RESEARCH ON MECHANICAL PROPERTIES OF GEO-POLYMER CONCRETE

Submitted in partial fulfilment of the requirements

for the degree of

BACHELOR OF ENGINEERING

in

CIVIL ENGINEERING

by

Shaikh Maaz Tufail (13CE52)

Murumkar Nabil Yaseen (14CE41)

Pathan Huzaif Nasir (14CE46)

Siddiqui Fahad Asif (14CE59)

Under the guidance of

Prof. Firoz Nadaf

Department of Civil Engineering

School of Engineering and Technology

Anjuman-I-Islam’s Kalsekar Technical Campus

New Panvel, Navi Mumbai-410206

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CERTIFICATE

This is to certify that the project entitled “Experimental Investigation on Geo-Polymer Concrete” is a bonafide work of **Mr. Shaikh Maaz (13CE52), Mr. Murumkar Nabil (14CE41), Mr. Pathan Huzaif (14CE46), Mr. Siddiqui Fahad (14CE59)** submitted to the University of Mumbai in partial fulfillment of the requirement for the award of the degree of “Bachelor of Engineering” in “Civil Engineering”.

Prof. Firoz Nadaf
(Project Guide)

Dr. R. B. Magar
(Head of Department)

Dr. Abdul Razzak Honnutagi
(Director,AIKTC)

APPROVAL SHEET

This dissertation report entitled "Experimental Investigation on Geo-Polymer Concrete" by **Mr. Shaikh Maaz (13CE52), Mr. Murumkar Nabil (14CE41), Mr. Pathan Huzaif (14CE46), Mr. Siddiqui Fahad (14CE59)** is approved for the degree of "Civil Engineering".

Examiners

1. ....

2. ....

Supervisors:

1. ....

2. ....

Date:

Place: New- Panvel

DECLARATION

We declare that this written submission represents our ideas in our own words and where others ideas or words have been included; we have adequately cited and referenced 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 submission. We understand that any violation of the above will be 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.

Shaikh Maaz Tufail (13CE52)

Murumkar Nabil Yaseen (14CE41)

Pathan Huzaif Nasir (14CE46)

Siddiqui Fahad Asif (14CE59)

Date:

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ABSTRACT

Increase in emission of carbon dioxide due to different industrial and non-industrial activities are causing a serious threat to environment. Cement being one of the major contributors in carbon dioxide emissions there is greater need felt throughout the world to reduce carbon dioxide emissions through cement manufacture. Industrial by-products like GGBS, fly ash and rice husk have a serious problems in waste disposal which affects economy of country. Geo-polymer concrete is a solution to this problem. Geopolymer is a class of aluminosilicate binding material synthesized by thermal activation of GGBS and fly ash. Geopolymer is produced due to alkalination of materials rich in aluminium and silicon with alkali solution, an aqueous solution of sodium hydroxide and sodium silicate. Alkali solution with 16M molar concentration was prepared with hydroxide to silicate ratio as 2.5.Different samples were casted with 50% GGBS, 25% PFA and 25% metakaolin. All the specimens were cured at 60 degree calcium in accelerated curing tank for 3 days. It was observed that geo-polymer concrete gives higher strength as compared to normal concrete.

Keywords – Carbon dioxide, GGBS, Fly ash, Geopolymer, alkalination, metakaolin.

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CHAPTER 1

INTRODUCTION

1.1 General

The most commonly used construction material in the world is Concrete and it stands second only to water in terms of most utilized substance on Planet Earth. Concrete is obtained by mixing cementicious materials, water, aggregates and SCM's if necessary and sometimes admixtures. The materials on mixing forms a mixture which is then placed in forms and allowed to cure resulting in hardened rock like mass known as Concrete.

1.2 Etymology and History

The word Concrete comes from "Concrtetus" a Latin word meaning compact or Condensed. Small-Scale use of cement dates back to thousands of years ago. Since 6500 BC Nabataea traders or Bedouins used self –cementing properties of cement to build kilns to supply mortar, construct concrete floors. However it was during Ancient Egyptian era and later Roman eras that concrete gained popularity and was commonly used for construction purpose. During Roman Era Roman concrete was made from quicklime, pozzolana and an aggregate of pumice.

After Roman Era use of burned lime and pozzolana was greatly reduced and by 14th century it was forgotten. From 14th century the use of cement started increasing. The Canal du Midi located in South France was constructed in 1670 using concrete and was considered to be a land mark structure.

The Industrial Era succeeded Roman era and during this era Joseph Aspdin developed Portland cement in 1824 which brought about a landmark change and provided an answer to mankind's quest for durable and strong binder. Gradually Reinforced concrete was introduced in the year 1849 which paved the way for use of concrete in mega structures like Dams.

1.3 Composition of Concrete

Concrete in broad sense is a product obtained from a combination of cementitious materials, water, aggregates and sometimes admixtures. The reaction between water and cementitious materials is entirely responsible for formation of concrete. However due to advancements made in research and technology wide range of products are being used currently to make concrete. These products include blast furnace slag, pozzolan, fly ash, micro silica etc. Normal curing, Steam curing, dry heat curing, shock vibrated, spraying and extruding are some of the techniques used for curing of concrete.

1.4 Types of Concrete

Since its discovery there has been advancement made in concrete. 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. **According to developments made in concrete and Construction Industry**

- GGBS or Slag based concrete
- Light weight concrete
- High density concrete
- Silica fume or alkofine concrete
- Foam concrete
- Floating Concrete
- Stamped concrete
- Self Compacting concrete
- Shotcrete
- Limecrete
- Pervious concrete

1.5 Effect of Concrete on Environment

The environmental effects of concrete, its manufacturing and its applications are like two sides of a coin. Some effects are useful whereas some are very harmful. Cement being a major contributor to concrete has its own environmental and social impacts which contributes largely to concrete. Cement industry is one of the primary producers of carbon dioxide (CO_2) a potent green house gas. Carbon Dioxide released from concrete is one of the primary reasons for increasing global temperature which may lead to drastic climate change in the future. According to a recent statistic the production of cement increases 3% annually and cement industry contributes 5% of total man made greenhouse gas emissions every year.

The production of One ton of cement liberates one ton of carbon dioxide in the atmosphere. The major reason for this release of CO_2 is heating of cement at a very high temperature to form clinkers. A major culprit of this is alite, a mineral which cures within hours and is responsible for imparting strength to concrete however this alite has to be heated to 1500 degrees in clinker forming process.

The Concrete Industry has recognized the effects of carbon dioxide on Environment. U.S.A being of the major users of cement formulated a 'Vision 2030: A Vision for U.S.A Concrete Industry'. One of the major points formulated was to reduce carbon dioxide emissions by reusing kiln dust or clinkers.

With nearly 460 million tonnes of cement production capacity, India is the second largest cement producer in the world and accounts for 6.9% of world's cement output. By FY20 it is expected that India's cement production capacity will reach 550 million tones.

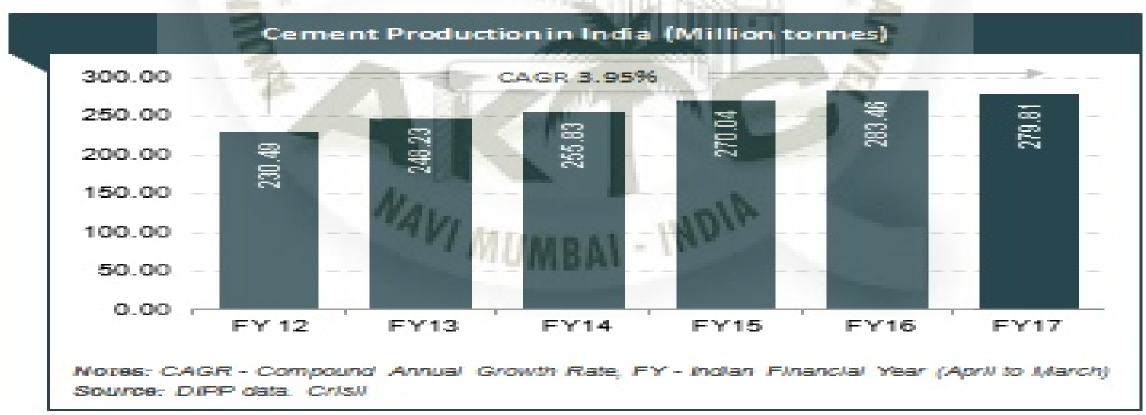


FIG: 1.1 CEMENT PRODUCTION IN INDIA

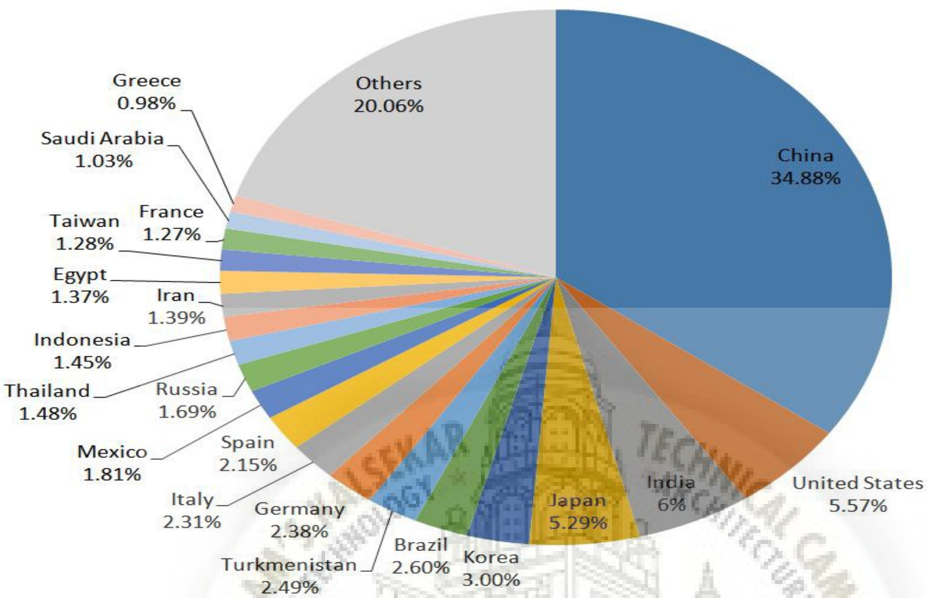


FIG: 1.2 TOP CEMENT PRODUCING COUNTRIES IN THE WORLD

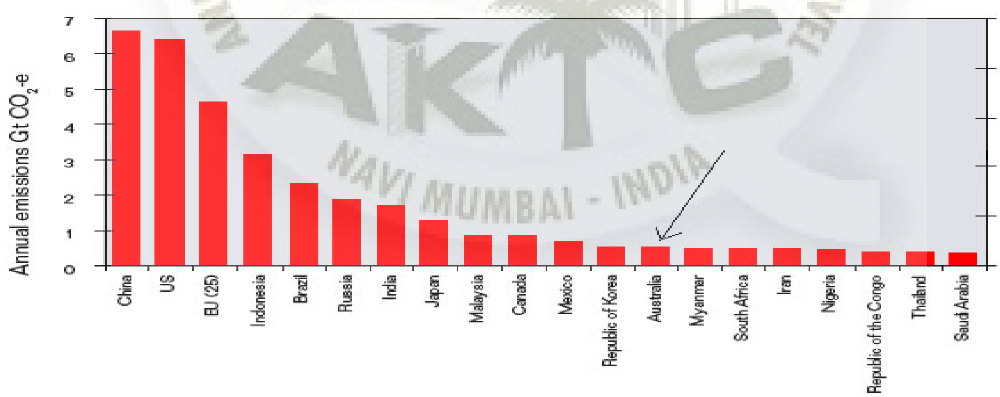


FIG: 1.3 TOP CARBON DIOXIDE EMMITTING COUNTRIES

Due to increase in cement production there has been an increase in carbon dioxide emission which has lead to increase in global carbon footprint. Efforts have been made throughout the world to reduce production of clinker based cement. Researches have been carried out to develop sustainable and eco-friendly materials to be used in concrete.

FIG: 1.4 GLOBAL CARBON FOOTPRINT

1.6 Geopolymer Background

A major catastrophic fire took place in a night club in France on 1st November 1971 which claimed the lives of 146 people. The cause of incident was later discovered to be polyurethane and paper mashes which were used to decorate the entire interior of the night club which proved to be the main cause for spreading of fire within no time.

Prof. Joseph Davidovits a French Chemist carried out a research to find a concrete which is good in appearance as well as fire resistant. In the year 1972 at Davidovit's private research laboratory located in Saint Quentin, France which later came to be known as Cordi-Geopolymere Geopolymer was discovered. Prof. Joseph Davidovits made a statement saying "a material has to be good in appearance as well as fire resistant. Nature states, selected inorganic materials are fire resistant so I developed inorganic polymer." He coined the name "geo-polymer" as the product obtained was inorganic and a cross linked structure.

After the discovery of geopolymer constant efforts were made to understand its cross linked structure as well as to present it to the entire construction industry. In June 1998 First European conference was held by geopolymer institute at university of Compiegne. The second conference was a landmark conference held at Saint Quentin, France in which 32 research papers were presented to more than 100 Scientist. Third conference was held at Australia in 2002 in Melbourne University where the idea of turning "Potential into Profit" was discussed. With recent developments made in geopolymer efforts have been made to use geopolymer throughout construction industry as well as use it military and civil works.

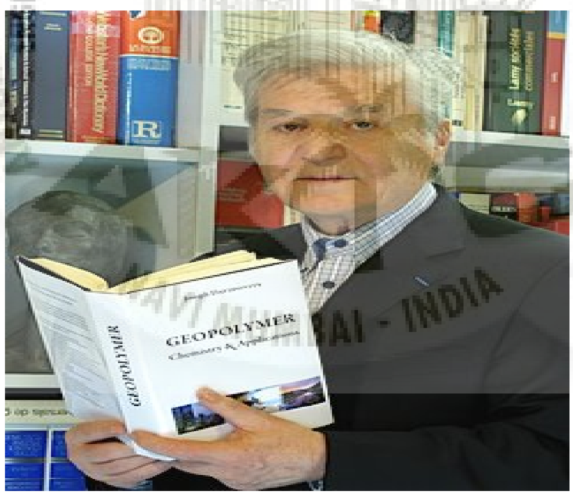


FIG: 1.5 PROF JOSEPH DAVIDOVITS

1.7 Aim and Objective of Present Study

1. To Study the gain of strength of geo-polymer concrete after curing.
2. To Study the tensile and flexural strength of geo-polymer based concrete.
3. To develop Split Tensile strength vs Compressive Strength Equation.
4. To develop Modulus of Rupture vs Compressive Strength Equation.

1.8 Methodology

1. Study of literature and collection of data
2. Procurement of Materials
3. General Inspection of Materials
4. Laboratory Test on Materials
5. Mix Design Calculations
6. Trial Mixes
7. If necessary correction of Mix Design after Trials
8. Casting of Cubes, Cylinder Moulds and Beams whose dimensions adhere to IS
9. Testing Of Specimen
10. Collection of Result Data
11. Interpretation of Results and Discussions
12. Concluding Remarks.

CHAPTER 2

LITERARURE REVIEW

2.1 General

Generally Strength is the first and biggest parameter considered while designing a concrete. Along with strength, properties like split tensile strength, flexural strength along with shrinkage, creep, workability etc are considered while designing. These can be achieved by good quality of materials along with proper control on concrete but the biggest challenge faced in geo-polymer is compatibility and suitability of geo-polymer constituent materials with each other.

Review of Equations and other criteria

1. Determination of compressive strength from cubes

Cube strength of concrete does not generally represent actual strength of concrete in the structure. However it is an important test which helps in establishing quality control measures. Cube strength gives a good indication of potential strength that can be achieved through the mix design. Compressive strength through cubes also helps in determining difference between mix design strength and strength achieved on site.

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 is generally taken after 28 days.

- Characteristic compressive strength of a motar measuring 100mm x 100mm x 100mm is generally taken after 28 days.

General Points to be considered while testing cubes for compressive strength:

1. Atleast 3 samples per batch have to be tested to monitor strength development over a given period of time to determine validity of test results.

2. Cubes that have been casted in accordance with a relevant standard special care should be taken to ensure that proper compaction of concrete is done which will prevent Honeycombing and influence of voids as their presence will give false values.

3. Rate of loading should be maintained and it should not be more than 14N/mm2.

4. Measured result should follow certain acceptance criteria.

5. According to Is 456:2000 acceptance criteria should comply with the following condition:

For mixes M15

Mean Strength ≥ fm + 0.825 x s.d

≥ fm + 3 N/mm2

For mixes M20 and above

Mean Strength ≥ fm + 0.825 x s.d

≥ fm + 4 N/mm2

2. Split tensile strength:

- **As Per IS 456:2000, clause 6.2.2**

$$E=0.7\sqrt{fck} \qquad \ldots\ldots\ldots\ldots\ldots(1)$$

- **As per ACI 318-95**

$$E=0.94\sqrt{fck} \qquad \ldots\ldots\ldots\ldots\ldots(2)$$

3. Flexural Strength:

- **As per Is 456:2000**

Fcr = 0.7√fck ……………(1)

2.2 Review of Literature:

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

2. Joseph Davidovits et al (2002) the Founder of Geo-Polymer Concrete gave a presentation describing following Geo-Polymer applications developed since 1972 in France, USA, Europe: Fire Resisting Wood Panels, Insulated panels and walls, Decorative Stone Artifacts, Foamed Geo-Polymer panels for thermal insulation, Low-tech Building Materials, Refractory Items, Thermal Shock Refractor, Aluminum Foundry Application, Energy Low Ceramic Tiles, Geo-Polymer Cement And Concrete. These applications show that these Geo-Polymer products have withstood 25 Years of time and are continuously commercialized.

3. Joseph Davidoits et al (2012) wrote about Geo-Polymer concrete and conventional concrete where in he described Portland cement Chemistry vs Geo-polymer Cement Chemistry, Alkali-Activated Materials vs Geo-Polymer Cements, Different Geo-Polymer Categories, User – friendly alkaline materials, Rock Based Geo-polymer concrete etc.

4. Shankar H Sanni and B Khadiranaikar et al,(2000) prepared different alkali solutions with sodium silicate and sodium hydroxide ratio varying from 2 to 3.5 for different grades of concrete. It was observed that specimens received white deposits on the surface during exposure to magnesium sulphate solution which gradually transformed soft and flaky fly ash into hard and rounded shape. It was also observed that higher ratio of sodium silicate to sodium hydroxide led to increase in compressive strength. Addition of chemical admixture i.e. super plasticizer labeled as "CONMIX SP-430" improved workability of geo-polymer concrete with little effect on compressive strength.

5. J.W.Wang and T.W.Cheng et al, (2005) wrote about production of geo-polymer with the Help of Coal Fly Ash Waste. Coal Ash is the main Waste from Power Plants with the estimation that 2 million tons per year coal ash wastes are generated. The aim was to develop a fly ash based geo-polymer concrete which can be fire resistant. Test Results showed that Geo-Polymer based on waste fly ash has greater physical/mechanical properties for resistance test.

6. V.S.Kamble, Prof.M.V.Nagendra, Dr.D.N.Shinde published a research in IJRASET 2016 on compressive strength of fly ash based geo-polymer concrete in which M40 grade of geo-polymer concrete was used constituting 85% fly ash and 15% cement. 6 cubes were casted and testing was done for 7 days and 28 days proper curing. The results obtained were that 85% fly ash based geo-polymer has low workability in 7 days and 28 days samples are very good and can be used for mass concrete work as well as highway work.

7. P.Yellaiah, Sanjay Kumar Sharma and T.D.Gunneswara Rao et al,(2014) published a research in ARPN Journal on Tensile Strength of Geo-Polymer where in the research was conducted by preparing Mortars at different curing temperatures and also increasing alkaline activator to fly ash ratio. 6 samples were prepared with 3 being cured at 30 Celsius and remaining at 60 Celsius. It was observed that on increasing curing temperature compressive and tensile strength of geo-polymer concrete increased this was due to complete polymerization taking place at elevated temperature. Similarly increase in alkaline activator to fly ash ratio also lead to increase in compressive strength and tensile strength; this was due to more availability of alkaline activator lead to better dissolution of fly ash.

8. B.Rajini and A.V.Narsima Rao et al (2015) carried out a research on mechanical properties of geo-polymer with GGBS and Fly Ash as source materials. The Aim was to determine strength of geopolymer having a combination of GGBS and Fly Ash as source.16 cubes were casted with different proportions of GGBS and Fly Ash. It was discovered that geo-polymer concrete blended with 100% GGBS and 0% fly ash had the highest strength at all curing periods and the value was greater than conventional concrete(OPC). It was also determined that 100% fly ash and 0% GGBS had the lowest strength at all curing periods. Similarly test samples were created for 80%GGBS and 20%fly ash, 60%GGBS and 40% fly ash, 40%GGBS and 60%fly ash and 20%GGBS and 80%fly ash. It was observed that samples having higher GGBS gave higher strength as compared to fly ash.

9. M.Kalvaini et al,(2015) carried out experimental research on Split tensile strength and Flexural strength of geo-polymer based concrete by changing molarity. A total of 12 cylinders for M-40 grade concrete were cast and results were tallied with normal concrete. It was observed that split tensile strength of normal concrete was less than geo-polymer concrete.

Similarly 6 beams were cast for 8M and 10M and compared with conventional concrete beams. It was observed that Flexural strength was less for geo-polymer concrete as compared to normal concrete.

10. Committee of Concrete Institute, Australia (2011) gave a brief explanation on correct practices for geo-polymer concrete production. Different curing methods and techniques on geo-polymer concrete including ambient atmospheric curing, dry curing, steam curing and wet curing along with curing time and curing temperature were explained. Mechanical Properties like split tensile strength, modulus of rupture were studied and their empirical equations were developed from ACI codes.

2.3 Concluding Remarks:

After a thorough study of previous works and literature we conclude the following:

- Molar concentration plays a very significant role in formation of geo-polymer concrete.
- Geo-Polymer mix can be designed by modifying IS code equation.
- By taking numerous trails of sand and other cementitious materials their quantity as well as characteristics can be determined.
- Ratio of Si: Al ratio plays a main role along with sodium hydroxide in formation of geo-polymer.
- GGBS plays a main role in imparting strength to geo-polymer concrete.
- Increasing alkaline activator to GGBS/Fly ash ratio leads to increase in strength.
- The ultimate aim is to develop a concrete that can reduce carbon dioxide emissions.

CHAPTER 3

GEO-POLYMER INVENTORIES

3.1 General

Inventories are nothing but materials used in production of geo-polymer concrete. Use of mineral admixture as a partial replacement of cement in concrete is a common practice adopted in Indian Concrete Industry as well as throughout the world. The most commonly used mineral admixture is GGBS and fly ash. Although silica fume, Metakaolin, Rice Husk Ash and Natural Pozzolan can be utilized their potential use is limited due to high price and due to unavailability of these materials.

Mineral Admixtures are generally obtained as a waste product obtained from thermal and nuclear power plants. These mineral admixtures pose a serious disposal problem as well as high maintainenace is required for their disposal. Their utilization as a material for geo-polymer concrete reduces disposal problem. These materials possess characteristics which help in enhancing mechanical properties of geo-polymer concrete as compared to OPC and PPC.

Generally used materials in Geo-Polymer concrete are as follows:

1. GGBS
2. PFA
3. Alkali Solutions
4. Aggregates (Coarse and Fine)
5. Water
6. SCM’s

1. GGBS

Blast Furnace slag is obtained as a byproduct during the manufacture of iron as a blast furnace. Slag is obtained from a fusion of limestone flux with ash from coke and siliceous and aluminous residue which is obtained from iron after its separation from ore. The slag thus obtained is rapidly allowed to cool down with water to form a glassy disordered structure. Slow cooling of slag enables a formation of crystalline well-ordered structure to form which is stable and non-reactive.

In order to achieve satisfactory properties molten slag is rapidly allowed to cool by jet streams of water or air under pressure. The slag gets easily granulated i.e. breakdown of slag occurs into sand-sized particles which enables it to be in glassy state. In this state slag is more reactive than in crystalline state obtained by slow cooling. The Granulated Sand like materials obtained is more suitable as concrete materials as compared to cementitious materials. The unground materials so obtained are not suitable as fine aggregate because they are weak, fluffy rather than solid particles. In order to be used as a cementatious material the ground slag should be fine or finer than cement as the fineness of slag (along with chemical composition) determines how rapidly the slag will react in concrete.

The use of GGBS has increased tremendously in the last few decades. GGBS has been used to make durable concrete in combination with OPC and other pozzolanic materials. European countries use the highest amount of GGBS followed by America and Asia to increase the lifespan of durable structures from 50 years to 100 years.

Concrete with GGBS cement sets more slowly as compared to OPC but has greater strength over a longer period of time in working conditions. This helps in lowering heat of hydration, lowering temperature and helps in avoiding cold joints. Use of GGBS as a cementatious material helps in reducing effect of chloride action on concrete, provides higher resistance to sulphate.

GGBS can be directly mixed with Portland cement, water and aggregates at the batching plant. GGBS can also be used as a direct replacement of cement, on a one-to-one basis by weight. Replacement levels can be from 30% to 80% but generally it is taken as 40% to 50%. In our project we are using GGBS and Fly Ash as cementatious material instead of cement to produce a more eco friendly concrete.

Chemical composition of slag depends on the available raw materials and blast furnace conditions. Major oxides present in GGBS are calcium, silicon, aluminum and manganese in combination with oxygen.

TABLE 3.1: COMPOSITION OF OXIDE PRESENT IN GGBS AND PORTLAND CEMENT

Oxide Composition	Portland Cement	GGBS
Cao	64	40
Sio2	21	36
Al203	6	10
Fe2o3	3	0.5
MgO	1.5	8.0
So3	2	0.2
K2o	0.8	0.7
Na2O	0.5	0.40

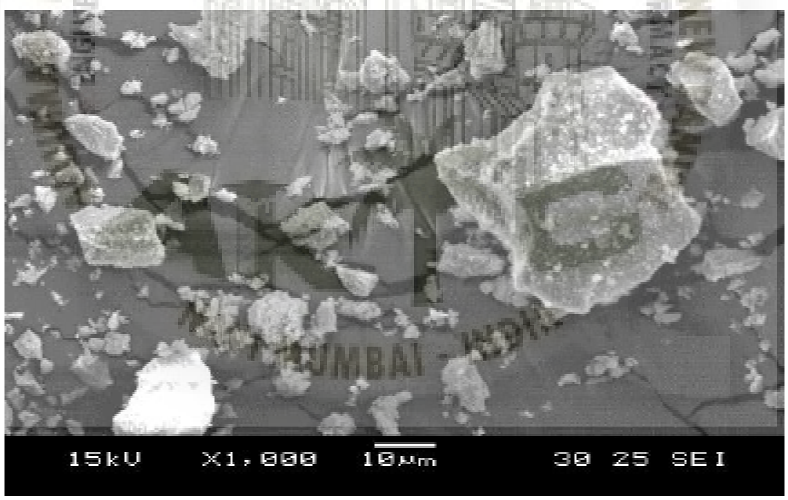


FIG 3.1: SEM OF GGBS

FIG 3.2: GGBS AVAILABLE IN MARKET

GGBS is used on a large scale in concrete due to its stability than other cementatious materials. Following points shed light on advantages of GGBS over other materials:

1. To use a cementatious material granulated slag must be grounded as fine as possible or finer than cement. The Fineness along with chemical composition helps in determining how quickly the slag will react in concrete.

2. GGBS helps in reducing heat of hydration and temperature cracks.

3. For alkalination as well as to make eco-friendly concrete.

Applications of GGBS:

1. Used in construction of all residential, commercial as well as industrial complexes.

2. Dams and other mass concrete works.

3. Water retaining structures.

4. Concrete roads and flyovers.

5. Ideal for marine construction.

6. Precast concrete

7. Foundation and pile construction.

2. PFA

Fly ash is a coal combustion product that contains particulates driven out of coal-fired boilers together with flue gases. In modern coal power plants, fly ash is generally obtained out of electrostatic precipitators or other filtration equipment before flue gases reach chimneys. The constituents of fly ash generally consist of one of the following: : arsenic, beryllium, boron, cadmium, chromium, hexavalent chromium, cobalt, lead, manganese, mercury, molybdenum, selenium, strontium, thallium, and vanadium. Fly Ash is generally a by-product of pulverized fuel coal in electrical furnace power generation plants at 1250 to 1600 Celsius. After Ignition most of the volatile matter and carbon in the coal are burnt off. During combustion impurities present in coal such as clay, feldspar, quartz and shale are carried of by fuel gases. After cooling the material that remains in glassy form is known as 'FLY ASH'

Earlier fly ash was generally released into the atmosphere which contributed to pollution but now-a-days due to Air Pollution Control Act it is mandatory to capture it with pollution control equipment before its release. In the US fly ash is generally stored at coal plants or used for land filling. About 43% is recycled and is used as pozzolan or as a replacement of Portland cement. After a long regulatory process, the EPA published a ruling in December 2014, which stated that coal fly ash is regulated on the federal level as "non-hazardous waste".

Fly ash materials which solidify rapidly and are collected by electrostatic precipitators while suspended in exhaust gases are spherical in shape. The range of fly ash generally varies from 1µm to 300µm with typical size measuring not less than 20µm.The colour of fly ash is generally grey with a relative density varying between 1.9 and 2.2. Fly Ash is a heterogeneous material. SiO_2, Al_2O_3, Fe_2O_3 and occasionally CaO are the main chemical components present in fly ashes.

ASTM C618 has defined two types of fly ash Class F and Class C. The chief difference between these classes is the amount of calcium, silica, alumina, and iron content in the ash. The chemical properties of the fly ash are largely influenced by the chemical content of the coal burned (i.e. anthracite, bituminous, and lignite).

When harder, older anthracite and bituminous coal are burnt typical Fly ash Class F is produced. This fly ash is pozzolanic in nature with Silica being the most important constituent and alumina and iron oxide are also present. Possessing pozzolanic properties, the glassy silica and alumina of Class F fly ash requires a cementing agent, such as Portland cement, quicklime, or hydrated lime—mixed with water to react and produce cementitious compounds. Alternatively, adding a chemical activator such as sodium silicate (water glass) to a Class F ash can form a geopolymer. Class C fly ash is produced by burning of younger lignite or sub-bituminous coal. . In the presence of water, Class C fly ash hardens and gets stronger over time. Class C fly ash generally contains more than 20% lime (CaO). Unlike Class F, self-cementing Class C fly ash does not require an activator. Alkali and sulphate (SO_4) contents are generally higher in Class C fly ashes.

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 have high calcium (10%-30%) but have relatively less carbon content which is generally less than 2%.

Class F fly ash was procured from a construction site at Taloja MIDC road for our project. As it was obtained from a construction site we assume it to be as per IS specifications. The use of Fly Ash can be done in two ways either it can be pre-blended cement or separately mixed with OPC. Here we are using in combination with GGBS to produce geo-polymer concrete as it is a concrete without cement.

FIG 3.3: FLY ASH AVAILABLE IN MARKET

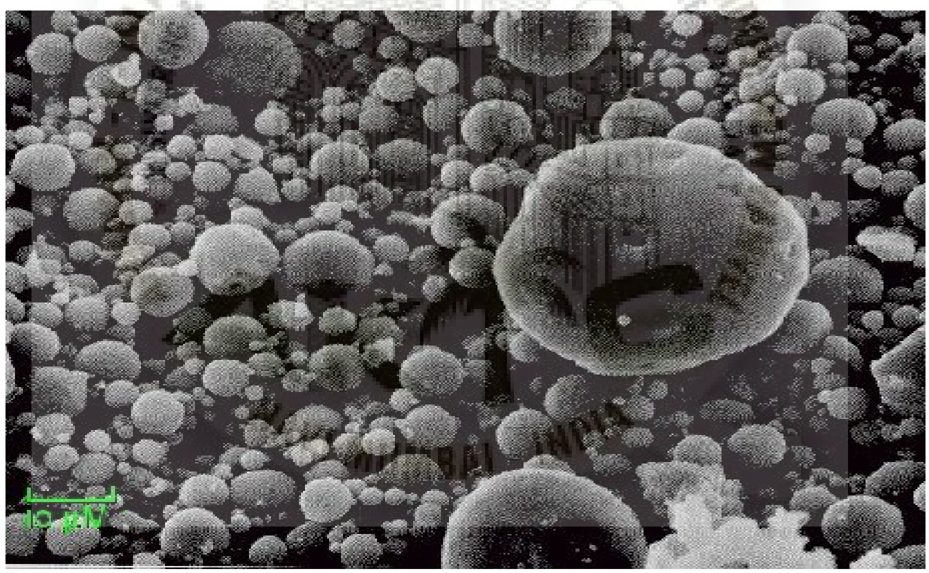


FIG 3.4: SCANNING ELECTRON MICROSCOPE (SEM) IMAGE OF FLY ASH

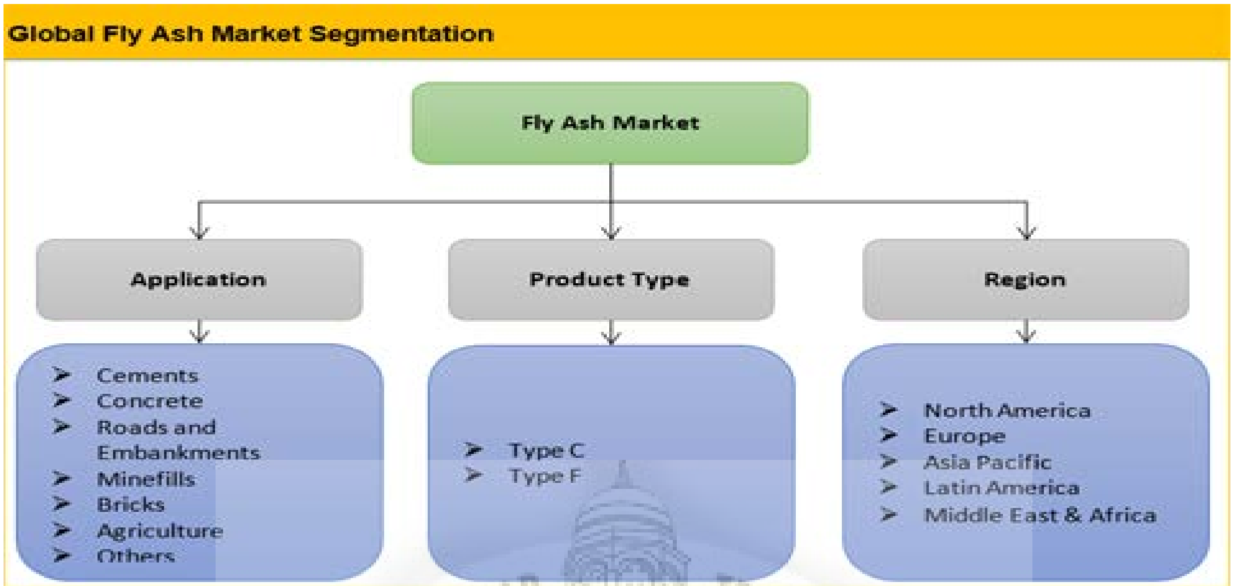


FIG 3.5: GLOBAL FLY ASH DISTRIBUTION

3. ALKALI SOLUTIONS

The alkali solutions are used for alkalination of cementatious materials which bring about a polymerization leading to formation of geo-polymer binder. Sodium Hydroxide and Sodium Silicate are used as medium to form alkali solutions. Sodium Hydroxide and Sodium Silicate were purchased from Mr.Niraj. A 14M concentration of NaoH was prepared in water in the lab. Sodium Silicate of 40% concentration and required grade was added to sodium hydroxide solution and alkali solution was prepared.

The solution so prepared was used within 24 hrs and was prepared 1 day before usage. This solution was prepared and kept covered at all times for gel formation.

FIG 3.6: SODIUM HYDROXIDE PELLETS

FIG 3.7: SODIUM SILICATE SOLUTION

FIG 3.8: SODIUM SILICATE PELLETS

4. Coarse aggregates:

Aggregate, is a broad category of coarse to medium grained particulate material used in construction, including sand, gravel, crushed stone, slag, recycled concrete and geosynthetic aggregates. Aggregates are the most mined materials in the world. Aggregates are a component of composite materials such as concrete and asphalt concrete; the aggregate serves as reinforcement to add strength to the overall composite material. Sources for aggregates can be grouped into three main areas: Mining of mineral aggregate deposits, including sand, gravel, and stone; use of waste slag from the manufacture of iron and steel; and recycling of concrete, which is itself chiefly manufactured from mineral aggregates. In addition, there are some (minor) materials that are used as specialty lightweight aggregates: clay, pumice, perlite, and vermiculite.

These aggregates provide about 75% of concrete volume making it one of the important constituents. These aggregates should meet certain requirements with respect to grading, shape, size and strength. Coarse aggregates are generally inert though they exhibit certain reactivity which is popularly known as AAR (alkali aggregate reactivity or reaction). Since geo-polymer is highly alkaline due to sodium hydroxide hence AAR marks significance importance.

The Coarse aggregates were obtained from a local distributor in New Panvel. Various lab tests were done to determine strength, grading as well as other properties for incorporation into mix design of design.

FIG 3.9: COARSE AGGREGATES

Aggregates are classified on the basis of:

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

Most concrete contain aggregates of size 40mm or 20mm and grading goes down to 150 microns or less. At times max size of aggregates is taken as 10 mm. Sometimes for large projects MSA of 150mm or above is used. Crushed downgraded aggregates are passed through screened rotating screens having 1 to 0.5 inch diameter mash. Hence crushed aggregates of size 30mm to 15mm respectively are available. Generally size of aggregate is increased to make economical concrete as this reduces amount of cement required in concrete due to reduction of surface area per unit weight of aggregates.

Limitations of MAS are due to:

- Maximum dimensions of concrete section should not be less than 4 times MAS.
- Concrete cover to include steel should not be less than MAS or should be 5mm more than MAS.

Coarse aggregates form the base of concrete. Hence naturally their properties and characteristics play an important role in fresh and hardened concrete. Naturally characteristics of concrete are also affected by properties of other constituent materials like cement, water, fine aggregates, mineral admixtures, SCM's etc. In addition to this concrete performance is also affected by mixing, transporting, placing, compaction and curing.

Properties	Influence on concrete performance
Specific Gravity/Porosity	**Strength, absorption and density.**
Chemical stability	**Durability, AAR.**
Gradation of particle size distribution	**Water demand, cohesion, bleeding, segregation, cement consumption.**
MAS	**Water demand, cement consumption and strength.**
Shape	**Water demand and packing.**

TABLE 3.2: PROPERTIES OF COARSE AGGREGATE AND THEIR EFFECT ON CONCRETE

5. Fine Aggregates

The aggregates whose size is less than 4.75mm are termed as Fine Aggregates. Its size ranges from 4.75mm to 150 microns. Any fraction lesser than 150 microns are termed as dust or silt. Due to recent developments made in construction industry fine aggregates are available in various categories like-M-Sand, river or natural sand, Gujarat sand, etc. Gujarat Sand was procured from local distributor in New Panvel.

Sand is a naturally occurring granular material composed of finely divided rock and mineral particles. It is defined by size, being finer than gravel and coarser than silt. The composition of sand varies, depending on the local rock sources and conditions, but the most common constituent of sand in inland continental settings and non-tropical coastal settings is silica (silicon dioxide, or SiO2), usually in the form of quartz. The second most common type of sand is calcium carbonate.

Fineness of aggregate plays an important role in concrete formation. It is very important to know fineness of aggregate as they significantly influence strength of concrete. Fine aggregates are divided into 4 Zones. Zone 1 represents coarse zone, Zone 4 represents finest zone whereas Zone 2 and 3 represent medium zone or fineness. The surface area of aggregate increase per unit weight when finer zone of fine aggregates are in excess which will result in excess cement paste requirement to bind the aggregate particles together and simultaneously more water will be required due to increase in surface area.

FIG 3.10: FINE AGGREGATES

Fine aggregates should selected in such a way that fine and coarse aggregate combination produce minimum voids in concrete and should lead to minimum cement paste formation. The properties of fine and coarse aggregates will vary from place to place depending upon particle size distribution of locally available materials.

Gradation of concrete also plays an important role in designing pump able concrete. Due to gap gradation in fine aggregates concrete becomes less cohesive and homogeneous and attains less adhesivity and hence results in choking of pump, thus affecting project.

6. Water

Water is the most critical constituent in designing of concrete however it is the cheapest material of all. It helps in bringing the consistency to mix while designing the concrete. Maximum water to binder ratio is specified as per IS 456:2000 clause 6.1.2, 8.2.4.1 and 9.1.2 table 5.

In general portable water can be used for mixing and curing of concrete. Presence of algae and bacteria leads to decrease in strength of concrete. Water used in the concrete should have Ph less than 6. Presence of oil in concrete is highly unwarranted as it causes decrease in strength. Similarly sea water cannot be used for concrete as it contains high risk of corrosion of reinforced steel and also increases AAR.

Water used in alkalination of geo-polymer was AIKTC tap water. Water was tested for Ph, chloride presence and nitrite presence and it was concluded that water was safe for use.

7. SCM's

SCM's are known as supplementary cementatious materials that are widely used in construction industry. Supplementary cementitous materials (SCMs), when used with Portland cement, contribute to the properties of concrete through hydraulic or pozzolanic activity or both. Besides GGBS and PFA there are many materials which can be used to improve concrete characteristics both in fresh and hardened concrete. Some of the commonly used SCM's are as follows:

- Silica fume
- Metakaolin
- Volcanic tuffs and pumices
- Surkhi
- Alco fines
- Micro fines
- Siliceous and Aluminous materials. Etc

Metakaolin was used as a SCM in geo-polymer project. Metakaolin is an anhydrous calcined form of the clay mineral kaolinite. Minerals that are rich in kaolinite are known as china clay or kaolin, traditionally used in the manufacture of porcelain. The particle size of metakaolin is smaller than cement particles, but not as fine as silica fume. The quality and reactivity of metakaolin is strongly dependent of the characteristics of the raw material used. Metakaolin can be produced from a variety of primary and secondary sources containing kaolinite:

- High purity kaolin deposits
- Kaolinite deposits or tropical soils of lower purity
- Paper sludge waste (if containing kaolinite)
- Oil sand tailings (if containing kaolinite)

ADVANTAGES:

- Increased compressive and flexural strengths
- Reduced permeability (including chloride permeability)
- Increased resistance to chemical attack
- Increased durability
- Reduced effects of alkali-silica reactivity (ASR)
- Enhanced workability and finishing of concrete
- Reduced shrinkage, due to "particle packing" making concrete denser
- Improved color by lightening the color of concrete making it possible to tint lighter integral color.

Metakaolin was procured from a construction site in Taloja.

8. Chemical Admixture

Admixtures are chemical compounds in concrete other than cement, water and aggregates and mineral additives that are added to concrete mix immediately before or during mixing to modify one or more specific properties of concrete in fresh or hardened state. Due to advancements made in construction industry concrete are used in numerous places in different conditions. In some conditions ordinary concrete fails to exhibit the required quality performance expected of it therefore in such cases it is necessary to modify the properties of concrete so as to make it more suitable for use hence in such cases admixtures are used to enhance properties of concrete. Some of the admixtures are listed below:

- Plasticizers
- Super plasticizers
- Retarders

- Accelerators
- Air entraining Plasticizers
- Air entraining admixtures
- Pozzolanic or mineral admixtures
- Workability admixtures
- Bonding admixtures
- Damp proofing and water proofing admixtures
- Corrosion inhibiting admixtures.

Mid pc admixture was used in geo-polymer concrete. It was obtained from local contractor at GTB. The compatibility of admixture has to be supervised before its usage in concrete especially in geo-polymer as it contains strong alkali like sodium hydroxide. Hence IS 9013 table 3.3 gives a chart based on requirement of chemical admixture.

CHAPTER 4

GEO-POLYMER CHEMISTRY

4.1 General

A Geo-Polymer is a mineral chemical compound or mixture of compounds consisting of repeating units. For example, -Si-O-Si-O- siloxo, poly(siloxo),-Si-O-Al-O- sialate, poly(sialate),-Si-O-Al-O-Si-O-sialate-siloxo,poly(sialate-siloxo) -Si-O-Al-O-Si-O-Si-O-sialate-disiloxo,poly(sialate-disiloxo),-P-O-P-O- phosphate, poly(phosphate), -P-O-Si-O-P-O- phospho-siloxo, poly(phospho-siloxo), -P-O-Si-O-Al-O-P-O- phospho-sialate, poly (phospho-sialate) -(R)-Si-O-Si-O-(R) organo-siloxo, poly-silicone, -Al-O-P-O- alumino-phospho, poly(alumino-phospho), -Fe-O-Si-O-Al-O-Si-O- ferro-sialate, poly(ferro-sialate) which are created through a process of geo-polymerization.

Ordinary Portland Cement (OPC) has a different chemistry to that of geo-polymer cement. A Geo-Polymer is made by activating alumino-silicate materials, such as fly ash and slag with alkali-based chemicals such as sodium hydroxide and sodium silicate. Geo-Polymer does not contain cement. Geo-Polymers have been known to be useful binders for last 100 years but due to recent development made in Australia and also due to the fact that they have less carbon dioxide emissions their use is on the increase.

Davidovits (1988) proposed that an alkaline liquid can be used to react with silicon and aluminum with source material like GGBS, PFA, Rice Husk etc. to produce binders. Because the chemical reaction that place in this case is polymerization he coined the term Geo-Polymer to represent these binders.

Geo-polymers belong to family of inorganic polymers. Chemical composition of geo-polymers is same as zeolitic materials but microstructure is different. Polymerization involves fast alkaline reactions on silicon-aluminium minerals that results in formation of 3D chain of Si-O-Al-O bonds according to Davidovits (1994).

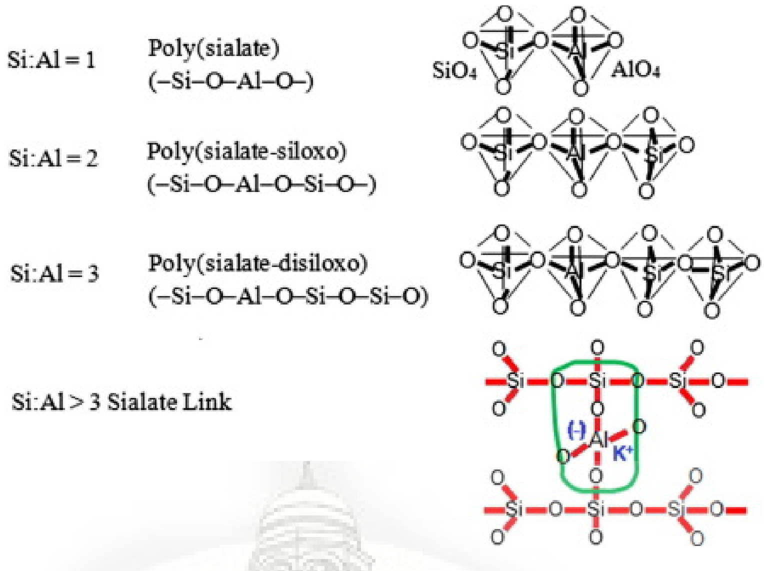


FIG 4.1: CHEMICAL STRUCTURE OF GEO-POLYMER

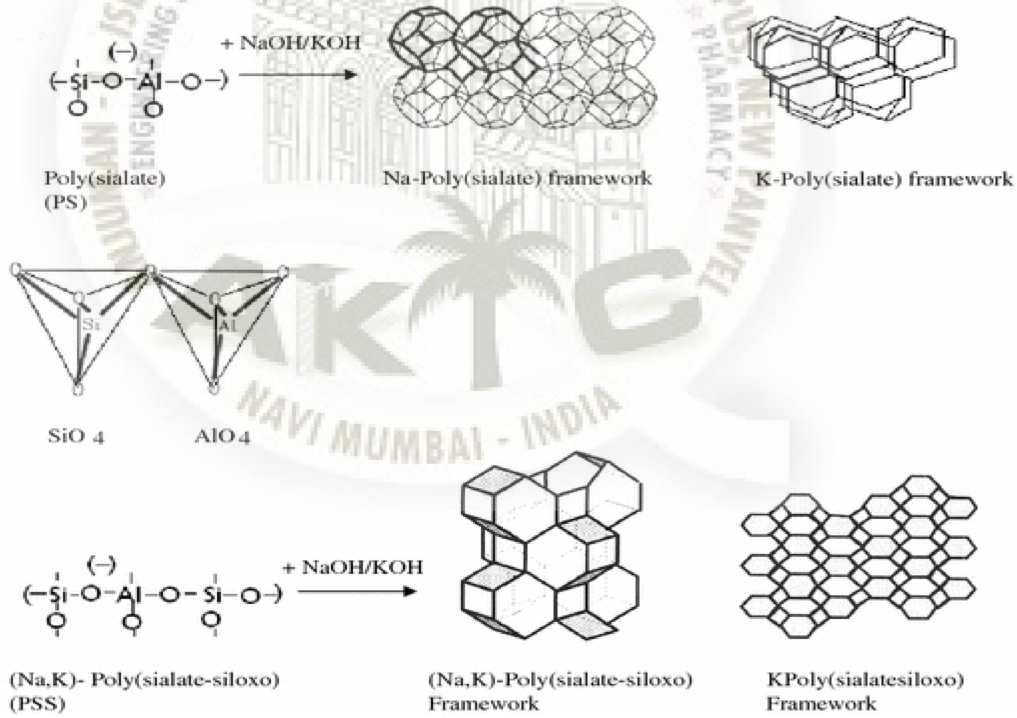


FIG 4.2: COMPUTER MOLECULAR REPRESENTATION OF GEO-POLYMER

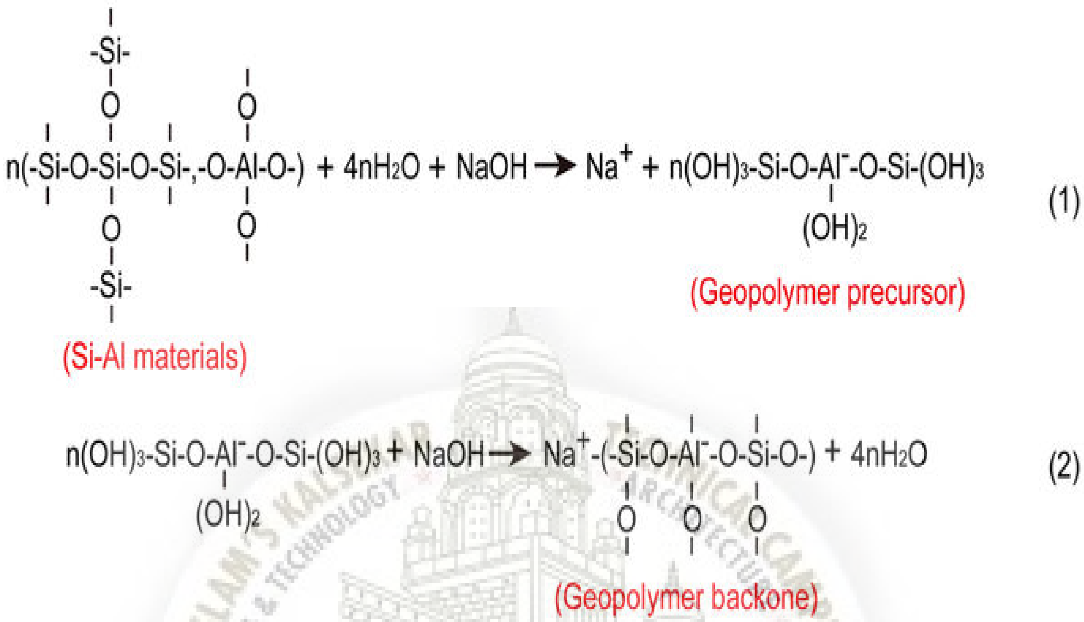


FIG 4.3: GEO-POLYMER MATRIX (1)

OR

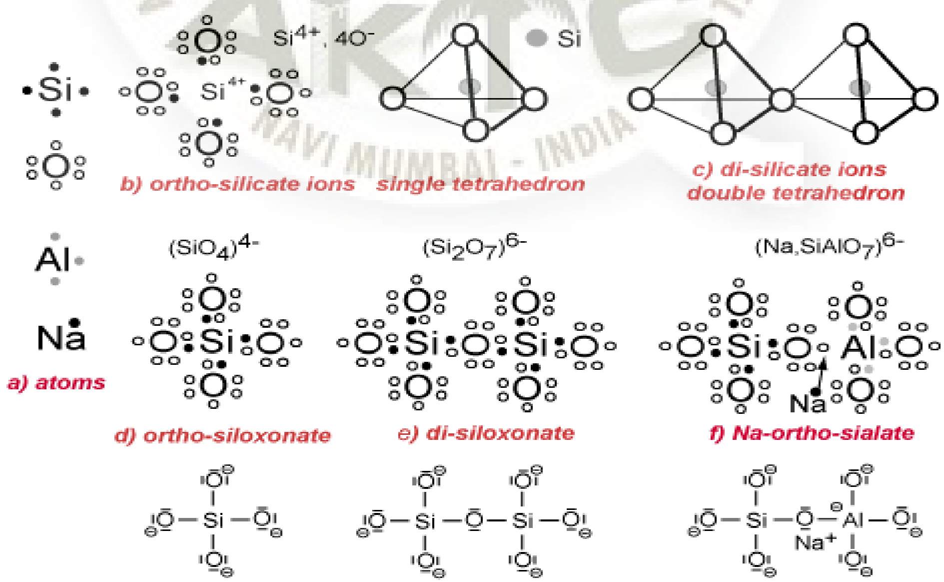


FIG 4.4: GEO-POLYMER MATRIX (2)

4.2 Polymerization Chemistry

Polymer means many. Hence a polymer is a cross linked structure consisting of many molecules and bonds linked with each other. A number of small molecules join together to form a macro molecule which is later called as polymer.

Si and Al forms four covalent bonds through an oxygen atom resulting in formation of 3D network hence geo-polymers are polyfunctional polymer. Geo-Polymer can be synthesized by poly condensation reaction of geo-polymer materials and alkali silicates. It involves heterogeneous chemical reaction between solid aluminosilicates oxides and alkali metal silicates at highly alkaline conditions at normal room temperature. Geo-Polymer cement so formed hardens at room temperature unlike ordinary Portland cement.

Chemical Reaction may comprise of the following steps:

- Si and Al atoms dissolve from source materials through action of hydroxide ions.
- Condensation of Percusor ions into monomers.
- Setting or polycondensation of monomers into polymeric structure.

A Geo-Polymer can take one of three forms:

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

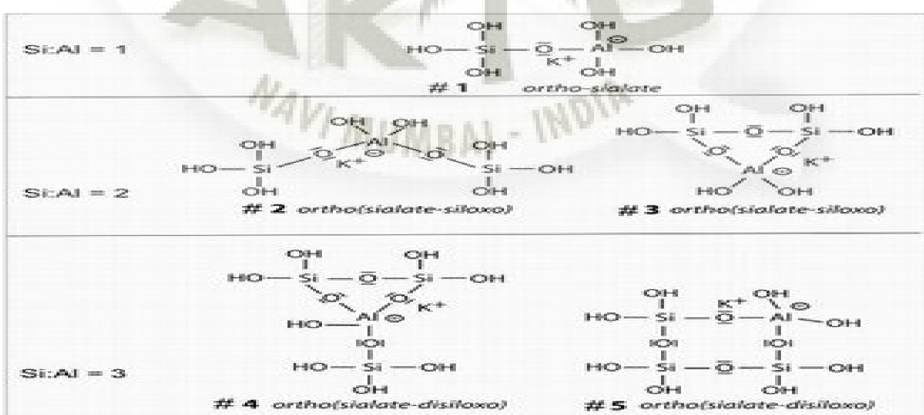


FIG 4.5: CHEMICAL STRUCTURE OF GEO-POLYMER

4.3 Formation of C-S-H edifice:

Molecular structure of GGBS shows a complex structure. GGBS contains ghelenite (aluminosilicate of Ca) and akerminite (magnesium silicate of Ca) both are solid solutions of melilite. Melilite is a type of crystallizing substance. Both these materials react under an alkaline medium which leads to alkalination of GGBS.

Intermediate by products formed during this process like aluminium hydroxide and magnesium hydroxide get consumed in this reaction. The second intermediate product like calcium di siloxonate serves as a partial binder like C-S-H gel during cement hydration. This will again polymerize and form coss linked matrix called geo-polymer matrix.

Calcium di siloxonate formed results in stronger binder like that of C-S-H formed during cement paste after initial setting time. Calcium hydroxide formed during polymerization reacts with excess sodium hydroxide to form C-(Na)S-H gel resulting in formation of inorganic polymer.

Calcium cyclo ortho silicate disiloxo is unstable as it tries to form covalent bonds with species of its same nature. Thus it undergoes polycondensation with metakaolin and forms calcium poly sialate disiloxo and sodium poly sialate disiloxo which combine to form a three dimensional polymer known as geo-polymer.

Overall scenario in case of cement and geo-polymer is the same as both form C-S-H gel. Hydration of cement paste results in formation of C-S-H gel which is responsible for binding. Similarly alkalination also leads to formation of C-S-H gel in geo-polymer which is responsible for binding of aggregates and loose materials in concrete.

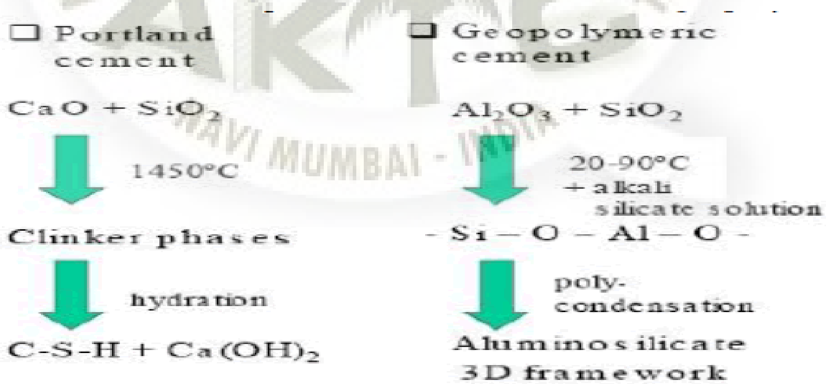


Fig 1: Comparison of Portland cement And Geopolymer Cement

FIG 4.6: PORTLAND CEMENT AND GEOPOLYMER CEMENT REACTION

The only difference between reaction mechanism of porland cement and geopolymer binder is initial reactants. In case of Portland cement, cement reacts with water to form a hydrating gel i.e C-S-H binder which is a exothermic reaction and sets in initial setting time.In case of geopolymer alkalination of GGBS with strong alkali like NaoH or KOH reacts to form intermediate products which condense to form C-S-H. Setting of geopolymer binder depends upon concentration of alkalination. Initial setting time of geopolymer is more than Portland cement.

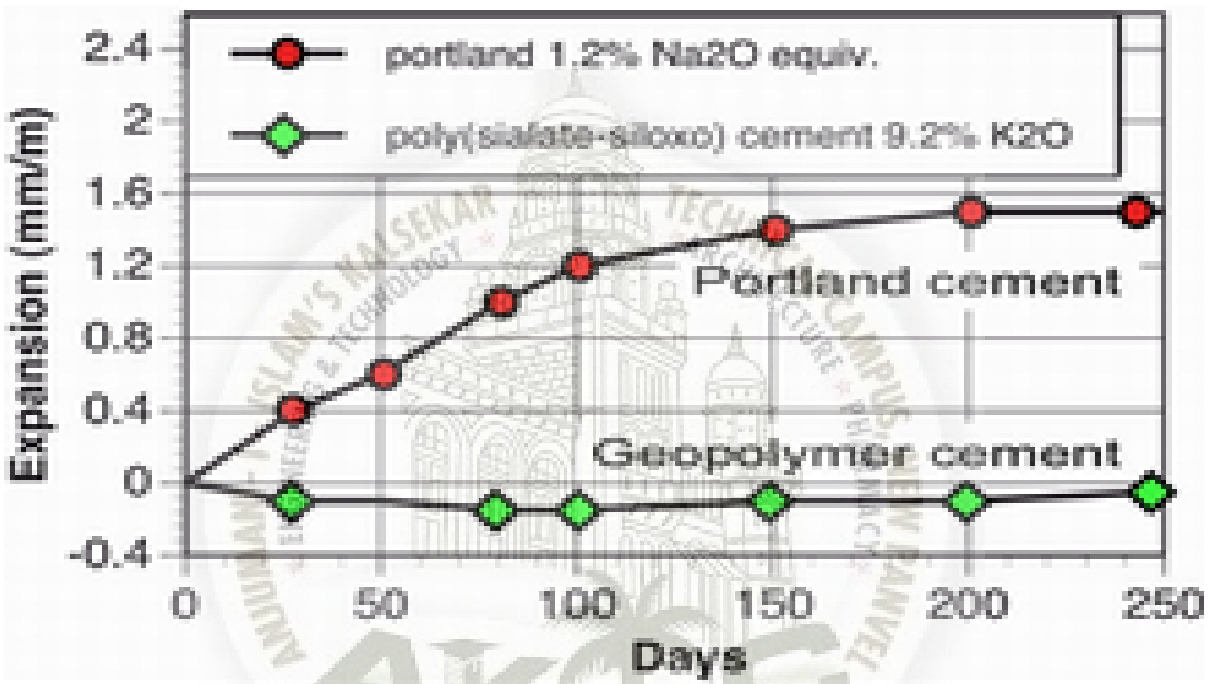


FIG 4.7: ALKALI AGGREGATE REACTIVITY OF PORLAND CEMENT V/S GEO-POLYMER CONCRETE

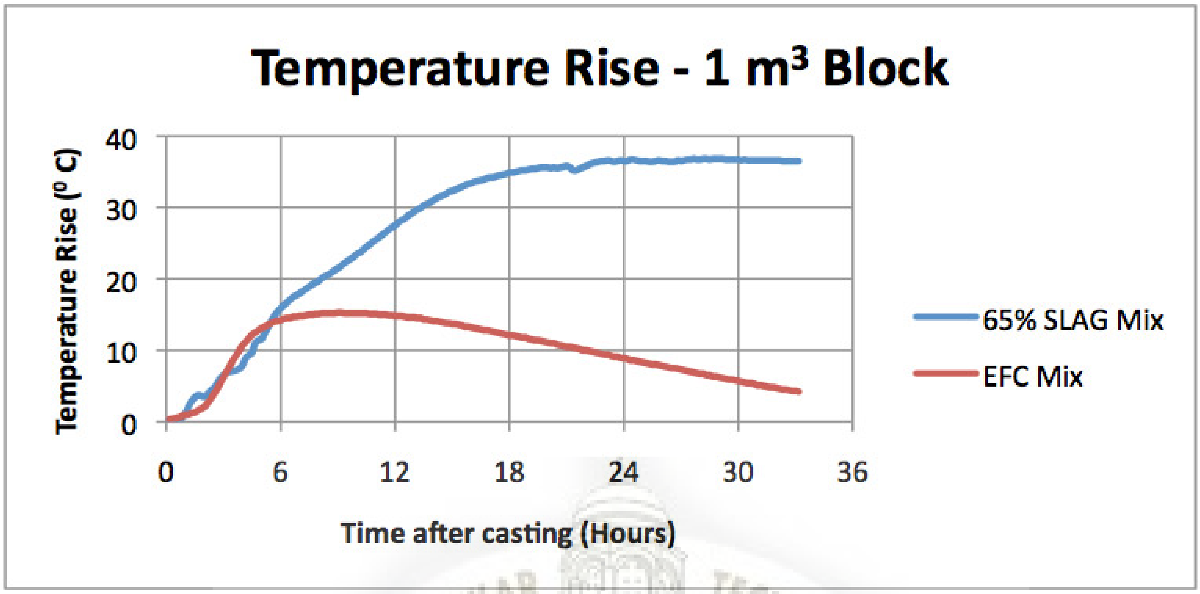


FIG 4.8: HEAT OF HYDRATION OF PORTLAND CEMENT V/S GEO-POLYMER CONCRETE

Fly ash added along with GGBS also participates in polymerization process and as a result forms a filler paste in the voids formed with GGBS.

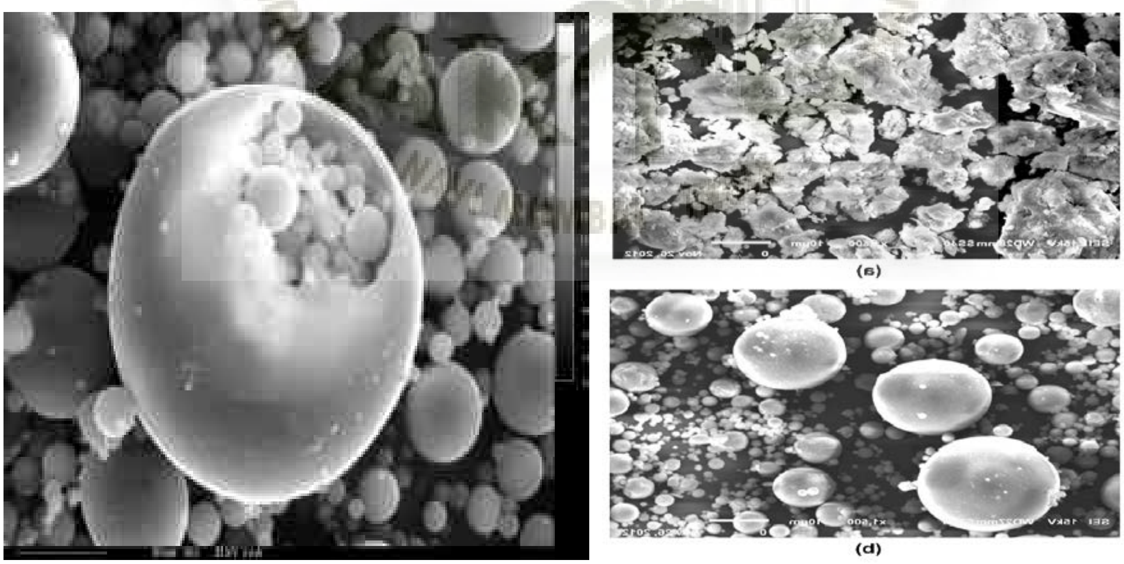


FIG 4.9: SEM OF UNTREATED FLY ASH (A) AND FLY ASH ON ALKALINATION (B)

CHAPTER 5

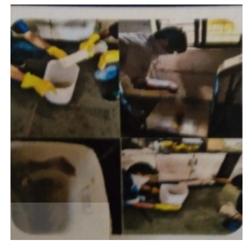
EXPERIMENTAL PROGRAMME

5.1 WBS of project

WBS i.e work break down structure is a schedule which typically separates and the divides the work into number of stages that can be carried out smoothly and efficiently. WBS is an important tool for smooth functioning and completion of project. It helps in maintaining the schedule and helps in reducing the economy of project. Mega projects, small projects, R & D projects, Industrial and Non-Industrial projects are included in WBS.

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

Typical WBS of our project is illustrated below:



MATERIAL PROCUREMENT

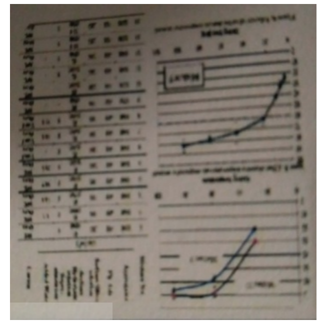
- GGBS
- Fly ash
- Metakaolin
- Aggregates
- Gujarat sand
- Sodium silicate
- Sodium hydroxide
- Chemical admixture

LABORATRY TEST

- Sieve analysis
- Aggregate impact & crushing test
- DLBD
- Water absorption
- Specific gravity
- Elongation and flakiness

ALKALINE SOLUTION PREPARATION

- Preparation of sodium hydroxide and aqueous solution
- Mixing of sodium hydroxide solution with sodium silicate to form alkali solution



BATCHING AND CASTING

- Weigh batching and dry mixing
- Edition of alkaline solution and admixture
- Wet mixing
- Casting
- compacting

POST CASTING TEST & CURING

- compression test
- split tensile test
- flexure test
- accelerated curing

RESULT AND DISCUSSION

- Interpretation and comparison of results
- Display of the same

5.2 LABORATRY TEST

Lab tests were done on aggregates. These test are essentials to achieve control on quality.

Lab test include:

- Sieve analysis
- Impact test
- DLBD
- Water absorption
- Specific gravity
- Crushing strength
- Flakiness
- Elongation
-

Lab test on sand include:

- Sieve analysis
- Silt content
- Bulkage
- Fineness
- Specific gravity

Mix design of any concrete cannot be done without these tests as these test determine strength and help in ensuring quality of concrete. Besides these hanfling, transporting, placing also play an important role in achieving good quality of concrete.

To perform correct tests on materials proper sampling of materials is necessary. Usually aggregates are sampled in quarters. IS 2386 (part 1 to 8) ,IS 2340 were used in testing of concrete.

5.2.1 LAB TEST ON COARSE AGGREGATES

5.3.1.1 Sieve Analysis

- Job-lab tests
- Type-CA
- Physical inspection-Sieve analysis
- DLBD-1.41 kg/l
- Source- Panvel
- Specific Gravity-2.64

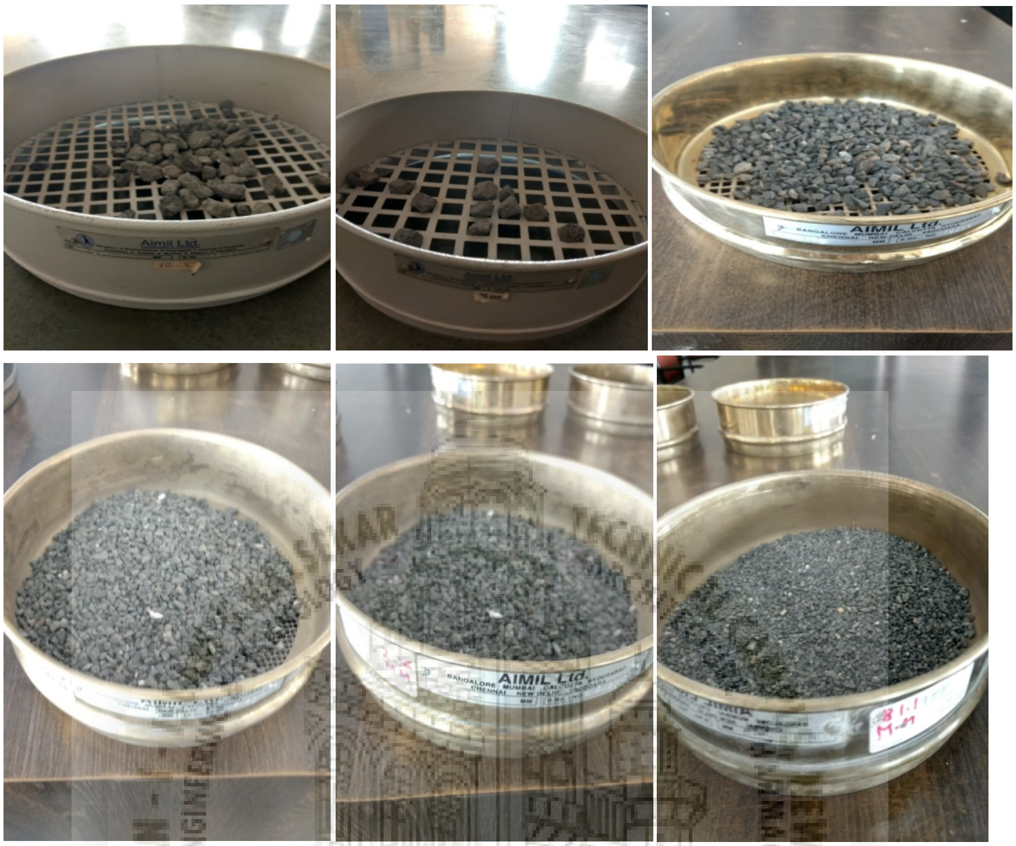


FIG 5.1: SIEVE ANALYSIS OF COARSE AGGREGATE

TABLE 5.2.1: SIEVE ANALYSIS OF C.A 10 mm

IS SIEVES	%Weight retained	Cumulative % Weight retained	Cumulative % Passing	Remarks
40mm	0	0	100%	
20mm	17.4	17.4	82.6	MAS=20 mm
16mm	40.75	58.15	59.25%	
12.5mm	31.35	89.5	68.65	
10mm	10.45	99.95	89.55	
4.75mm	0.05	100	99.95	
2.36mm	0	0	0.05	

5.3.1.2 Aggregate Impact Value Test

- Total weight of dry sample= 0.58
- Weight of aggregate passing through 2.36 mm IS sieve= 0.05
- Aggregate Impact Value= 0.05/0.58 x100 = 8.62

5.2.2: Toughness OF AGGREGATE BASED ON AGGREGATE IMPACT VALUE

Aggregate Impact Value (%)	Aggregate Quality	Result
<10	Exceptionally Strong	Yes
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

$$DLBD = A+B/V = 1.42 \text{ kg/l}$$

5.3.1.4 Percentage Voids in Aggregates

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

$$e = G-\gamma/G \times 100 = 46.22\%$$

5.3.2 Lab tests on Fine aggregates

5.3.2.1 Bulking of fine aggregates

- y= mark of sand level after mixing in water

% bulking = 200/y -1=2.67%

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

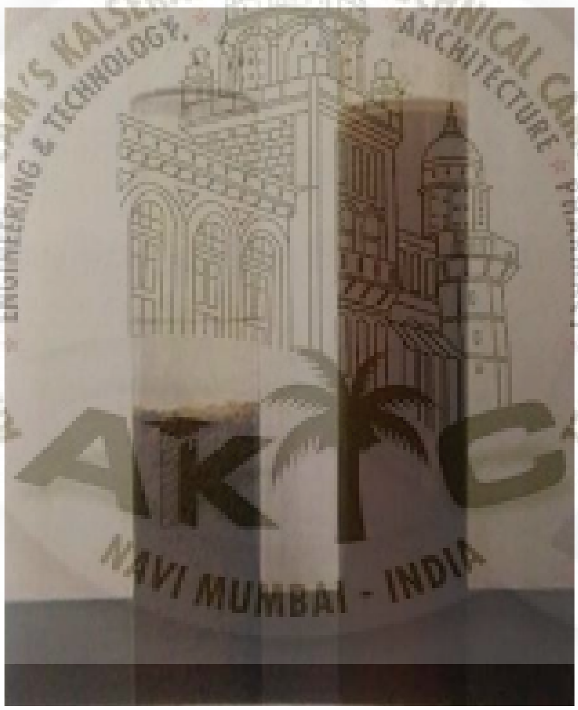


FIG 5.2: BULKING OF FINE AGGREGATE

5.3.2.2 Determination of clay and fine silt content

- A= Total volume of sample
- B= Volume of silt

Percentage Impurities=B/A x100 =6/96 x 100= 6.25 %

Here impurities are greater than 6% hence entire sample 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 AGGREGATE

IS SIEVES	% weight retained	Cumulative % weight retained	% weight passing	Remarks
4.75mm	19.55	19.55	80.45	0.5% oversize
2.36mm	43	62.55	57	
1.18mm	27.25	89.8	72.75	
600micron	5.25	95.05	94.75	
300micron	2.15	97.2	97.85	
150micron	1.15	98.35	98.85	
pan	1.65	100	98.35	

FIG 5.4: GRADATION OF SAND AFTER SIEVE ANALYSIS

5.3 Concrete Mix Design and Proportioning

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

It is the process of selecting suitable ingredients of concrete and determining their relative proportions required with the object of producing concrete and certain minimum strength and durability as well as to ensure it is economical. There are various methods of mix design available. Before commencing concrete mix design it is necessary to study specifications of concrete and also have enough information of environment around the structure. Here geo-polymer concrete is done by AMBUJA METHOD with some modifications.

5.4.1 Objective of Mix Design

- To achieve necessary compressive strength
- To get required workability
- To achieve durability
- To achieve economic concrete

5.4.2 Methods of Concrete Mix Design

Other than Ambuja cement Method the following methods are adopted:

- IS method
- ACI method
- Maximum density method
- Minimum voids method
- Fineness modulus method

5.5 Mix Design Calculation Worksheet

TABLE 5.1: GEO-POLYMER CONCRETE MIX DESIGN WORKSHEET

Sr No	Requirements	Specific data
1a	Specified Minimum Strength	M30
b	Durability Requirements	
	• Exposure	Moderate
	• Max W/C ratio	0.45
	• Max aggregate size	10mm
	• Minimum Cementatious content	550 kg/cu.m
	• Minimum Concrete Grade	M30
c	Required workability slump	Medium 75-100mm
d	Fine aggregates	
	• Type	Gujarat Sand
	• Passing 600 microns IS sieve(%) pure sand	94.75%
	• Zone	3
	• Percentage retained 4.75 mm sieve	20%
	• Specific gravity	2.71
	• DLBD	1.42 kg/liters
e	Coarse Aggregate	
	• Type	Crushed and angular
	• Percentage passing 10mm IS sieve	89.55%
	• Maximum Aggregate Size	10mm
	• Percentage passing 4.75mm IS sieve	99.95%
	• Specific Gravity	2.68
	• DLBD	1.15 kg/liters
2	Target Mean Strength	
	• Standard Deviation(s)	5+1=6
	• Value of t	1.65
	• Fm	39.9 N/sq-mm
3	Proportion of fine aggregate	33%
4	Proportion of course aggregate	67%
5	Aggregate Cement Ratio	
	• MAS	10 mm

	• Type of aggregate FA CA	Gujarat Sand Crushed Rock
	• Degree of Workability	Medium
	• Zone	3
	• Adopted w/c ratio	0.46
	• Aggregate value FA CA	4.55 3.4
	• Aggregate proportion FA CA	30% 70%
	• Final A/C ratio	3.8
7	Calculation of geo-polymer constituents	
	• Calculation of NaOH pellets to be mixed in 1L of water	16M = 16 x 40 =640g
	• Sodium Silicate to Sodium Hydroxide Solution	2.5
	• Sodium Hydroxide content in aqueous solution	1640g
	• Sodium Silicate Content	4100g
8	Final w/c ratio	0.45
9	Weigh Batching	
	• Cementatious material	550 kg/cube meter
	• Fine aggregate (Sand)	496.24 kg/ cubic meter
	• Coarse aggregate	903.68 kg/ cubic meter
10.	Result and Trial Mixes	
	• Workability Targeted Achieved Remarks	75-100mm 172mm Highly Workable
	• Compaction Factor	0.99
	• Cohesiveness	Very Good
	• Average weight of cube	15 kg
	• Density of concrete	4444 kg/cubic meter
	• Cementatious content of bricks	550 kg/cu-m
	• Durability conditions	Satisfied
11.	Proportions	1: 1.14: 2.66 (adopted)

5.5 Methodology

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

- Finalized mix proportions forM30 grade of concrete.
- The alkali solution was prepared in laboratory by mixing sodium hydroxide and sodium silicate in required proportion as mentioned in mix design. The alkali solution was prepared 1 day prior to casting.
- All the apparatus and equipments were made ready for casting. They include pan mixer, Slump cone apparatus, compaction factor apparatus, tamping rod, buckets, trays, dry and wet clouds, travels etc.
- After weigh batching, materials were introduced in pan mixer in sequence. GGBS, Fly ash and Metakaolin was introduced in pan mixer. Coarse aggregates and sand after washing were introduced in pan mixer. After dry mixing alkali solution was then added to the mix.
- Immediately after the mixing was over it was observed that concrete was getting more cohesive. Slump Cone Test and Compression and compaction factor test were performed to test its workability.
- 150 x 150 x 150 mm cubes, 150 x 300 mm cylinders and 150 x 150 x 700 mm geopolymer beams were casted.
- Concrete was poured in 3 layers as per specifications and compacted.
- All the samples were kept on vibrating table and vibrated for 2 minutes to let all entrapped air escape. The samples were kept in accelerated curing at 60 degree celcius and left there for 3 days.

5.6 Observations during concrete

During casting various new parameters were observed:

- The targeted workability was 75 to 100 mm slump according to mix design but we achieved 172 mm slump. This could be due to Increase in aqueous solution of alkali silicates.
- Colour of geopolymer was found to be typical. The colour was found out to be brownish white due to presence of GGBS and Fly Ash.
- The alkali reaction of Sodium Hydroxide and Sodium Silicate was tough to handle as it was very reactive when it comes in contact with air.

- After demoulding it was observed that setting time of geopolymer was much quicker as compared to cement concrete.
- Pond curing is not available for geopolymer. As cement is not present there is no heat of hydration. If pond curing is tried geopolymer binder and slurry will wash out after immersing in water.
- Mix cannot be touched by bare hands as it has adverse effects. High concentration of alkali can cause severe burns on skin.

FIG 5.5.1: PREPARATION OF ALKALI SOLUTION

FIG 5.5.2: BATCHING

FIG 5.5.3: DRY AND WET MIX OF CONCRETE IN PAN MIXER

FIG 5.5.4: ADDITION OF ALKALI SOLUTION IN PAN MIXER

FIG 5.5.5: CUBES OF GEO-POLYMER PREPARED IN LAB

FIG 5.5.6: BEAM OF GEO-POLYMER CASTED IN LAB

5.7 CURING OF CONCRETE

Curing of Concrete was done by accelerated curing method. After demoulding the samples were wrapped in plastic bags so that evaporation of excess moisture due to heat is avoided. The samples were kept in accelerated curing tank at 60degrees for 3 days and after removal were kept in atmospheric curing for testing at 28 days.

FIG 5.7.1 ACCELERATED CURING TEST SAMPLES

5.8 TESTING ON HARDENED CONCRETE

Testing on Hardened Concrete was done by Following types:

- Compressive Strength
- Split Tensile Strength
- Flexural Strength

Testing is done with specifications specified in IS 516, IS 9013 and IS 14858. Compressive strength of cubes at different days were obtained. Split Tensile and flexural strength at 28 days was obtained. While testing all parameters were kept in mind. After testing various failure patterns were observed and noted. Study of kind of failure, reasons for the same its effect and causes were studied thoroughly.

Photographs were taken showing pattern of failure of various samples.

FIG 5.8.1: COMPRESSION TEST AND MODES OF FAILURE

FIG 5.8.2: MODES OF FAILURE OF CUBE SAMPLES

FIG 5.8.3: MODES OF FAILURE IN CYLINDER

FIG 5.8.4: MODES OF FAILURE IN BEAM SAMPLE

CHAPTER 6

RESULTS AND DISCUSSIONS

6.1 General

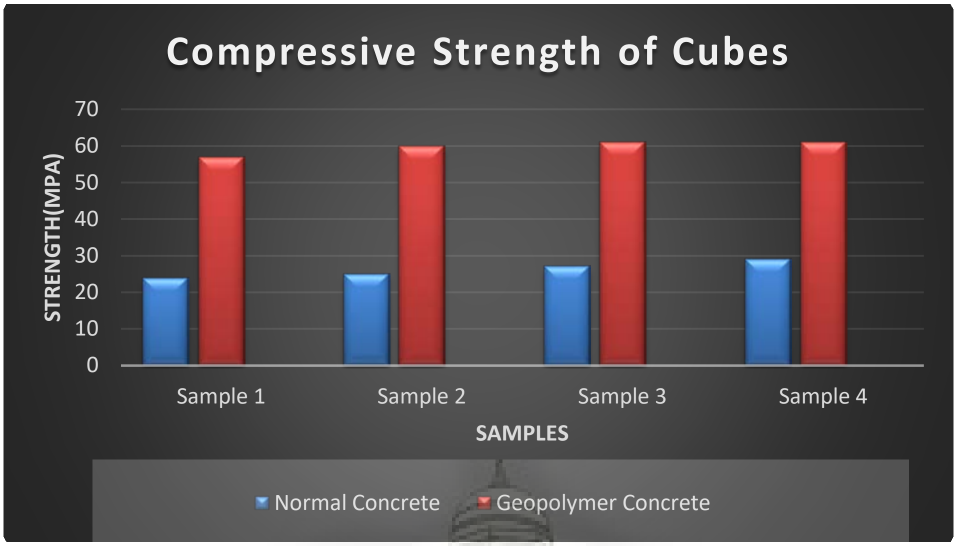
Test results of present study are briefly discussed in this chapter. Geo-Polymer is a cement free concrete in which GGBS and Fly Ash are the constituent materials instead of cement and alkali solutions are used to prepare C-S-H gel which acts as a binder. The effect of alkali solution on constituents of geo-polymer concrete is studied in this chapter. Tabulated charts and graphical results are incorporated in this chapter.

6.2 Compressive Strength

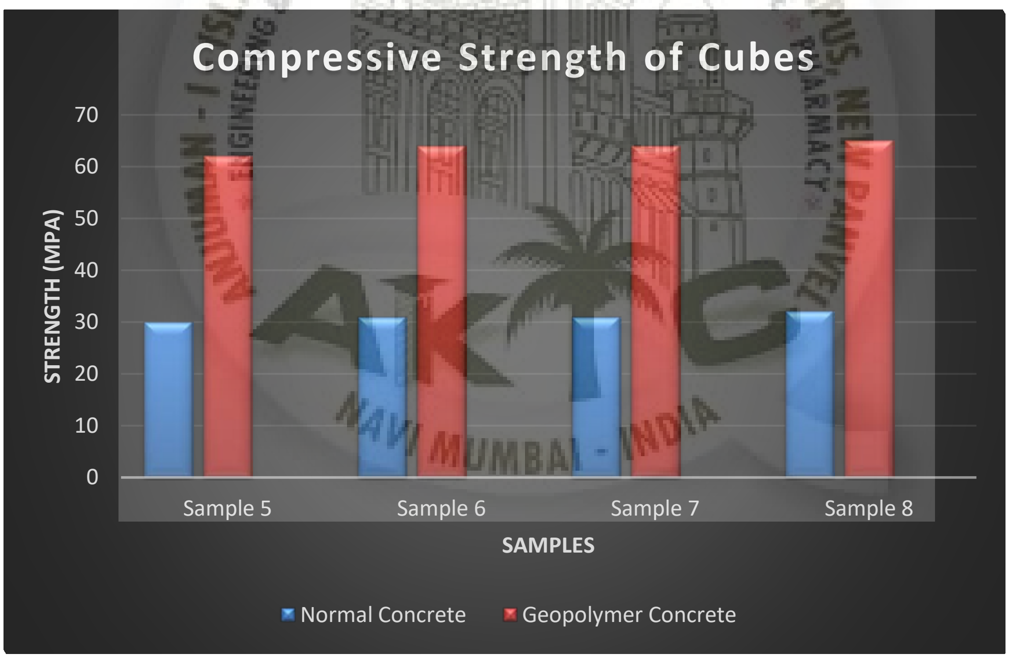
Compressive strength of geo-polymer concrete specimens was determined at 1, 3, 7 and 28 days following all IS specifications. Testing was carried out in accordance with IS 516, IS 1199, IS 9013, IS 14858. Results obtained were compared with normal concrete and concluded. 100% Fly ash based concrete was tested as trial and compared with a geo-polymer concrete consisting of GGBS and Fly Ash both.

Metakaolin was also used as constituent material in this study. Its effect on increasing strength of geo-polymer concrete was studied.

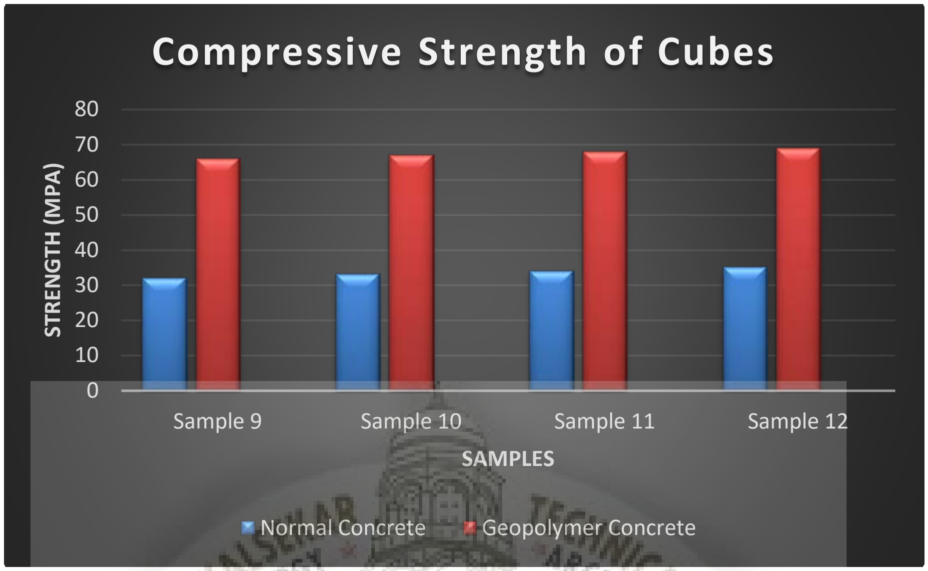
Similarly by increasing alkali solution its effect on geo-polymer concrete was studied.



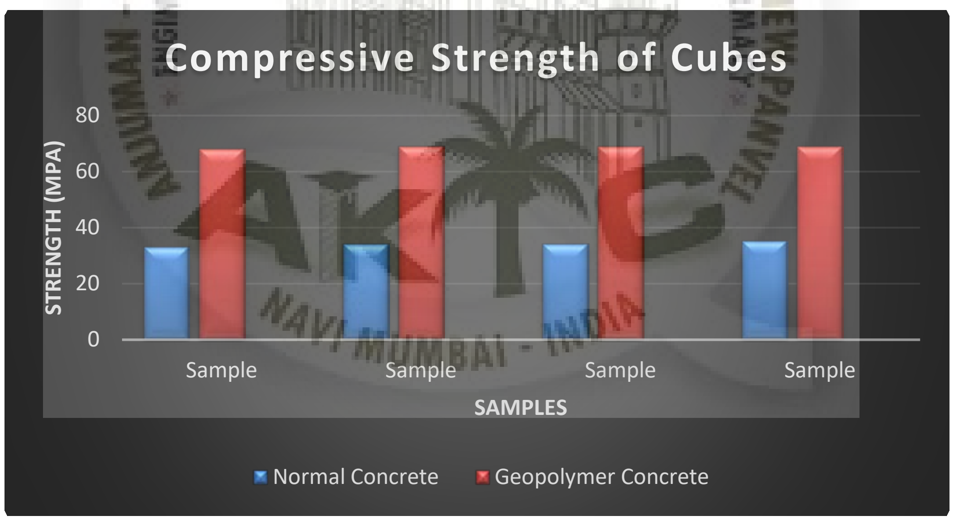
GRAPH 1 COMPARISION OF COMPRESSIVE STRENGTH BETWEEN NORMAL CONCRETE AND GEO-POLYMER



GRAPH 2: COMPARISION OF COMPRESSIVE STRENGTH BETWEEN NORMAL CONCRETE AND GEO-POLYMER



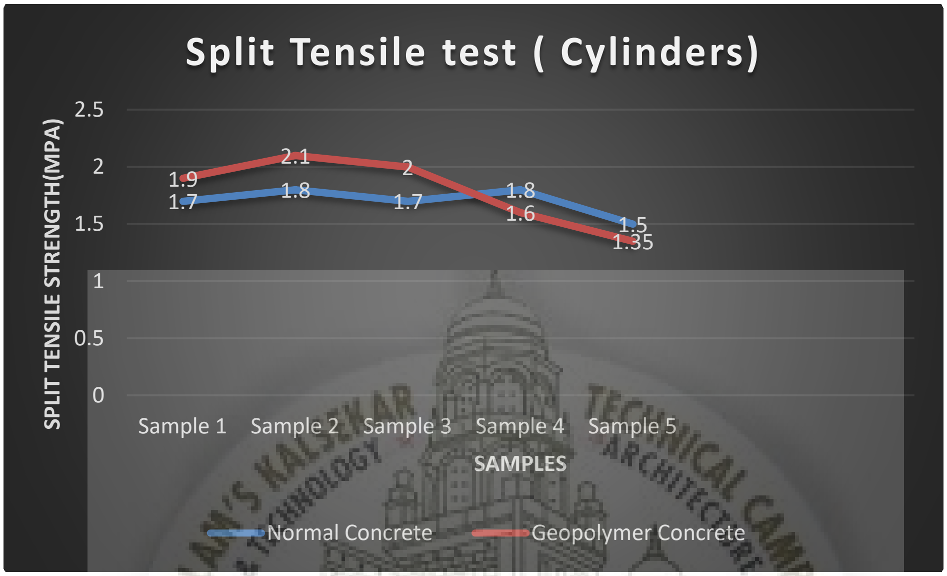
GRAPH 3: COMPARISION OF COMPRESSIVE STRENGTH BETWEEN NORMAL CONCRETE AND GEO-POLYMER



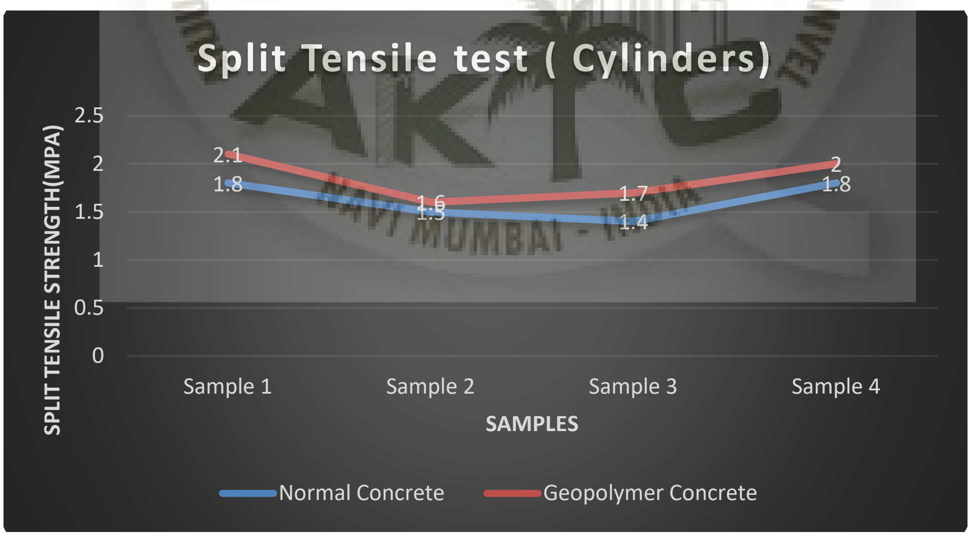
GRAPH 4: COMPARISION OF COMPRESSIVE STRENGTH BETWEEN NORMAL CONCRETE AND GEO-POLYMER

6.5 Split tensile strength

Split tensile strength of concrete was performed on cylinder. Following test results show split tensile strength.

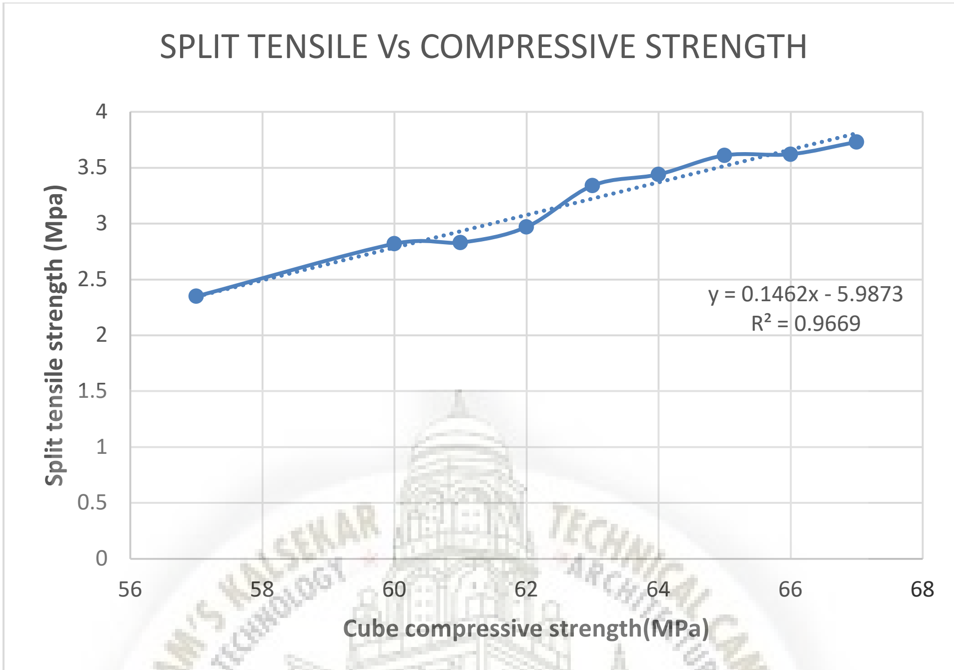


GRAPH 5: SPLIT TENSILE STRENGTH BETWEEN NORMAL CONCRETE AND GEO-POLYMER

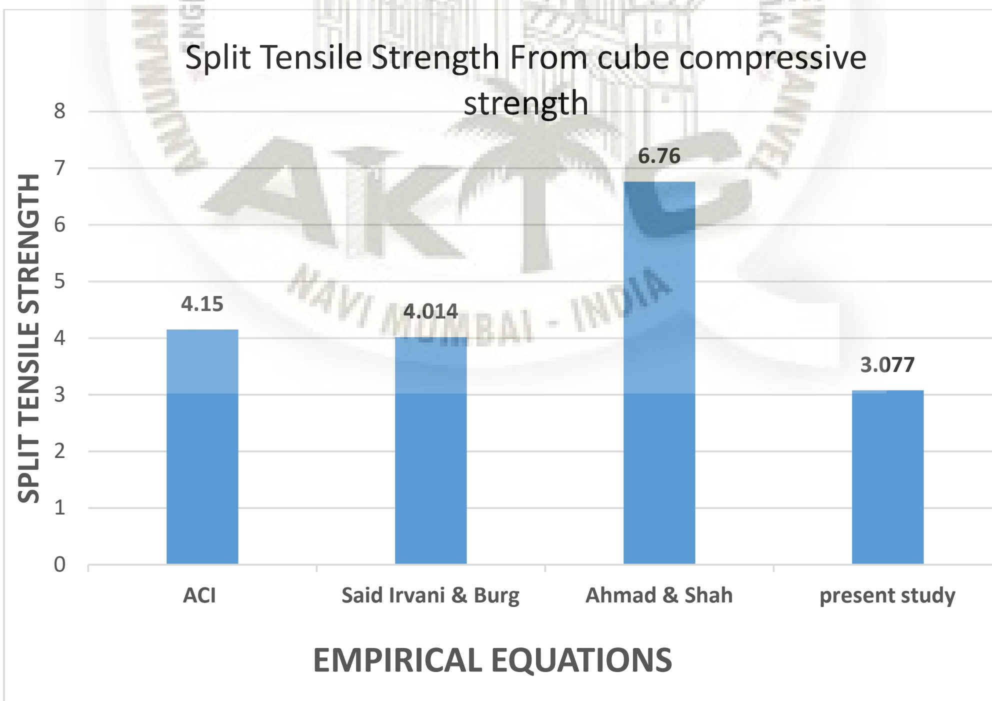


GRAPH 6: SPLIT TENSILE STRENGTH BETWEEN NORMAL CONCRETE AND GEO-POLYMER

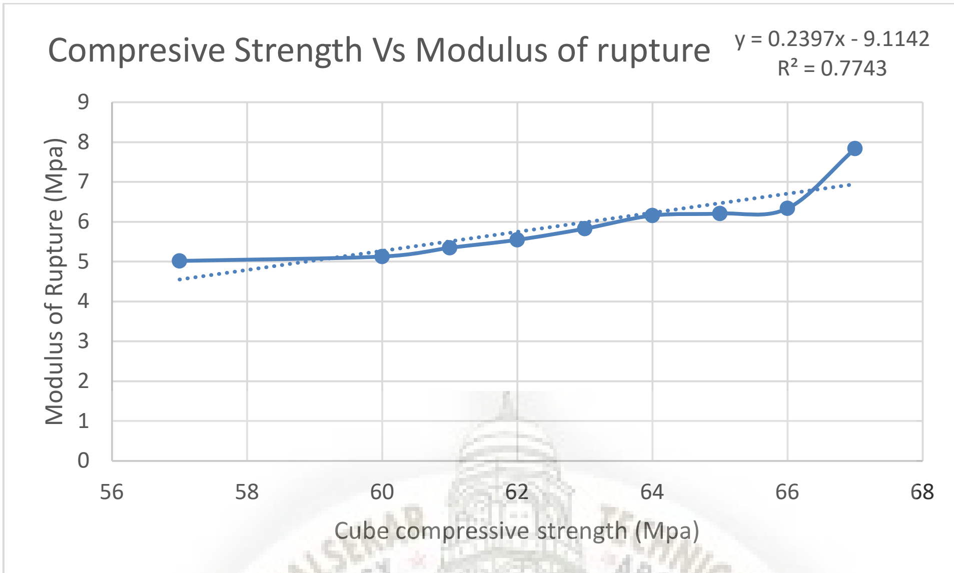
6.6 EQUATIONS AND BAR CHART:



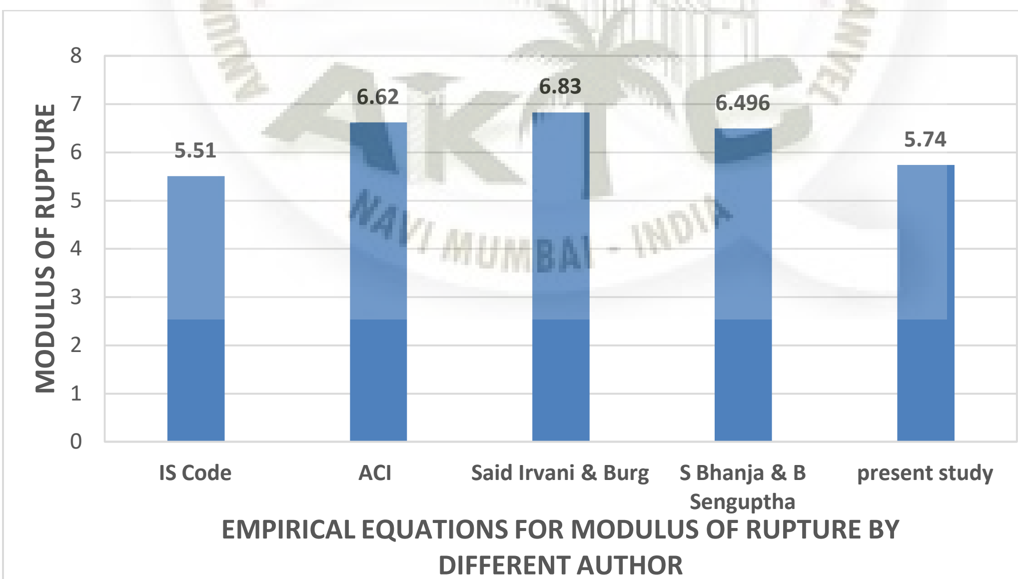
GRAPH 6.6.1: GRAPH OF SPLIT TENSILE STRENGTH V/S COMPRESSIVE STRENGTH



GRAPH 6.6.2: BAR CHART OF SPLIT TENSILE STRENGTH V/S COMPRESSIVE STRENGTH



GRAPH 6.6.3: GRAPH OF MODULUS OF RUPTURE V/S COMPRESSIVE STRENGTH



GRAPH 6.6.4: BAR CHART OF MODULUS OF RUPTURE V/S COMPRESSIVE STRENGTH

CHAPTER 7

CONCLUSIONS

7.1 Conclusions of present study

Following Conclusions were obtained:

- Mixing of Concrete was easily done in Pan Mixer.
- Tilting Mixer Could not perform proper mixing as constituent materials like GGBS, PFA and Metakaolin got struck at the sides of mixer.
- After addition of aggregates the mix was found out to be very dry.
- On addition of alkali solution the mix got thicker. After some interval of time the mix became cohesive.
- Addition of Super plasticizer helped in achieving workability to the mix.
- Great care was taken in adding the mix in standard moulds. Slurry was formed very quickly during vibration hence finishing was not required.
- Initial setting time was very less as compared to normal concrete.
- Initial test was done on 100% fly ash based Geo-Polymer concrete which did not meet the desired compressive strength.
- Another sample consisting of PFA, GGBS and metakaolin was prepared with ratio 25:50:25.
- Alkali solution was also increased by 20% from original mix.
- As alkali solution was increased it was observed that the samples gave a much higher strength.
- Geo-polymer concrete was observed to be brownish in colour due to presence of PFA and GGBS.
- Equations was developed for split tensile vs compressive strength and compressive strength vs Modulus of rupture.

- Equations were compared and it was observed that the strength achieved was less as compared to conventional concrete equations.
- Geo-Polymer concrete is much more economical than conventional concrete on material basis.

7.2 FUTURE SCOPE

As geo-polymer concrete is a new type of concrete it has tremendous scope. Some of those are listed below

- Extensive research can be carried out in geo-polymer concrete.
- Effect on steel can be studied.
- High Strength Geo-Polymer concrete can be designed with silicates and hydroxides of potassium.
- Self compacting concrete can be made using different mineral and chemical admixtures.
- Shear strengthening of geopolymer with fibres can be studied.
- Ultra high strength geopolymer concrete can be achieved by addition of quartz sand, fume etc.

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