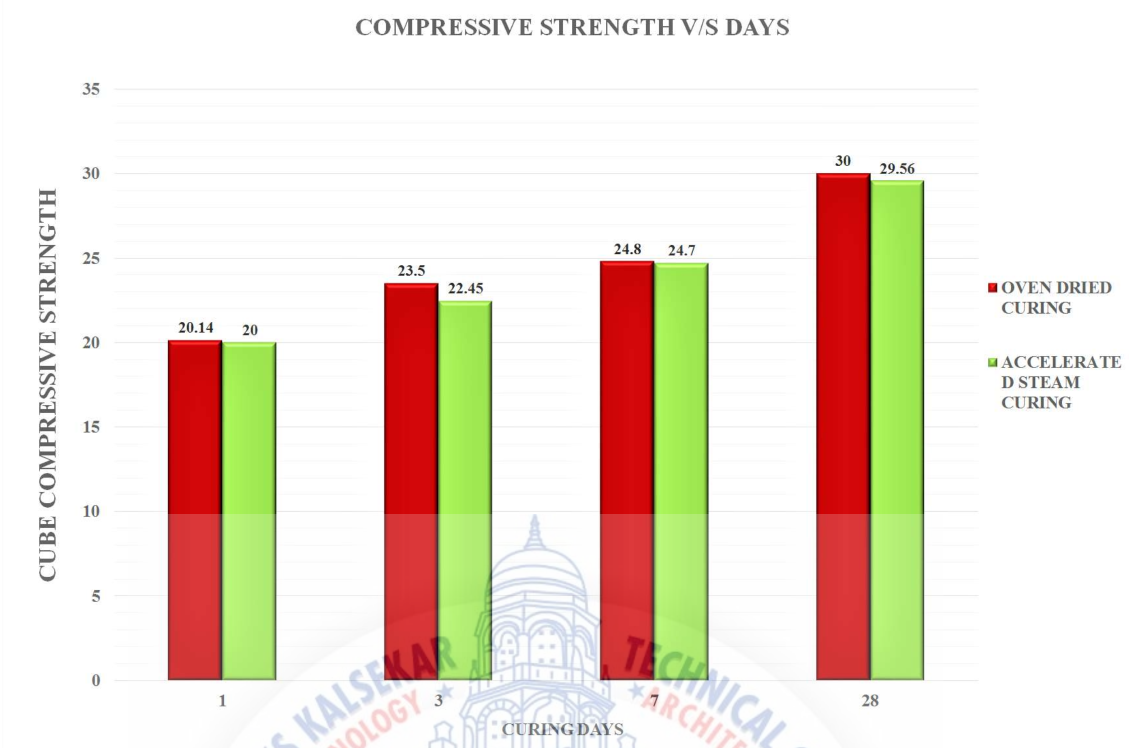


FIG 6.1: 100% PFA WITH 18 M CONCENTRATION.

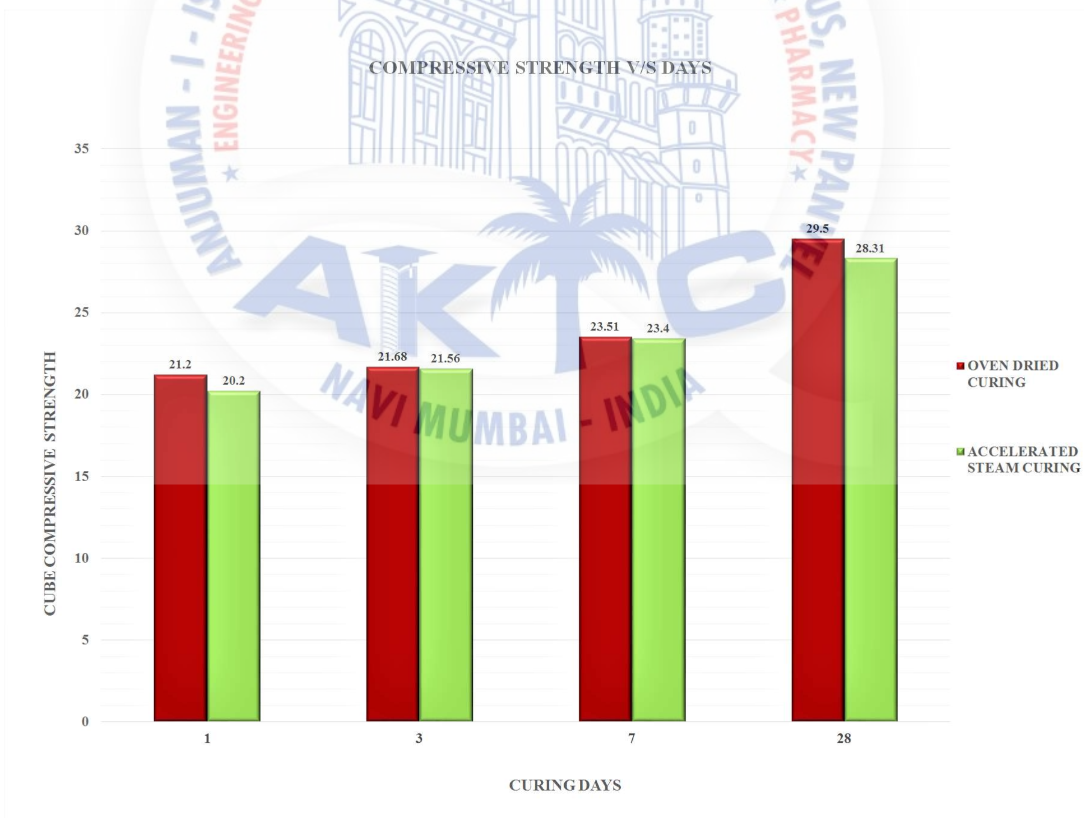


FIG 6.2: 100% PFA WITH 20 M CONCENTRATION.

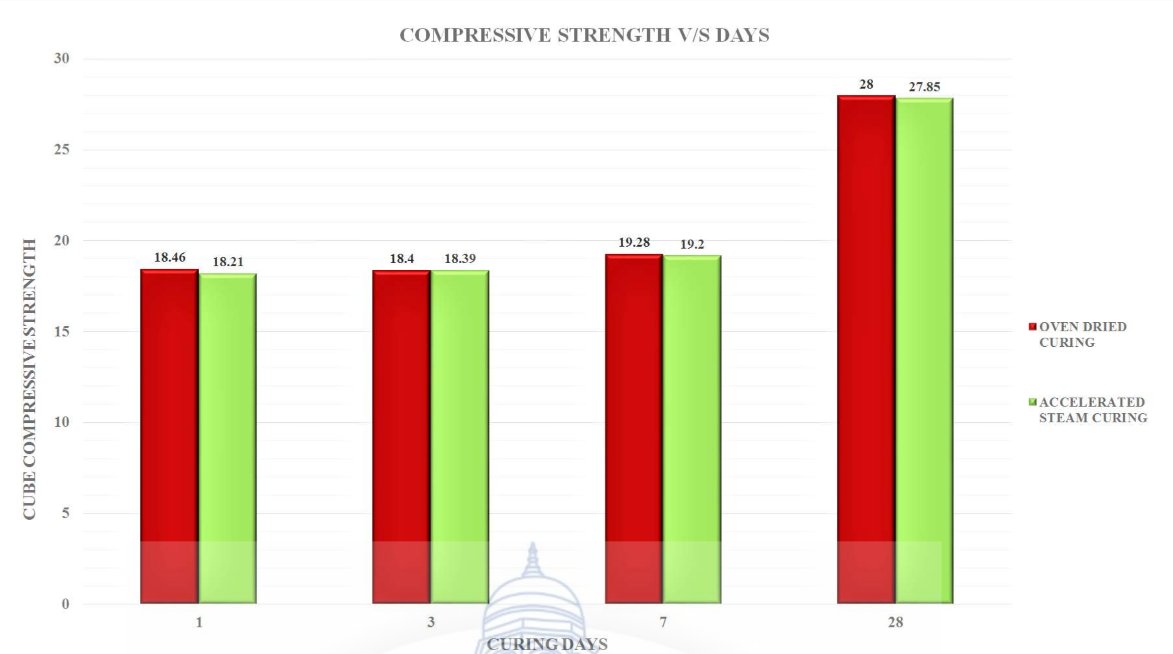


FIG 6.3: 100% PFA WITH 22 M CONCENTARTION.

Strength of oven dried concrete is slightly more as compared to accelerated steam cured concrete at 60 ° C. Geopolymer concrete gains much higher strength at initial time of curing and gains slow strength at later ages. 100 % fly ash based concrete was used with geopolymer hardener i.e. alkali solution.

FIG 6.4: PFA AND GGBS IN RATIO OF 3:7 WITH 16 M CONCENTRATION.

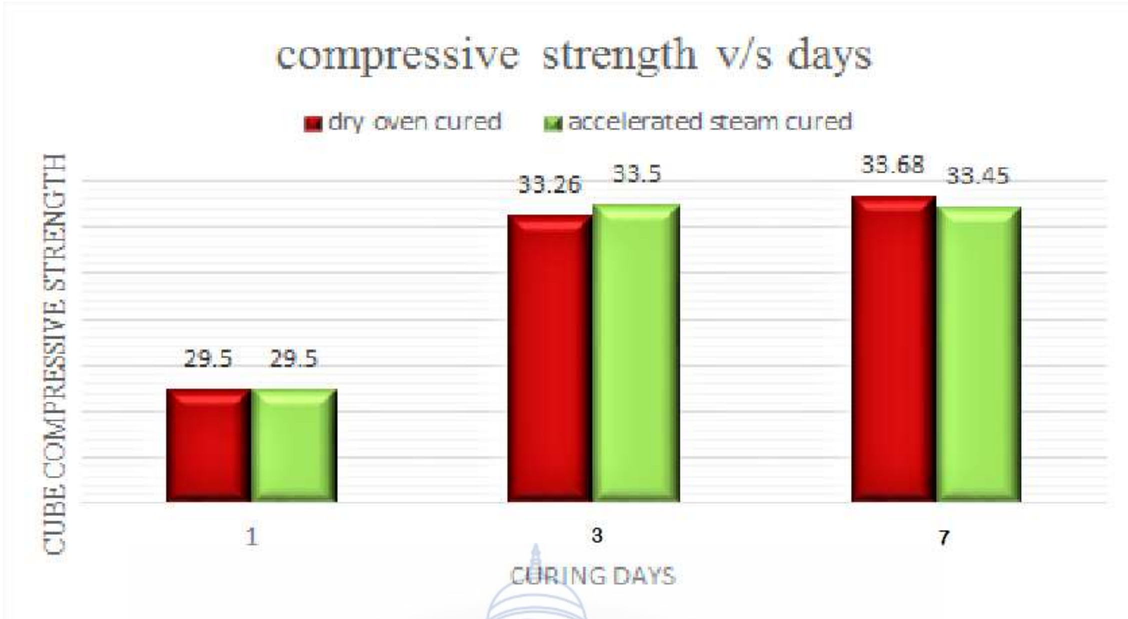


FIG 6.5: PFA AND GGBS IN RATIO 3:7 WITH 18 M CONCENTRATIONS.

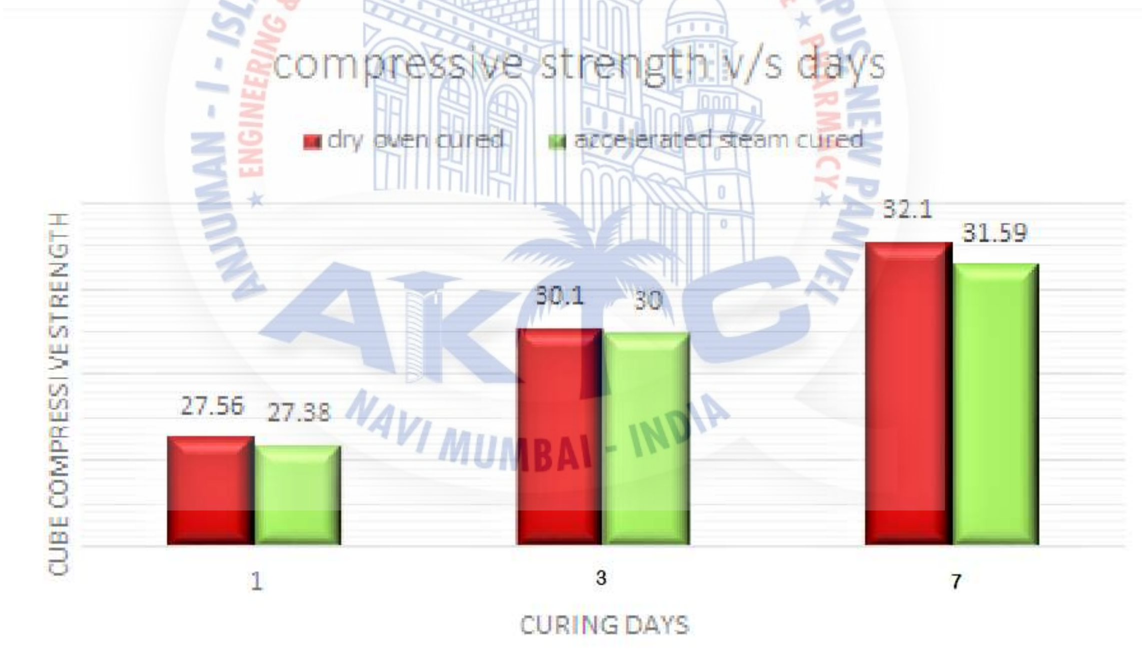


FIG 6.6: PFA AND GGBS IN RATIO 3:7 WITH 20 MOLAR CONCENTRATION.

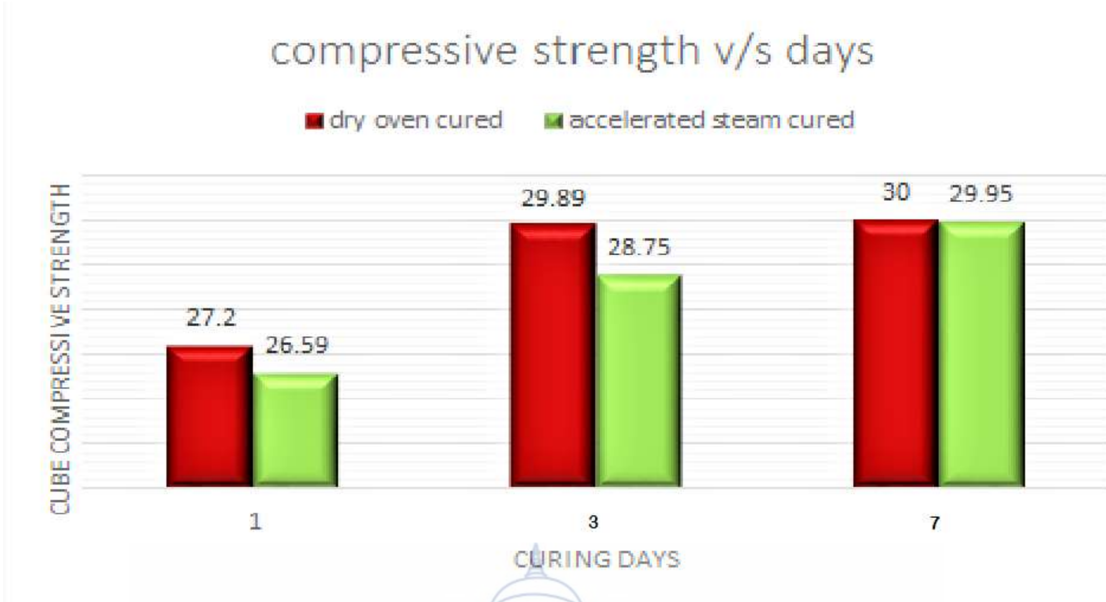


FIG 6.7: PFA AND GGBS IN RATIO 3:7 WITH 22 MOLAR CONCENTRATION

Test results using GGBS showed that polymerisation takes place more efficiently. GGBS incorporates additional strength to concrete. The strength of oven dried cured concrete gave higher strength as compared to accelerated steam cured concrete. Design strength is achieved in both cases.

6.3 Split Tensile strength of concrete.

Split tensile strength of concrete was performed on cylinders varying in molar concentrations of sodium hydroxide. Following test results are displayed in graphical form.

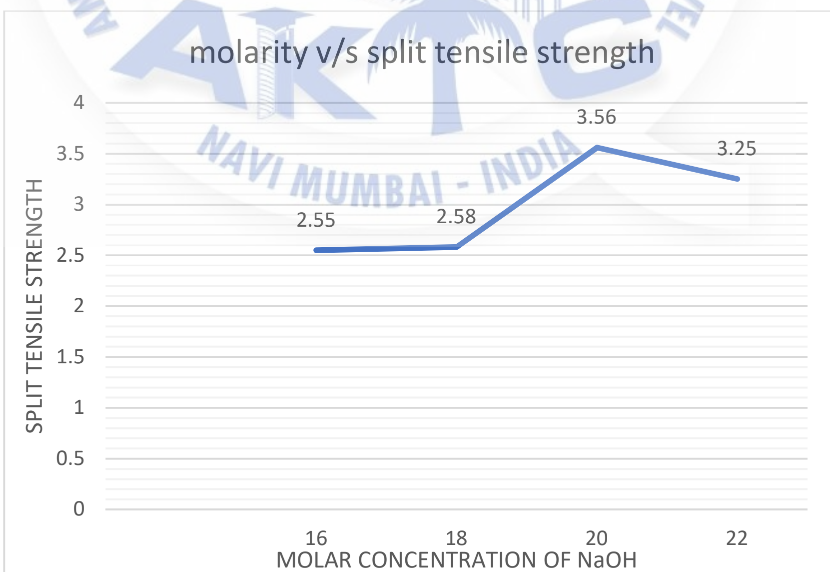


FIG 6.8: COMPARISION OF SPLIT TENSILE STRENGTH AND MOLAR CONCENTRATION OF SODIUM HYDROXIDE.

Here we observed that as molar concentration increases, split tensile strength of concrete also increases, but after 20 M concentration, it decreases slightly but near to theoretical tensile strength as obtained by equation quoted by IS. Brittle nature of concrete is observed. During the crushing of 18 M concentration specimen, a slight crack was observed until crushing. Specimens of 20 and 22 M concentrations had split into two equal half's after testing as shown in fig 5.20.

6.4 Workability of fresh geopolymer concrete.

Slump test was performed on fresh geopolymer concrete. Targeted slump was 100 mm but, slump range of 150 to 180 mm is achieved. Following figure shows the graphical representation of workability and molarity of fresh geopolymer concrete.

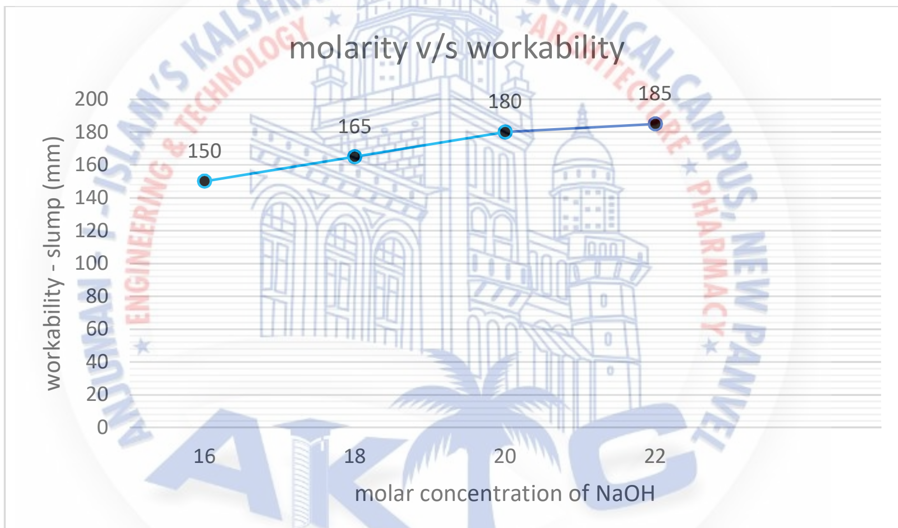


FIG 6.9: MOLARITY OF SODIUM HYDROXIDE COMPARED WITH WORKABILITY OF CONCRETE.

As it was observed that slump achieved is higher than targeted, as molarity increases, workability increases. It can be concluded that due to polymerisation reaction between alkali solutions and GGBS, it liberated water and to make the paste homogenous. In addition to that, superplasticizer played its important role in increasing workability. The additional water liberated during the polymerisation and mixing of concrete and binders adds to additional workability. This may also result in less cohesivity and reduced mechanical properties.

Since extra water is liberated due to polymerisation process and as a result it adds in to its water to cementitious ratio. This can be controlled by making suitable changes and correction in the water content or gauging water of the mix. The amount of extra water added or deducted can be suitably adjusted in the mix design.

The additional water or gel may result in decreases in compressive strength and other mechanical properties of hardened concrete.

6.5 Comparison of compressive strength of cement concrete and geopolymer concrete.

TABLE 6.1 COMPRESSIVE STRENGTH OF CONCRETE AT VARIOUS AGES.

Days	Compressive strength in %
1	16
3	40
7	65
14	90
28	100

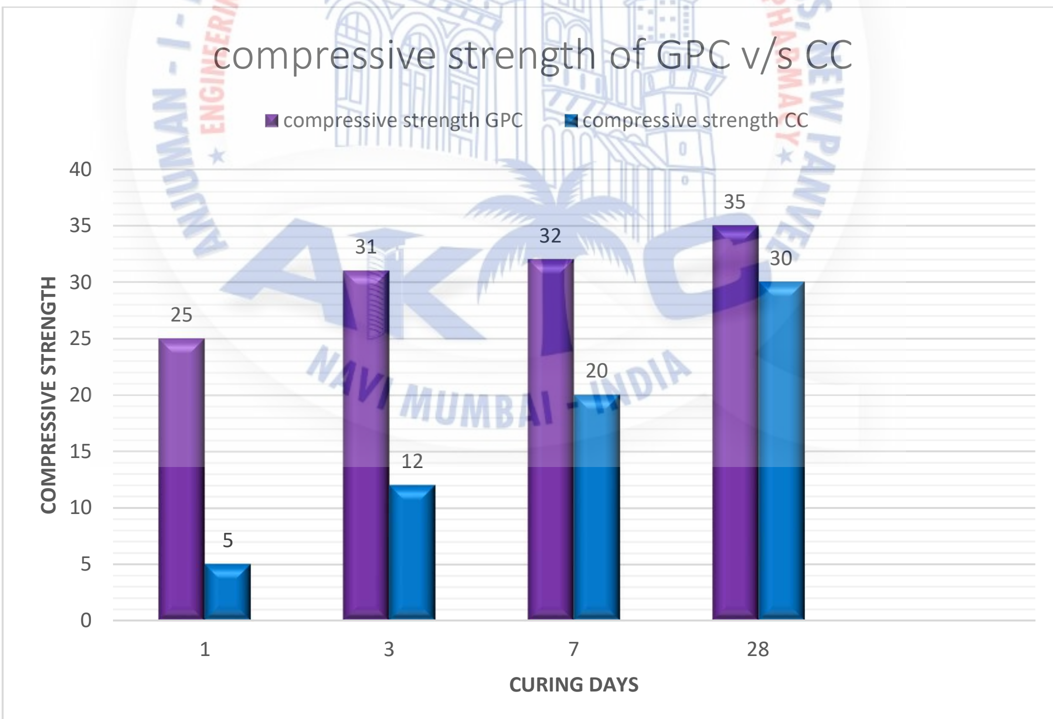


FIG 6.10: COMPARISION OF COMPRESSIVE STRENGTH OF CEMENT CONCRETE WITH GEOPOLYMER CONCRETE WHEN NORMALLY CURED AND ACCELERATED CURED RESPECTIVELY.

It can be observed that, one day strength of geopolymer concrete is much higher as compared to normally cured cement concrete. Geopolymer concrete gains much higher strength during the initial period and later it gains strength extremely slowly.

6.6 Cost analysis

TABLE 6.2 COST COMPARIRION WORKSHEET OF GPC AND CCC

Sr no	Materials	Unit	Rate	Geopolymer concrete	Conventional Concrete	Amount	
						GPC	CCC
1	Cement	bag	350	-	10	-	3500
2	Fine aggregates	Brass	1500	156.3	156.3	3500	3500
3	Coarse aggregates	Brass	2500	364.7	364.7	1800	1800
4	Sodium silicate	kg	110	1.8	-	510	-
5	Sodium hydroxide	kg	300	4.7	-	1052	-
6	Fly ash	kg	1.5	137.4	-	206.1	-
7	GGBS	kg	5	320.6	-	1603	-
8	Water	kg	1.5	206	206	309	309
	TOTAL					8980	9109

CHAPTER 7

CONCLUSIONS

7.1 Conclusions of present study

Following conclusions were obtained…

- Pan mixer mixed all the dry constituent materials efficiently.
- When water was added to the dry mix containing fly ash only along with both fine and coarse aggregates, the mix was very dry.
- On adding the geopolymer binder, the mix started getting thicker. As the mixing time increased, cohesivity increased thus resulting into consistent mix. Addition of superplasticizer added to tremendous increase in workability.
- On performing the cohesive test, result turned out to be satisfactory.
- Slump cone test and compaction factor test was performed on fresh concrete which gave a slump of 155 mm and compaction factor of 0.89.
- The mix was carefully casted in standard moulds. On vibrating, slurry was formed in a minute on the top surface of the moulds, thus eliminating the effort to finishing. The mix did not segregate.
- The initial setting time of mix was initially higher, about 2 days.
- On testing, it was observed that compressive strength was not achieved. 60 % strength was achieved in 7 days of only fly ash based geopolymer concrete. However, the strength of dry oven cured specimens was slightly higher as compared with those which are steam cured.
- Another mix was made using GGBS and fly ash. Both were used in the ratio of 30:70 respectively.

- Mixture was cohesive and results of cohesive test was very good.
- As the molarity was increased, workability also increased but it resulted in the decrease in compressive strength. This may be due to the leachate formed during polymerisation consisting of precipitates of hydroxides of aluminium, calcium and magnesium.
- Geopolymer concrete was brownish white due to the use of GGBS and fly ash.
- Design strength was achieved within 28 days using GGBS in concrete. Strength was much higher in initial period and then gained strength slowly.
- It is considerably economical than conventional concrete as per material basis.

7.2 Future scope

As it is a new type of concrete, a new technology with its various benefits and profits, it has tremendous future scope. Some of those are listed below.

- Extensive research can be carried out in geopolymer concrete.
- Effect on its alkalinity on corrosion of steel can be studied.
- High strength concrete can be achieved by using geopolymer binder
- Self-compacting concrete can be made using different mineral and chemical admixtures in geopolymer concrete.
- More innovative and new technology research can be carried out by deeply studying geopolymer chemistry.

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