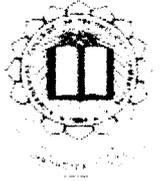




**DEVELOPMENT OF FLYASH BASED FIBER
REINFORCED GEOPOLYMER CONCRETE**



A Project Report

F-2232

Submitted by

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In partial fulfillment for the award of degree

Of

MASTER OF ENGINEERING

in

STRUCTURAL ENGINEERING

**DEPARTMENT OF CIVIL ENGINEERING
KUMARAGURU COLLEGE OF TECHNOLOGY**

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JUNE - 2008

BONAFIDE CERTIFICATE

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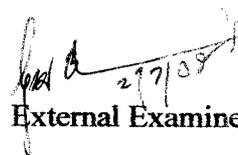
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To whomsoever it may concern

This is to certify that **Mr. Anil P Jose** (Roll No.-71206413001), final year student of Master of Structural Engineering from Kumaraguru College of Technology, Coimbatore has successfully completed a project titled **“Development of Flyash based Fiber Reinforced Geopolymer Concrete”** during the period of December 2007 to June 2008.

The processed flyash of required quantity and technical support for this project has been sponsored by m/s ACC Limited, SU - Coimbatore.

During this period, his work and conduct was found to be very good.

We wish him success in all his future endeavors.

For ACC Ltd.

A. Sudhahar,
Assistant Manager,
CSS Incharge - SU Coimbatore.

ABSTRACT

ABSTRACT

Various civil engineering projects are carried out throughout the country and around the world in order to meet the needs of the society. Construction activities involve the use of large quantity of materials of which the usage of concrete is to be highlighted. Portland cement is an important ingredient in the Conventional concrete. It was found that production of one ton of cement emits approximately one ton of carbon dioxide to the atmosphere. On the other hand, large quantity of fly ash is generated around the world, which is a waste material from thermal power plants, and India is found to produce the highest quantity of fly ash when compared with other countries. Most of the fly ash so produced is not effectively used, and the factories find difficulty in disposing these materials.

Flyash based geopolymer concrete (GPC) is an innovative material for the construction industry as it's free from hydration process, alkali and aggregate reaction and is highly durable in aggressive environment. This project report describes the characteristic properties of fly ash based geopolymer concrete with and without fibers. The special properties of geopolymer concrete can further enhance the economic benefits. Moreover, reduction of one ton of carbon dioxide yields one carbon credit and, the monetary value of that one credit is approximately 20 Euros. This carbon credit significantly adds to the economy offered by the geopolymer concrete. In all, there is so much to be gained by using geopolymer concrete.

Fiber reinforced Geopolymer concrete (FRGPC)

In this project, steel fibers (Dramix) with high tensile strength were used as reinforcing material in FRGPC mixes. Various tests were conducted to find the optimum fiber content in FRGPC mixes. The required number of specimens were casted and tested as per IS and ASTM specifications. The ratio of steel fibers added were 0.25%, 0.50% and 0.75% of the total volume of concrete. The split tensile strength of the FRGPC increases when compared to strength of GPC with and without fibers. The FRGPC mixes exhibited an increase in modulus of rupture with the age of curing (oven). The stress-strain relations were also studied and were found to be better than GPC. Water absorption and acid resistance of FRGPC was found to be better than GPC.

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*LIST OF SYMBOLS AND
ABBREVIATIONS*

LIST OF SYMBOLS AND ABBREVIATIONS

| | | |
|--------------|----------|--|
| ASTM | - | American Standard for Testing Materials |
| CA | - | Coarse Aggregate |
| CF | - | Compaction Factor |
| FA | - | Fine Aggregate |
| FRC | - | Fiber Reinforced Concrete |
| FRGPC | - | Fiber Reinforced Geopolymer Concrete |
| GPC | - | Geopolymer Concrete |
| HFRC | - | Hybrid Fiber Reinforced Concrete |
| IS | - | Indian Standards |
| JSCE | - | Japanese Standard |
| NSC | - | Normal Strength Concrete |
| PFRC | - | Polypropylene Fiber Reinforced Concrete |
| SFRC | - | Steel Fiber Reinforced Concrete |
| SWA | - | Saturated Water Absorption |
| W/B | - | Water Binder Ratio |
| μ | - | Microns |
| δ | - | Deflection |

INTRODUCTION

CHAPTER -1

INTRODUCTION

1.1 GENERAL

Precast construction is now the back-bone for the construction industries and concrete is one of most widely used construction material in India. It is usually associated with Portland cement as the main component for making concrete. The production of ordinary Portland cement contributes a lot in the worldwide to greenhouse effect. It has been reported that many concrete structures, especially those built in corrosive environment started to deteriorate after 20 to 30 years, even though they have been designed for more than 50 years of service life. Conventional concrete has very less resistance to fire. Though the use of Portland cement is still unavoidable until the foreseeable future, many efforts are being made in order to reduce the use of Portland cement in concrete. Mineral admixture like fly ash, silica fume, rice husk ash, metakolin, ground granulated blast furnace (GGBS), slag etc, serves as supplementary cementations materials.

In order to produce environmental friendly concrete, the development of inorganic alumino-silicate polymer, called Geopolymer, synthesized from materials of geological origin or by-product material such as fly ash, rich husk, silica fume, metakodline, slag etc can be used. The Geopolymer paste can be utilized as the binder to produce concrete, instead of the cement paste.

1.2 ADVANTAGES OF USING MINERAL ADMIXTURES

- Energy saving and environment production
- Good volume stability
- Reasonable strength gain in a short time
- Abundant raw material resources
- High fire resistance and low thermal conductivity
- Protective coatings and repair material
- Shotcreteing works
- High performance fibre reinforced laminates

1.3 SALIENT FEATURES OF GPC

- Enhances microstructure of concrete
- Very high early age strength
- Less micro cracks and more nano cracks
- Powerful confinement of aggregates and matrix
- High fire resistance and low thermal conductivity
- High durability even in sever environmental conditions

1.4 BACKGROUND OF THE PROJECT

Portland cement concrete is a mixture of Portland cement, aggregates, and water. Concrete is the most often-used construction material. The worldwide consumption of concrete was estimated to be about 8.8 billion tons per year (Metha2001). Due to increase in infrastructure developments, the demand for concrete would increase in the future. The manufacture of Portland cement releases carbon dioxide (CO₂) that is a significant contributor of the greenhouse gas emissions to the atmosphere. The production of every tone of Portland cement contributes about one tone of CO₂. Globally, the world's Portland cement production contributes about 1.6 billion tons Of CO₂ or about 7% of the global loading of carbon dioxide into the atmosphere (Metha 2001, Malhotra 1999; 2002). By the year 2010, the world cement consumption rate is expected to reach about 2 billion tonnes, meaning that about 2 billion tons CO₂ will be released. In order to address the environmental effect associated with Portland cement, there is a need to use other binders to make concrete.

One of the efforts to produce more environmentally friendly concrete is to replace the Portland cement in concrete with by-product materials such as fly ash. An important achievement in this regard is the development of high volume fly ash (HVFA) concrete that utilizes up to 60 percent of fly ash, and yet possesses excellent mechanical properties with enhanced durability performance. The test results show that HVFA concrete is more durable than Portland cement concrete (Malhotra 2002).

Another effort to make environmentally friendly concrete is the development of inorganic alumina-silicate polymer, called Geopolymer, synthesized from materials of geological origin or by-product materials such as fly ash that are rich in silicon and aluminum (Davidovits 1994, 1999).

Flyash is one of the source materials for geopolymer binders, and is available abundantly worldwide, but till date its utilization is limited. From 1998 estimation, the global coal ash production was more than 390 million tons annually, but its utilization was less than 15% (Malhotra 1999). In USA, the annual production of fly ash is approximately 63 million tons, and only 18 to 20% of that total is used by the concrete industries (ACI 232.2R-03 2003). In the future, fly ash production will increase, especially in countries like China and India. From these two countries, it is estimated that by the year 2010 the production of the fly ash will be about 780 million tones annually (Malhotra 2002).

Accordingly, efforts to utilize this by-product material in concrete manufacture are important to make concrete more environmentally friendly. For instance, every million tons of fly ash that replaces Portland cement helps to conserve one million tons of lime stone, 0.25 million tonnes of coal and over 80 million units of power, not withstanding the abatement of 1.5 million tonnes of CO₂ to atmosphere (Bhanumathidas and Kalidas 2004).

1.5 INTRODUCTION TO GEOPOLYMERS

1.5.1 Terminology and chemistry

The term ‘geopolymer’ was first introduced by Davidovits in 1978 to describe a family of mineral binders with chemical composition similar to zeolites but with an amorphous microstructure. He also suggested the use of the term ‘poly (sialate)’ for the chemical designation of geopolymers based on silico-aluminate. Sialate is an abbreviation for Silicon-oxo-aluminate. Poly(sialates) are chain and ring polymers with Si⁴⁺ and Al³⁺ in IV-fold coordination with oxygen and range from amorphous to semi-crystalline with the empirical formula:



Where “z” is 1, 2 or 3 or higher up to 32; M is a mono valent cation such as potassium or sodium, and “n” is a degree of polycondensation. It has also distinguished 3 types of polysialates, namely the Poly(sialate) type (-Si-O-Al-O), the Poly(sialate-siloxo) type (-Si-O-Al-O-Si-O) and the Poly(sialate-disiloxo) type (-Si-O-Al-O-Si-O). The structures of these polysialates can be schematised as in Figure. Devidovit’s proposed that an alkaline liquid could be used to react with the silicon (Si) and the aluminum (Al)

plays no role in the chemical reaction of water in a Portland cement concrete mixture during the hydration process.

There are two main constituents of geopolymers, namely the source material and alkaline liquids. The source materials for geopolymers based on alumina-silicate should be rich in silicon (Si) and aluminum (Al). These could be natural minerals such as kaolinite, clay, etc. Alternatively, by-product material such as fly ash, silica fume, slag, rice-husk ash, red mud, etc can be used as source materials. The choice of the source material for making geopolymer depends on factors such as availability, cost, and type of application and specific demand of the end users.

*MAIN THEME OF THE
PROJECT*

CHAPTER-2

MAIN THEME OF THE PROJECT

2.1 LITERATURE REVIEW

Davidovits (1988) introduced the term 'geopolymer' in 1978 to represent the mineral polymers resulting from geochemistry. Geopolymer, an inorganic alumina-silicate Polymer is synthesized from predominantly silicon (Si) and aluminum (Al) material of geological origin or by-product material. The chemical composition of geopolymer materials is similar to zeolite, but they reveal an amorphous Microstructure (Davidovits 1999). During the synthesized process, silicon and aluminum atoms are combined to form the building blocks that are chemically and structurally comparable to those binding the natural rocks.

Most of the literature available on this material deals with geopolymer pastes. **Davidovits and Sawyer (1985)** used ground blast furnace slag to produce geopolymer binders. This type of binders patented in the USA under the title Early High-Strength Mineral Polymer was used as a supplementary cementing material in the production of precast concrete products. In addition, a ready-made mortar package that required only the addition of mixing water to produce a durable and very rapid strength gaining material was produced and utilized in restoration of concrete airport runways, aprons and taxiways, highway and bridge decks, and for several new constructions when high early strength was needed.

Geopolymer has also been used to replace organic polymer as an adhesive in strengthening structural members. Geopolymers were found to be fire resistant and durable under UV light (**Balaguru et al 1997**) **van Jaarsveld, van Deventer, and Schwartzman (1999)** carried out experiments on geopolymers using two types of fly ash. They found that the compressive strength after 14 days was in the range of 5 – 51 MPa. The factors affecting the compressive strength were the mixing process and the chemical composition of the fly ash. A higher CaO content decreased the microstructure porosity and, in turn, increased the compressive strength. Besides, the water-to-fly ash ratio also influenced the strength. It was found that as the water-to-fly ash ratio decreased the compressive strength of the binder increased.

Palomo, Grutzeck, and Blanco (1999) reported the influence of curing temperature, curing time and alkaline solution-to-fly ash ratio on the compressive strength. It was reported that both the curing temperature and the curing time influenced the compressive strength. The utilization of sodium hydroxide (NaOH) combined with sodium silicate (Na_2Si_3) solution produced the highest strength. Compressive strength up to 60 MPa was obtained when cured at 85°C for 5 hours.

Xu and van Deventer (2000) investigated the geopolymerization of 15 natural Al-Si minerals. It was found that the minerals with a higher extent of dissolution demonstrated better compressive strength after polymerization. The percentage of calcium oxide (CaO), potassium oxide (K_2O), the molar ratio of Si-Al in the source material, the type of alkali and the molar ratio of Si/Al in the solution during dissolution had significant effect on the compressive strength.

Swanepoel and Strydom (2002) conducted a study on geopolymers produced by mixing fly ash, kaolinite, sodium silica solution, NaOH and water. Both the curing time and the curing temperature affected the compressive strength, and the optimum strength occurred when specimens were cured at 60°C for a period of 48 hours.

van Jaarsveld, van Deventer and Lukey (2002) reported the interrelationship of certain parameters that affected the properties of fly ash-based geopolymer. They reported that the properties of geopolymer were influenced by the incomplete dissolution of the materials involved in geopolymerization. The water content, curing time and curing temperature affected the properties of geopolymer; specifically the curing condition and calcinations temperature influenced the compressive strength. When the samples were cured at 70°C for 24 hours a substantial increase in the compressive strength was observed. Curing for a longer period of time reduced the compressive strength.

2.2 OBJECTIVES AND SCOPE OF THE INVESTIGATION

The objective of the present investigation is to study the following properties of fly ash based geopolymer concrete.

- To study the performance characteristics of materials used
- To study the workability characteristics of the FRGPC

- To study the mechanical properties like compressive strength, split tensile strength, stress-strain behavior of FRGPC
- Toughness factor of FRGPC
- Durability properties like water absorption

2.3 MATERIAL USED

- Fly ash used in this study is (class F) dry fly ash from ACC, Coimbatore as per IS 1489 (Part 1) – 1991
- Locally available river sand of fineness modulus of 2.7 is used as fine aggregate
- Crushed blue granite as per IS:383-1970 passing through 20mm sieve and retained on 10 mm sieve is used as coarse aggregate
- Locally available sodium silicate solution and sodium hydroxide pellets
- Distilled and raw water as per IS:456-2000 is used for the concrete preparation
- Steel fibers of hooked type with length of 60mm and diameter of 0.5mm was used as ferrous fiber

2.4 PROPERTIES OF MATERIALS

2.4.1 Flyash

Fly ash also known as Pulverized Fuel Ash (PFA) is the byproduct resulting from incomplete combustion of powdered coal in the generation of electric power. About 80% of the coal ash is eventually carried out with the flu gases by means of electrostatic precipitators. The degree and nature such as shape, surface texture and presence of magnetite depends on the source of coal, combustion environment and methods of collecting fly ash.

The color of fly ash ranges from almost cream to dark grey depending upon the proportion of unburned carbon present. Hence it has almost same colour of the cement. The specific gravity varies from 1.9 to 2.4. The specific surface area was found to be $320\text{m}^2/\text{kg}$ and they are mostly glassy hollow spherical particles. Bulk density of dry fly ash was approximately 800 kg/m^3 . The fineness modules of fly ash were $357\text{ m}^2/\text{kg}$. The chemical composition details of fly ash as per the supplier are shown in the Table 2.1.

Table 2.1 chemical composition of Fly ash *

| Constituent | Percentage (%) |
|--------------------------------|-----------------------|
| SiO ₂ | 54.5 |
| Al ₂ O ₃ | 28.2 |
| MgO | 1.2 |
| SO ₃ | 0.3 |
| Autoclave expansion | 0.04 |
| Loss of ignition | 2.3 |

*Tested at ACC-R&D Lab,Coimbatore

The reactivity of the pozzolanic material with hydrated lime was conducted as per IS: 1727-1967 and the specimen of size was used. The moulds for 50mm cube specimens should be metal not attacked by lime pozzolanic mortar. The interior face of the specimen moulds was thinly covered with mineral oil and the moulds was then placed on the plane, non-material used for the standard test mortar was lime; pozzolanic: standard sand in proportion of 1; 2M: 9 by weight, blended intimately.

Where,
$$M = \frac{\text{Specific gravity of pozzolana}}{\text{Specific gravity of lime}}$$

With the dry material as specified above trial mortars with different percentage of water until specified flow was obtained. The materials for each batch of moulds were mixed separately using the quantities of dry materials confirming to the proportions obtained and the quantity of water as determined from the flow table test. Mixing of mortar was done mechanically. The prepared mortar was placed in the 50mm cube mould in a layer of about 25mm thickness and was tamped 25 times with the tamping rod. The surface of the specimen in the mould was covered with a smooth and greased glass plate with the cover plates under wet gunny bags for 48 hours the specimens were removed and cured at 90 to 100 percent relative humidity at 50+ 2°C for a period of 8 days. The cured specimen from the humidity chamber was tested for compressive strength and the value was found to be 4MPa.

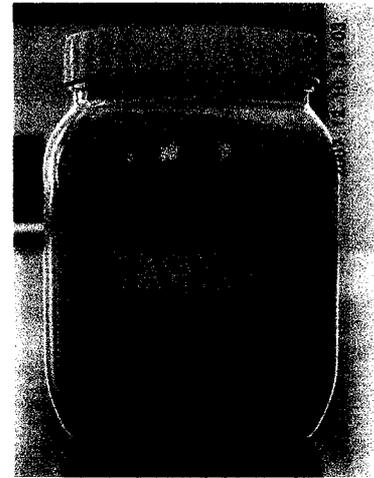
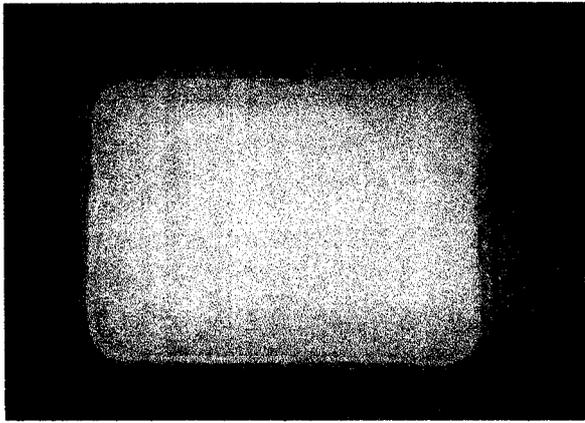


Fig 2.1 Binding material-Fly ash (class F type)

2.4.2 Aggregates

a) Fine aggregates

The physical properties like fineness modulus, specific gravity, Bulk density were studied as per IS; 383-1978, and the obtained results were as shown in Table 2.2

Table 2.2 Properties of fine aggregates

| Test | Result obtained | As per IS: 383 - 1978 |
|-----------------------------------|-----------------|-----------------------|
| Fineness modulus | 2.7 | Medium sand |
| Specific gravity | 2.6 | 2.55 minimum |
| Bulk density (kg/m ³) | 1607 | - |

b) Coarse aggregate

The physical properties of coarse aggregates like fineness modulus, specific gravity, bulk density, impact test and crushing strength test were performed as per IS: 383-1978, and the test results obtained were shown in Table 2.3

Table 2.3 properties of coarse aggregate

| Test | Result obtained | As per IS: 383 - 1978 |
|--------------------------------|-----------------|-----------------------|
| Fineness modulus | 5 | 5 to 7 |
| Specific gravity | 2.64 | 2.6 minimum |
| Bulk density kg/m ³ | 1580 | - |
| Impact value (%) | 32.5 | < 45 % |
| Crushing value (%) | 34.5 | < 45 % |

The aggregate crushing and impact values were found to be within in the limits i.e. the percentage of those values were less than the 45 %. The aggregates were found to be good and angular in shape. It's well fit to be used in concrete.

2.4.3 Alkaline solution

a) Sodium hydroxide solution

Sodium hydroxide (NaOH) in flake or pellet form with 97%-98% purity was used. The NaOH solids were dissolved in water to make the solution. The mass of NaOH solids in a solution varied depending on the concentration of the solution expressed in terms of molar(M). (14M=404 grams of NaOH solids per liter).

b) Sodium silicate solution

Commercially available sodium silicate powder is mixed in required amount of distilled water in order to make sodium silicate solution. This process is tedious and hence commercially available sodium silicate solution is used, but this proves to be highly uneconomical. In this project locally available sodium silicate solution is used and this is economical too. The chemical and physical analysis report of the sodium silicate solution obtained from soap solution is given in APPENDEX B.

2.4.4 Steel fiber

A steel fiber of hooked type with length of 60mm and diameter of 0.5mm was used as ferrous fiber. The steel fiber of required quantity was obtained from DRAMIX, TATA wire Division. The detailed list of properties of steel fiber provided by the manufacturer is as given in APPENDEX A.

2.5 PERFORMANCE CHARACTERISTICS OF MATERIAL

2.5.1 Test on fly ash

Processed fly ash was used for replacing the cement in the concrete. The test for determining the reactivity of the pozzolanic material with hydrated lime was performed as per IS: 1727 – 1967 and the details of the particle size, specific gravity, fineness, and the bulk density of fly ash provided as per the supplier are discussed in Table 2.1.

2.5.2 Source Materials and Alkaline Liquids

The alkaline liquid used was the combination of sodium silicate solution and sodium hydroxide solution. The sodium silicate solution ($\text{Na}_2\text{O}=13.7\%$, $\text{SiO}_2=29.4\%$

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& H₂O=55.9%) was obtained from soap industry. Sodium hydroxide (NaOH) in flake or pellet form with 97%-98% purity may be used. The NaOH solids are dissolved in water to make the solution. The mass of NaOH solids in a solution varied depending on the concentration of the solution expressed in terms of molar(M).(14M=404 grams of NaOH solids per kg).The sodium silicate solution and NaOH solution is mixed together at least one day prior to use to prepare the alkaline liquid.

2.5.3 Tests on Aggregate

Fine Aggregate

Fine aggregate used for concrete was well graded locally available river sand passing through 4.75mm and retained on 300 micron, to achieve minimum void ratio and the properties of fine aggregates like fineness modulus. Specific gravity and bulk density were studied as per IS: 383-1970 and the test results are shown in Table 2.2.

Coarse aggregate

Locally available blue granite was used. Crushed granite stones of size passing through 20mm sieve and retained on 4.75 mm sieve as per IS: 383-1970 was used for experimental purposes. Tests such as fineness modulus, specific gravity , bulk density, aggregate impact value and aggregate crushing values were performed as per IS :2386-1963 and the results are shown in Table 2.3.

2.5.4 Tests on concrete

Fresh concrete

Compacting factor test and flow table test were conducted on fresh concrete as per IS: 1199 -1959 to know the workability of concrete.

Hardened concrete

The hardened properties of concrete like compressive strength test, split tensile test, stress strain characteristics and the micro structural properties like saturated water absorption for the concrete mixes were conducted as per IS: 516-1959,IS: 5816-1999 and ASTM standards and test results are shown in respective tables.

2.5.5 Experimental program

Fiber reinforced geopolymer concrete (FRGPC) were prepared using different percentage of steel fibers by volume of concrete. The details of specimens casted are as

given in Table 2.1. 100 mm x 100 mm x 100 mm cubes specimen were casted for compressive strength and for durability study of both in GPC and FRGPC. 150mm x 300mm cylinders specimen were casted for split tensile strength and stress - strain curves both in GPC and FRGPC. Unreinforced beams of size 100 mm x 100 mm x 500 mm were casted to study flexural behavior and the toughness index.

TABLE 2.4: Details of specimens casted

| Mix designation | Percentage of fiber added with respect to volume of concrete | Specimen details | |
|-----------------|--|---------------------|------------------|
| | | mm | No. of specimens |
| FRGPC-00 | 0 | Cubes (100x100x100) | 12 |
| | | Cylinders (150x300) | 9 |
| | | Beam (100x100x500) | 3 |
| FRGPC-25 | 0.25 | Cubes (100x100x100) | 12 |
| | | Cylinders (150x300) | 9 |
| | | Beam (100x100x500) | 3 |
| FRGPC-50 | 0.50 | Cubes (100x100x100) | 12 |
| | | Cylinders (150x300) | 9 |
| | | Beam (100x100x500) | 3 |
| FRGPC-75 | 0.75 | Cubes (100x100x100) | 12 |
| | | Cylinders (150x300) | 9 |
| | | Beam (100x100x500) | 3 |

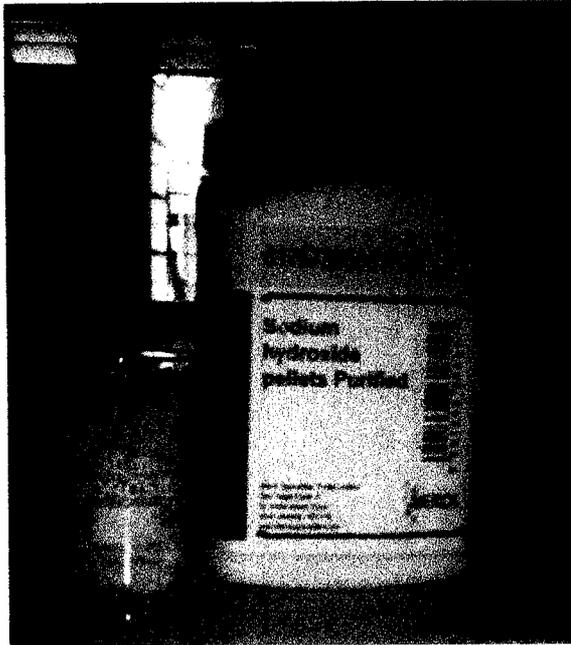
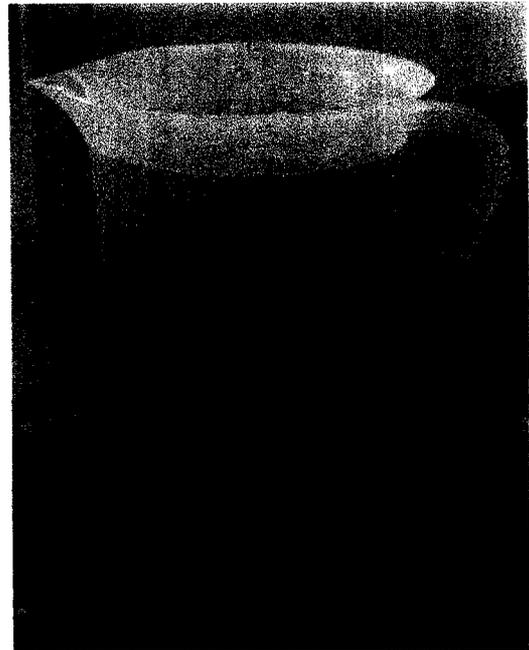


Fig 2.2 Sodium hydroxide pellets



**Fig 2.3 Sodium silicate solution
(From soap industry)**

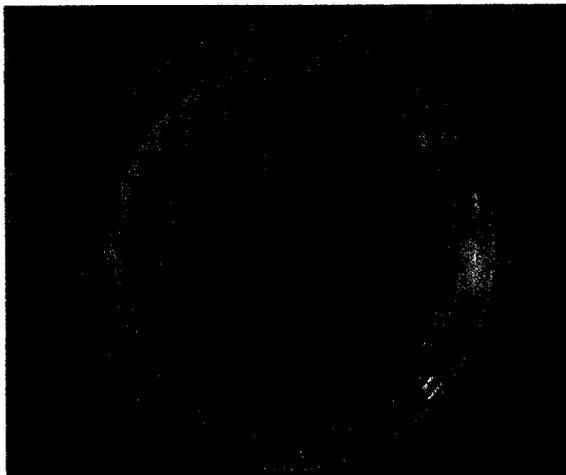
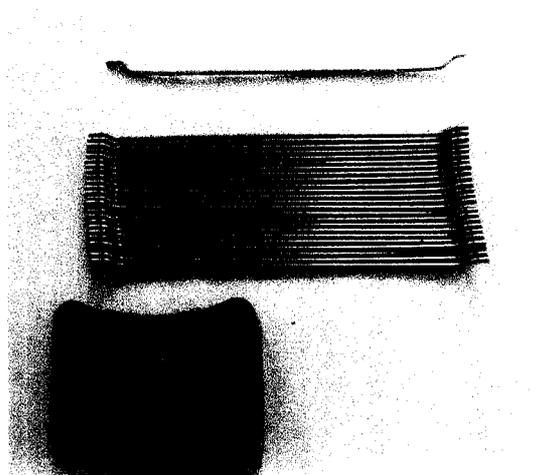


Fig 2.4 Alkaline solution



**Fig 2.5 Separated and glued Steel
fiber (DRAMIX)**

*MIX DESIGN OF
GEOPOLYMER CONCRETE*

CHAPTER 3

MIX DESIGN OF GEOPOLYMER CONCRETE

3.1 INTRODUCTION

Concrete mixture design process is vast and generally based on performance criteria. The role and the influence of aggregate are considered to be the same as in the case of Portland cement concrete. The mass of combined aggregate may be taken to be between 75% and 80% of the mass of geopolymer concrete. The performance criteria of a geopolymer concrete mixture depend on the application. For example, the compressive strength of hardened concrete is selected as the performance criteria. In order to meet these performance criteria, the alkaline liquid-to-fly ash ratio by mass, water-to-geopolymer solids ratio by mass, the wet-mixing time, the heat-curing temperature, and the heat-curing time are selected as parameters. Locally available sodium silicate solution from soap industry with SiO₂-to-NaO ratio by mass of approximately 2 i.e., Na₂O=14.7%, SiO₂=29.4% and water = 55.9% by mass, and sodium hydroxide solids (NaOH) with 97-98% purity are recommended. The ratio of sodium hydroxide solution to sodium silicate solution by mass is taken as 0.4.

Mix proportion

There are no relevant codes available for preparation of Geopolymer concrete (GPC). Mixture proportion of fly ash based geopolymer concrete with design compressive strength of 35Mpa. The unit weight of concrete is used 2400 Kg/m³. Take the mass of combined aggregate is 77% of the mass concrete, i.e. $0.77 \times 2400 = 1848 \text{ Kg/m}^3$. The combined aggregate may be selected to match the standard grading curves used in the design of Portland cement concrete mixtures. The combination of different size aggregates were decided on the basis of experimentation. The different sizes of aggregates used were 20mm, 16mm, 12.5mm and 10mm. All the four different sized aggregates were taken in different combinations, keeping all other factors constant, as shown in the Table 3.1. About seven different mixes were designed and cubes were casted and tested. As per IS specification it was found that mix design II gave better strength of 26MPa. For the corresponding mix, the aggregate comprised of 415Kg/m³ (25%) of 20mm aggregate, 415Kg/m³ (25%) of 16mm aggregate, 415Kg/m³ (25%) of 12.5mm aggregate, 415Kg/m³ of 10mm aggregates, and 443 Kg/m³ of fine sand. The

fineness modulus of the combined aggregate is approximately 5.0 and the Fineness of Fly Ash is 357m²/kg and the alkaline liquid to fly ash ratio by mass as 0.6 for composition of fly ash shown in table 3.1. The geopolymer concrete mixtures are designed using locally available sodium silicate solution from soap industry with SiO₂-to-Na₂O ratio by mass of approximately (2), i.e., Na₂O=14.7%, SiO₂=29.4%, and water=55.9% by mass, is selected. The sodium hydroxide solids (NaOH) with 97-98% purity were obtained from commercial source and the solution with a concentration of 16M is prepared. This solution comprises 26.2% of NaOH solids and 68.6% water, by mass. The aggregate are assumed to be in saturated surface dry condition. The geopolymer concrete must be wet mixed at least for four minutes and hot air oven cured at 100°C for 24 hours after casting. The series of the GPC mixtures are obtained as shown in Table 3.1.

Table 3.1 : Geopolymer concrete mix proportions (Trial 1)

| Mix | I | II | III | IV | V | VI | VII |
|--|----------|-----------|------------|-----------|----------|-----------|------------|
| Flyash(kg) | 338 | 338 | 338 | 338 | 338 | 338 | 338 |
| Alkaline solution (kg) | 208 | 208 | 208 | 208 | 208 | 208 | 208 |
| Extra water(kg) | 18 | 18 | 18 | 18 | 18 | 18 | 18 |
| Sand(kg) | 443 | 443 | 443 | 443 | 443 | 443 | 443 |
| 20mm Agg. (kg) | 194 | 415 | 415 | 995 | 497.5 | 581 | 0 |
| 16mm Agg. (kg) | 324 | 415 | 580 | 0 | 497.5 | 331.5 | 664 |
| 12.5mm Agg. (kg) | 324 | 415 | 415 | 665 | 332.5 | 581 | 664 |
| 10mm Agg. (kg) | 452 | 415 | 250 | 0 | 332.5 | 166 | 332 |
| Superplasticiser(kg) | 20 | 20 | 20 | 20 | 20 | 20 | 20 |
| Temperature of curing (°c) | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Time of curing (Hrs) | 24 | 24 | 24 | 24 | 24 | 24 | 24 |
| Compressive strength (N/mm²) | 17.0 | 26.0 | 12.5 | 23.5 | 25.5 | 10.0 | 11.5 |

Table 3.2 : Geopolymer concrete mix proportions

| Mix | II-A | II-B | II-C | II-D | II-E | II-F | II-G | II-H | II-I |
|------------------------|------|------|------|-------------|------|------|------|------|------|
| Fly ash(kg) | 326 | 326 | 326 | 326 | 326 | 326 | 350 | 350 | 350 |
| Alkaline solution (kg) | 230 | 180 | 165 | 230 | 240 | 250 | 245 | 192 | 175 |
| Extra water(kg) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 16 | 21.5 |
| Sand(kg) | 443 | 443 | 443 | 443 | 443 | 443 | 443 | 443 | 443 |
| 20mm Agg. (kg) | 415 | 415 | 415 | 415 | 415 | 415 | 415 | 415 | 415 |
| 16mm Agg. (kg) | 415 | 415 | 415 | 415 | 415 | 415 | 415 | 415 | 415 |
| 12.5mm Agg. (kg) | 415 | 415 | 415 | 415 | 415 | 415 | 415 | 415 | 415 |
| 10mm Agg. (kg) | 415 | 415 | 415 | 415 | 415 | 415 | 415 | 415 | 415 |
| Superplasticiser(kg) | 20 | 50 | 65 | 0 | 0 | 0 | 21 | 53.5 | 70 |
| Temperature of curing | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Time of curing (Hrs) | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 |
| Compressive strength | 23.0 | 22.5 | 20.0 | 37.0 | 29.5 | 31.0 | 20.0 | 20.5 | 15.5 |

Table 3.3 : Geopolymer concrete mix proportions for testing

| Mix | FRGPC-00 | FRGPC-25 | FRGPC-50 | FRGPC-75 |
|------------------------|----------|----------|----------|----------|
| Fly ash(kg) | 326.5 | 326.5 | 326.5 | 326.5 |
| Alkaline solution (kg) | 230 | 230 | 230 | 230 |
| Extra water(kg) | 0 | 0 | 0 | 0 |
| Sand(kg) | 443 | 443 | 443 | 443 |
| 20mm Agg. (kg) | 415 | 415 | 415 | 415 |
| 16mm Agg. (kg) | 415 | 415 | 415 | 415 |
| 12.5mm Agg. (kg) | 415 | 415 | 415 | 415 |
| 10mm Agg. (kg) | 415 | 415 | 415 | 415 |
| % of steel fiber | 0 | 0.25 | 0.50 | 0.75 |
| Temperature of curing | 100 | 100 | 100 | 100 |
| Time of curing (Hrs) | 24 | 24 | 24 | 24 |

On the basis of the results obtained, Mix II was selected and the aggregate ratio was kept constant the quantity of fly ash and ratios of alkaline solution to fly ash were changed along with the ratio of superplasticisers. Test was conducted for different mixes and maximum compressive strength of 37MPa was obtained. Details are as shown in Table 3.2.

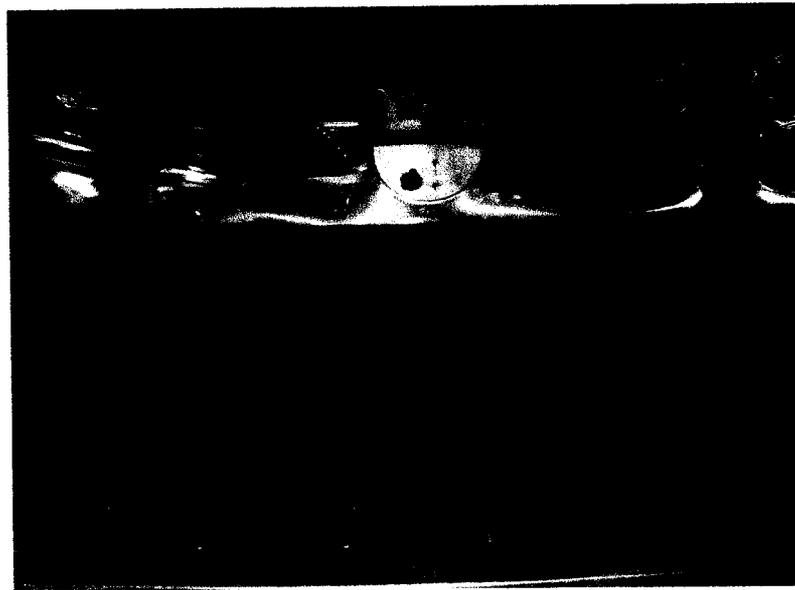


Fig 3.1 : Oven curing with steel modulus

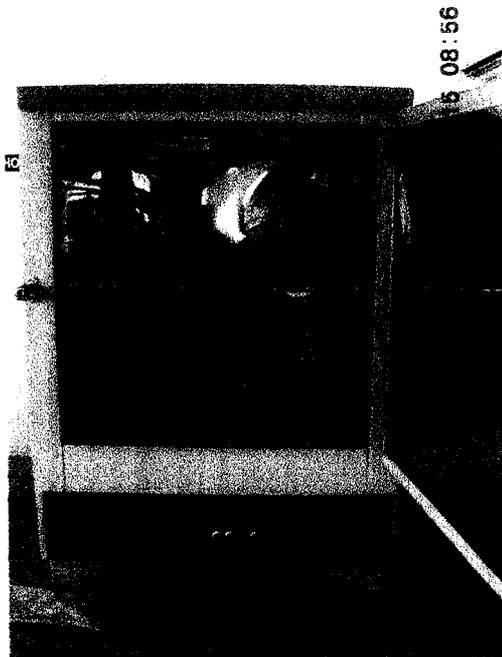


Fig 3.2 : Oven curing without moulds

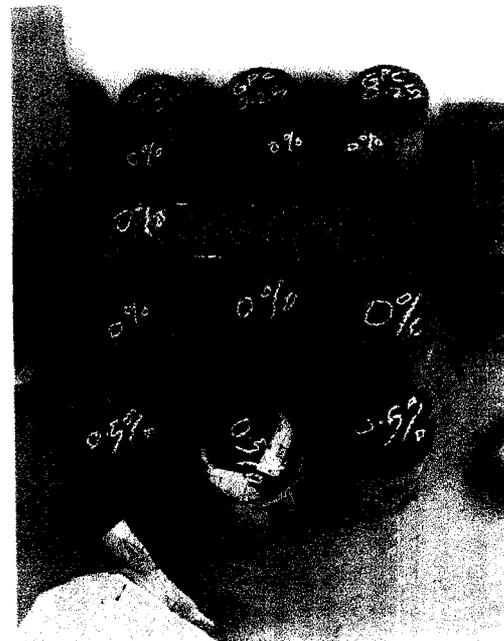


Fig 3.3 : Sample specimen's casted

*TEST, RESULTS AND
DISCUSSION*

CHAPTER 4

TEST, RESULTS AND DISCUSSION

4.1 TEST RESULTS ON FRESH CONCRETE

4.1.1 Compaction factor

The compacting factor test is one of the most efficient tests for measuring the workability of concrete as per IS: 1199-1959. It is the most precise, sensitive and particularly useful for concrete mixes of very low workability as are normally used. GPC can be handled for 60-100 minutes. The workability of fresh geopolymer concrete is expected to be moderate. If needed, commercially available super plasticizer of about 1.5% of mass of fly ash, i.e. $408 \times (1.5/100) = 6 \text{ Kg/m}^3$ may be added to the mixture to facilitate ease of placement of fresh concrete. Water content and Super Plasticizer play an important role with regard to Workability Concrete. The results obtained from the compaction factor test for all the 4 mixes of GPC are shown in the Table 4.1.

$$\text{Compaction factor} = \frac{\text{Weight of partially compacted concrete}}{\text{Weight of fully compacted concrete}}$$

Table 4.1 Test results of compaction factor values for FRGPC

| MIX | FRGPC-00 | FRGPC-25 | FRGPC-50 | FRGPC-75 |
|-----|----------|----------|----------|----------|
| C.F | 0.90 | 0.86 | 0.84 | 0.73 |

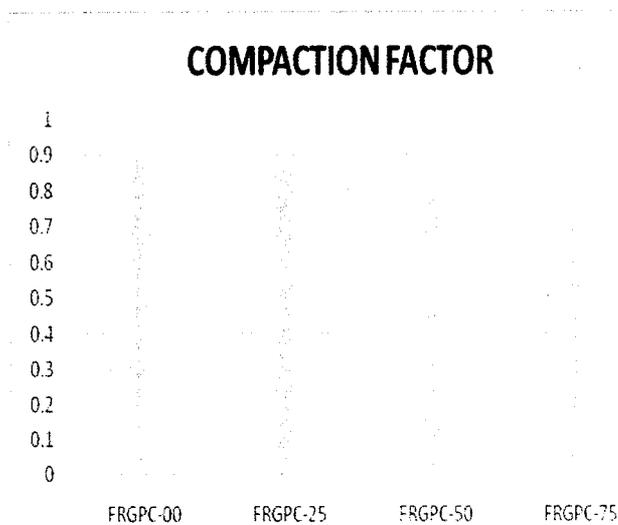


Fig 4.1 Compaction factor



Fig 4.2 Compaction factor test set up

4.1.2 Flow table test

Flow table test is used in finding out the workability of concrete that are not workable in the normal sense, the test uses intergal vibration. The test was conducted as per IS: 1199-1959. The results are as shown in Table 4.3. The workability is found to be moderate. The concrete may be compacted using needle vibrators. The workability also decreases with the increase in fiber percentage.

Table 4.2 Test results of Flow table test for FRGPC

| Mix | FRGPC-00 | FRGPC-25 | FRGPC-50 | FRGPC-75 |
|-----------------------------|----------|----------|----------|----------|
| Flow ability percentage (%) | 81 | 79 | 75 | 71 |

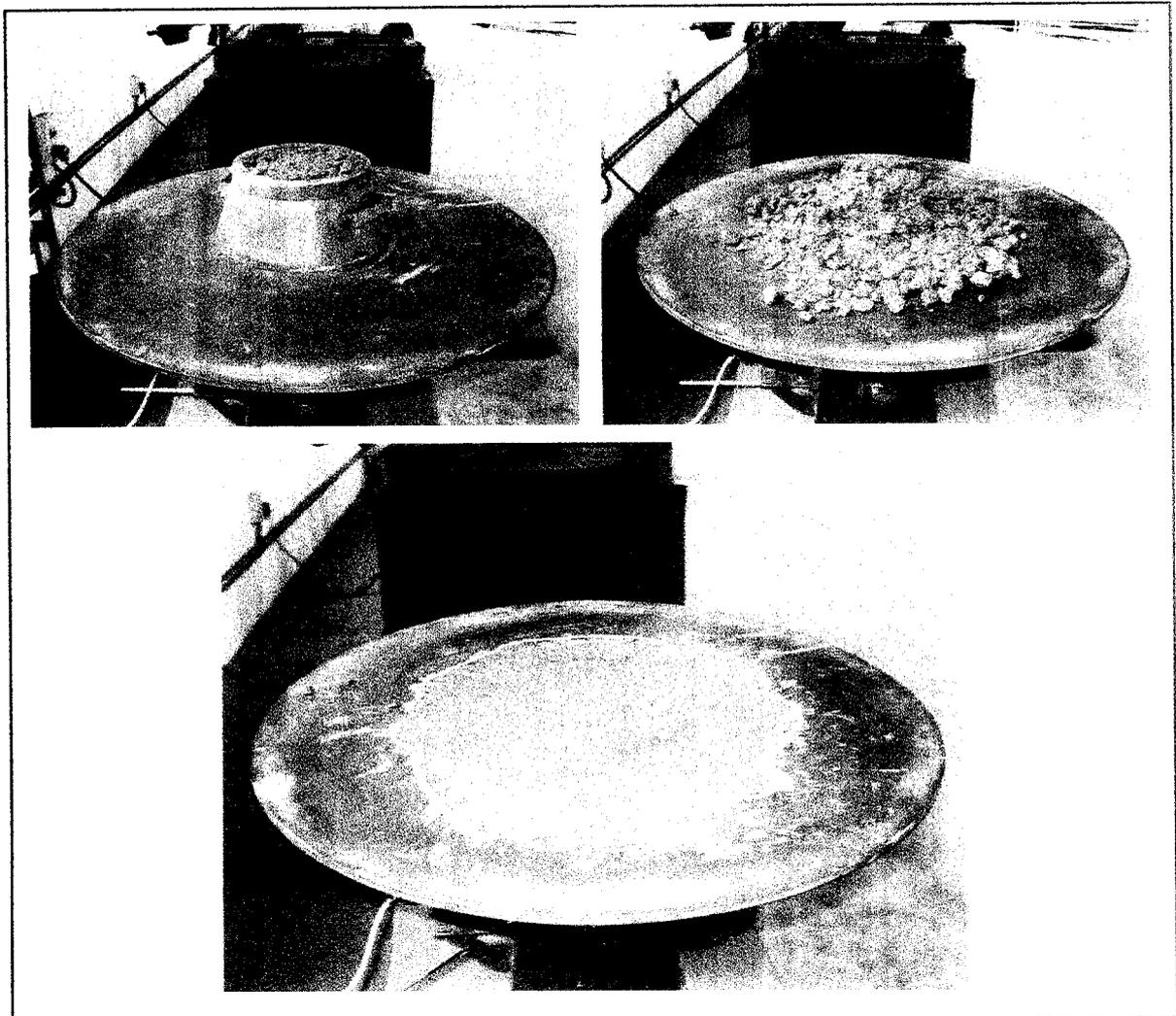


Fig 4.3 Flow table test

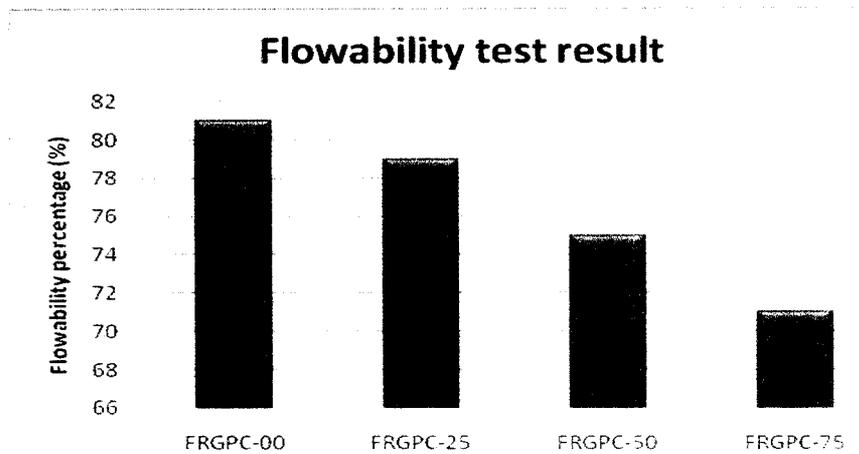


Fig 4.4 Flowability test result (%)

From the results obtained and when compared to the IS code, it's clear that the workability of GPC is very low without superplasticisers and it decreases as the percentage of fiber increases. It is preferred to use needle vibrators while casting the structural elements. Superplasticisers of limited quantity can also be used in accordance with IS code.

4.2 TEST RESULTS ON HARDENED CONCRETE

Test on Hardened Concrete

The hardened properties of concrete like compressive strength test, split tensile strength test, stress strain curve and the micro structural properties like saturated water absorption for the concrete mixes were conducted as per IS: 516-1959, IS:5816-1999 and ASTM standards and test results were shown in Table 4.4.

4.2.1 Compressive strength

The compressive strength is a measure of the concrete's ability to resist loads which tend to crush it. The compressive strength of FRGPC was conducted on the cubes of size 100mm were tested as per IS 516 –1959 specifications and the experimental setup as shown in Fig. 5.4 The density of the specimens were also determined at the same time. The cubes were tested for compressive strength at 12th, 18th and 24th hours of oven curing. Then the cubes are demoulded after 12 hours of curing and re-cured in hot air oven for a period of 6 to 15 hours, 3 specimens were tested at different curing time and the values of the test result are shown in the Table 4.4. From the results obtained it is

clear that increase in fiber dosage decreases the compressive strength. Hence it is advisable to use ordinary GPC without fiber reinforcement for compression members.

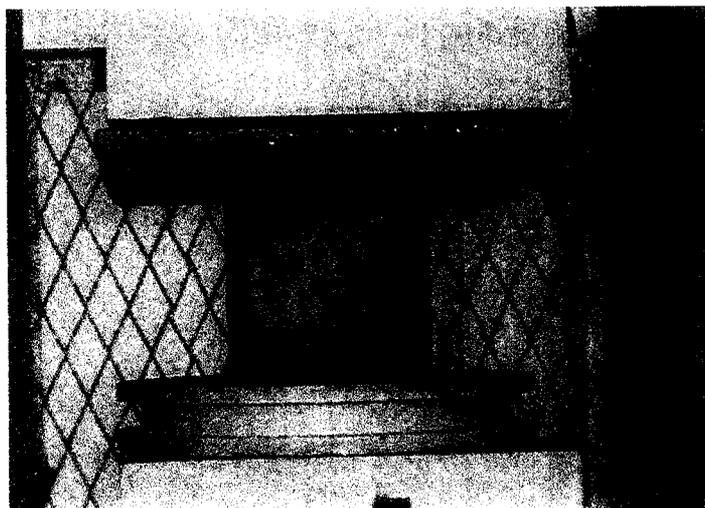


Fig 4.5 compression test setup

Table 4.3 Compression test results of FRGPC

| Mix design | Time of curing | Ultimate load in kN | Compressive strength in N/mm ² |
|------------|----------------|---------------------|---|
| FRGPC-00 | 15 hours | 220 | 22.0 |
| | 18 hours | 290 | 29.0 |
| | 24 hours | 370 | 37.0 |
| FRGPC-25 | 15 hours | 190 | 19.0 |
| | 18 hours | 265 | 26.5 |
| | 24 hours | 355 | 35.5 |
| FRGPC-50 | 15 hours | 160 | 16.5 |
| | 18 hours | 250 | 25.0 |
| | 24 hours | 340 | 34.0 |
| FRGPC-75 | 15 hours | 150 | 15.0 |
| | 18 hours | 225 | 22.5 |
| | 24 hours | 320 | 32.0 |

COMPRESSIVE STRENGTH OF GPC

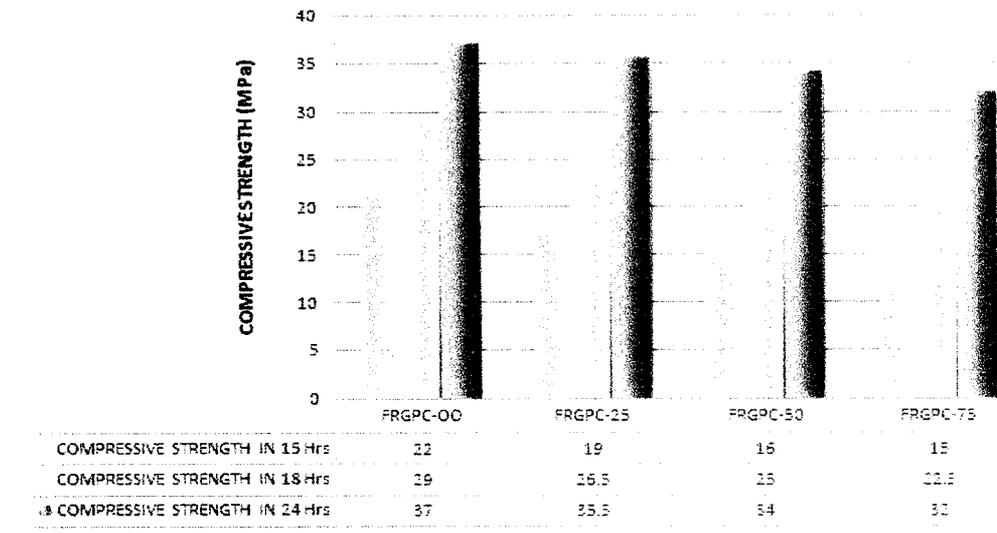


Fig 4.6 Compression test results of FRGPC



Fig 4.7 Crack pattern of cube after Compression test

4.2.2 Split tensile strength

Split tensile strength test is an indirect method of finding the tensile strength of concrete. It is easy to perform and gives more uniform strength than direct tension test. The specimen is loaded horizontally between the loading surfaces of the compression testing machine and is loaded until the failure of the cylinder. Split tensile test was conducted after 15th, 18th and 24th hours of oven curing. Then the cylinder are demoulded and re-cured in hot air Oven for a period of 6 and 12 hours, 3 specimens were tested at different curing time and the values of the test result are shown in the Table 4.5., 3 specimens were tested and the average values of the test result are shown in the Table

4.5. The test was conducted based on IS standards. The test were in accordance with ASTM C192

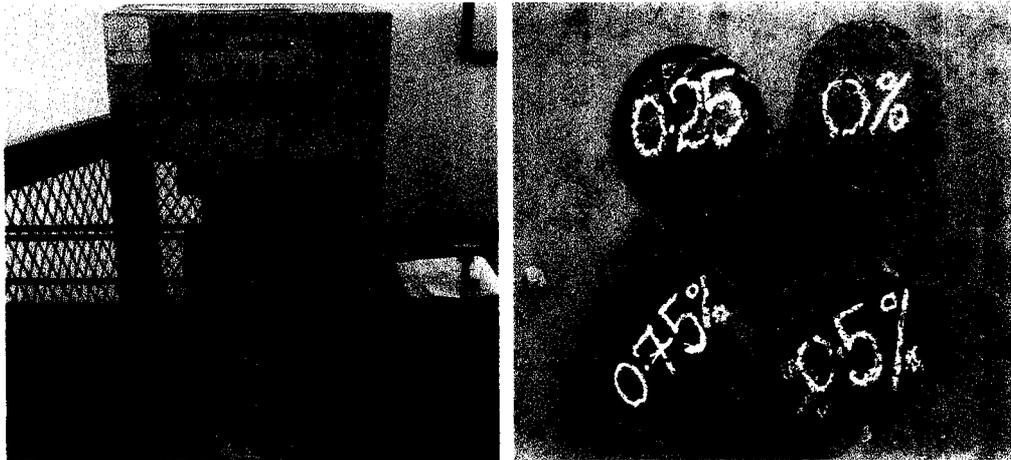


Fig 4.8 split tensile test on FRGPC Fig 4.9 FRGPC after split tensile test

Table 4.4 Test Result of Spilt Tensile Strength of GPC

| Mix designation | Age of curing | Load applied kN | Average Split tensile strength in N/mm² |
|------------------------|----------------------|----------------------------|---|
| FRGPC-00 | 15 hours | 119 | 1.68 |
| | 18 hours | 135 | 1.91 |
| | 24 hours | 156 | 2.21 |
| FRGPC-25 | 15 hours | 121 | 1.71 |
| | 18 hours | 142 | 2.01 |
| | 24 hours | 163 | 2.31 |
| FRGPC-50 | 15 hours | 125 | 1.77 |
| | 18 hours | 159 | 2.25 |
| | 24 hours | 178 | 2.52 |
| FRGPC-75 | 15 hours | 132 | 1.87 |
| | 18 hours | 168 | 2.38 |
| | 24 hours | 190 | 2.69 |

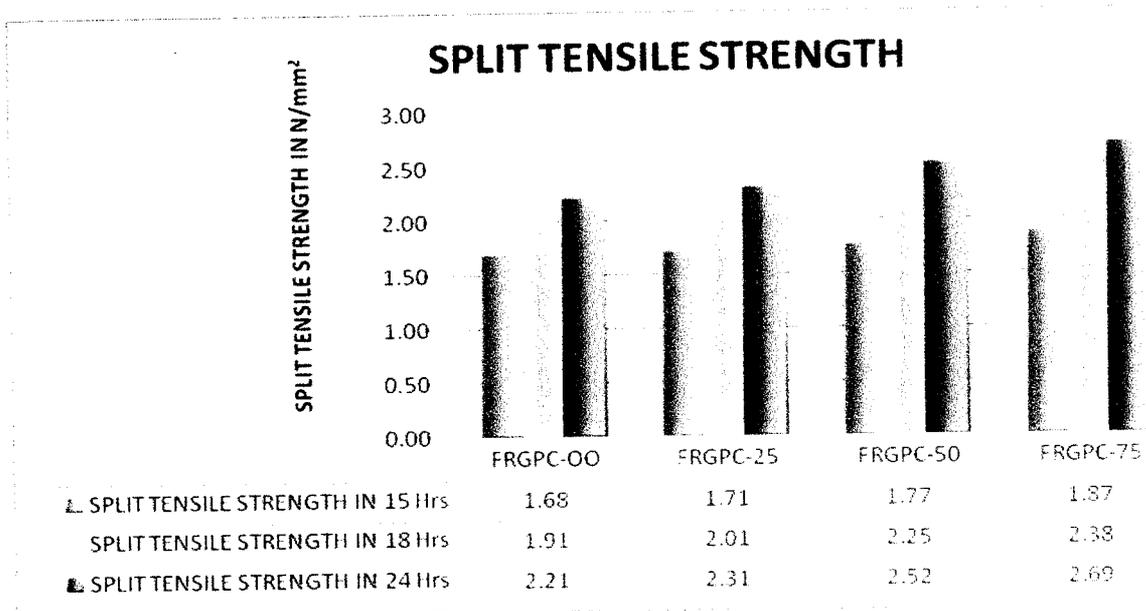


Fig 4.10 Split tensile test results of FRGPC

4.2.3 Stress strain behavior of FRGPCs

The test for stress strain curve for the FRGPC specimens were studied for 24 hours of oven cured specimens. The test specimens were prepared in accordance with the procedure laid for compressive strength testing and the test was carried out as per ASTM Designation: C469-94. Eight cylinders of 150mm diameter and 300mm length were used for the test, four for finding the maximum compressive strength of the cylinder and other four to study the stress strain relationship by applying maximum load of eighty percent of the compressive strength. The extensometer were fixed and then the specimen was placed in the testing machine and accurately centered as shown in the Fig 4.12. The axial stress strain curves of FRGPC in uniaxial compression is shown in Fig:4.11.

Table 4.5 Test Results of Stress Strain Curves of FRGPCs

| Mix | 40% of Max compressive strength kN/mm ² | Strain at 40% of Max compressive strength x 10 ⁵ | Modulus of elasticity N/mm ² |
|----------|---|--|--|
| FRGPC-00 | 50 | 8.21 | 30,654 |
| FRGPC-25 | 65 | 12.80 | 31,253 |
| FRGPC-50 | 110 | 23.57 | 31,955 |
| FRGPC-75 | 90 | 21.26 | 30,889 |

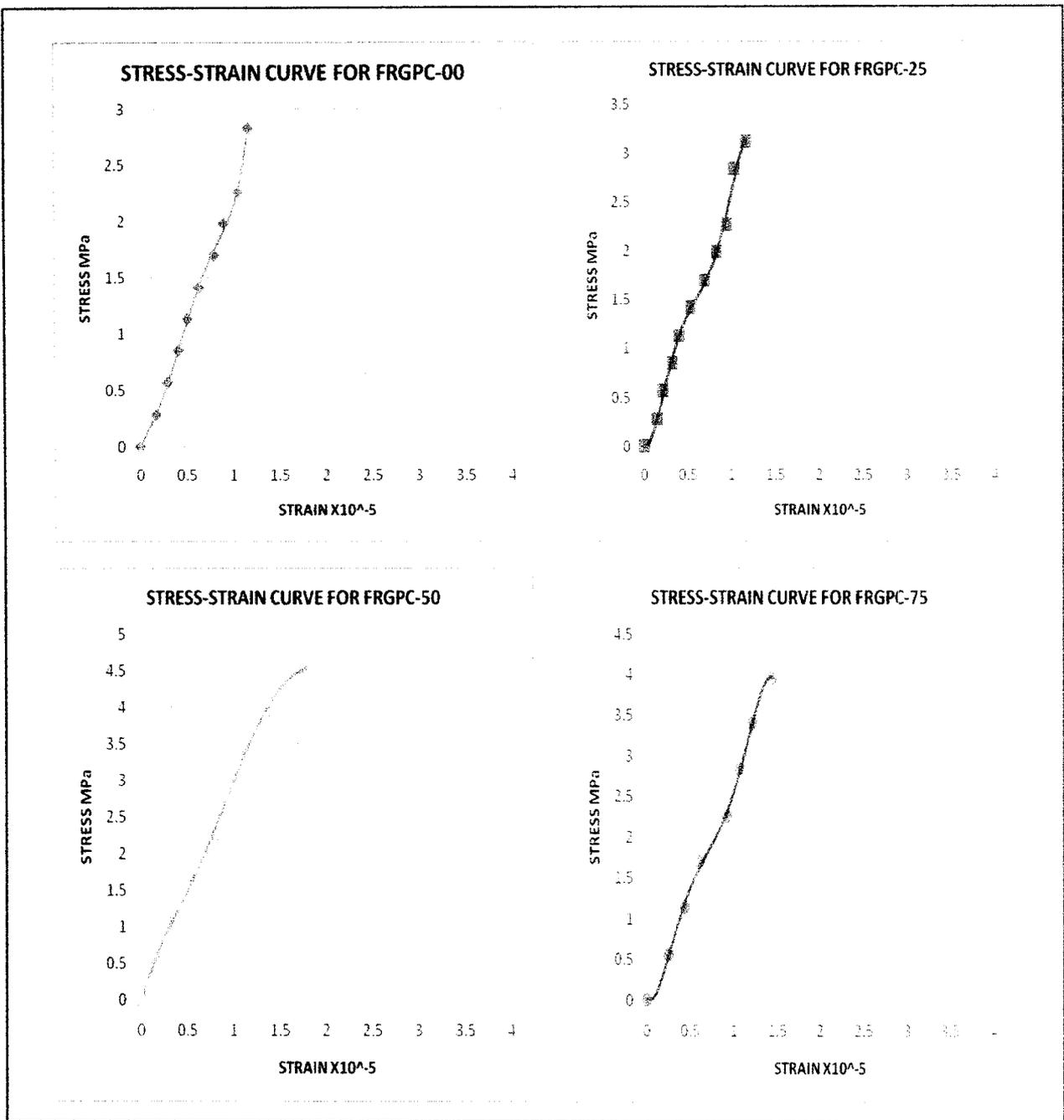


Fig 4.11 Stress strain curves of FRGPCs

From the above graph we conclude that the stress-strain curve is very much similar to stress-strain curve conventional of concrete. The stress-strain curve relation is shown as given in equation obtained from the graph.

For FRGPC-00

$$y = 8.441x^5 - 18.90x^4 + 12.54x^3 - 1.666x^2 + 1.730x - 0.001$$

$$R^2 = 0.999$$

For FRGPC-25

$$y = -19.64x^5 + 59.01x^4 - 60.86x^3 + 24.66x^2 - 0.553x + 0.003$$

$$R^2 = 0.997$$

For FRGPC-75

$$y = -9.545x^5 + 34.45x^4 - 43.23x^3 + 22.06x^2 - 1.204x + 0.003$$

$$R^2 = 0.999$$

For FRGPC-50

$$y = 1.093x^5 - 5.734x^4 + 10.09x^3 - 7.194x^2 + 4.749x - 0.023$$

$$R^2 = 0.997$$

Where $x = \text{Strain}$

$Y = \text{Stress}$

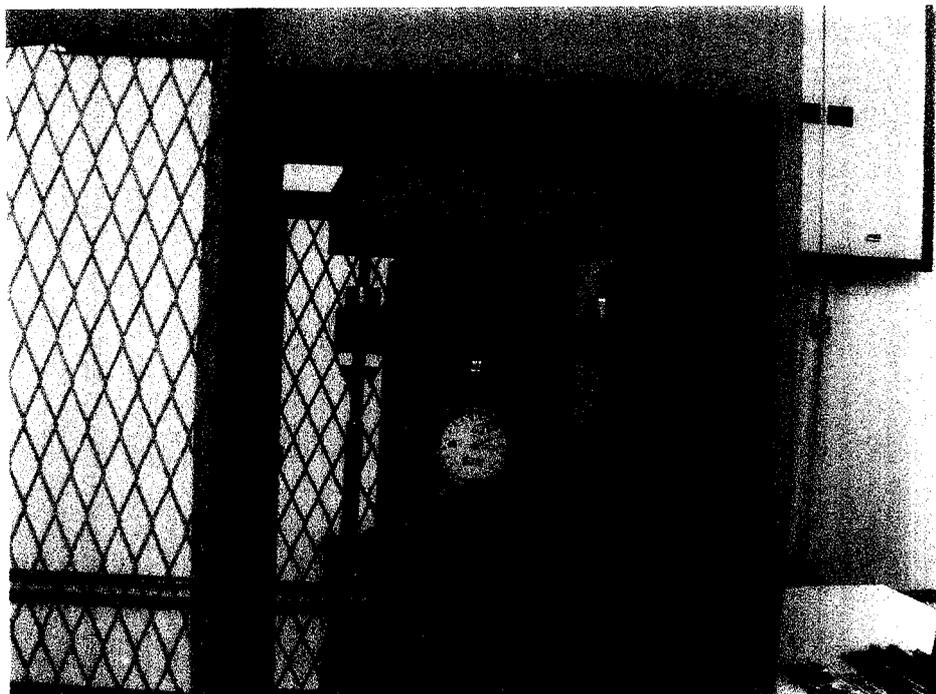


Fig 4.12 Stress strain test arrangements for FRGPCs

4.2.4 Flexural strength of concrete

Flexural strength is one measure of the tensile strength of concrete. It is a measure of an unreinforced concrete beam or slab to resist failure in bending. It is measured by loading 100mm x 100mm concrete beam with a span length of 500mm. The flexural strength is expressed as modulus of rupture (MR) in MPa and is determined by

standard testing methods ASTM C 78 (third-point loading) or ASTM C 293 (center-point loading).

Flexural modulus of rupture is about 10 to 20 percent of compressive strength depending on the type, size and volume of coarse aggregate used. However the best correlation for specific materials is obtained by laboratory test for given materials and mix design. The MR determined by third point loading is lower than MR determined by center-point loading, sometimes as much as 15%. The test for flexural strength have been carried out using third point loading.

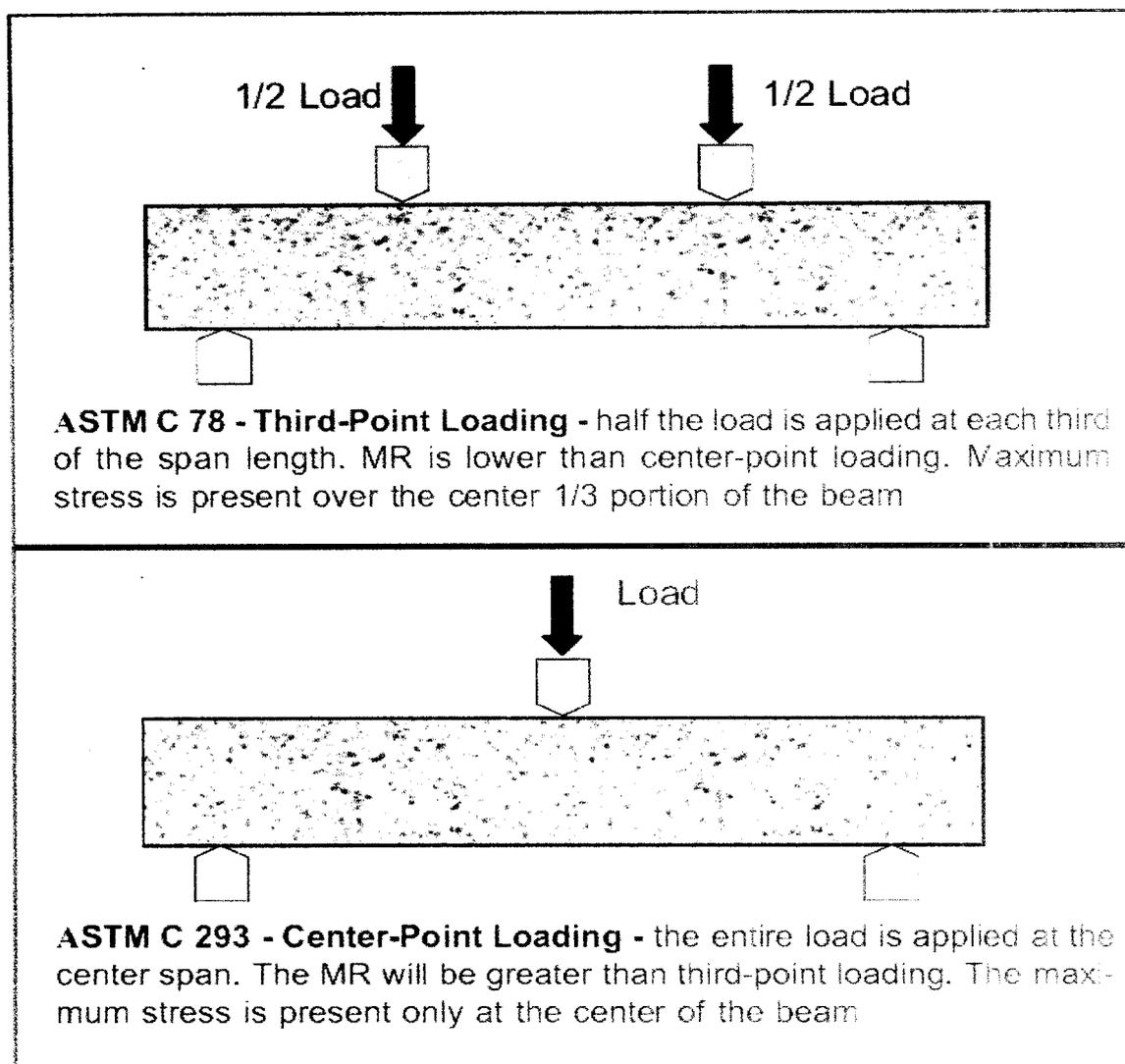


Fig 4.13 ASTM procedure for determining flexural strength

Calculate the modulus of rupture as follows:

$$R = \frac{3PL}{2bd^2}$$

Where: R = Modulus of rupture, MPa or psi.

P = Corrected load indicated, N or lb.

L = Span length, mm or in., between supports (or 18 in. or 457 mm)

b = Width of beam at point of fracture, mm or in.

d = Depth of beam at point of fracture, mm or in.

Table 4.6 Test result for flexural strength of concrete

| Mix designation | Flexural strength MPa |
|-----------------|--------------------------|
| FRGPC-00 | 4.80 |
| FRGPC-25 | 4.98 |
| FRGPC-50 | 5.26 |
| FRGPC-75 | 4.77 |

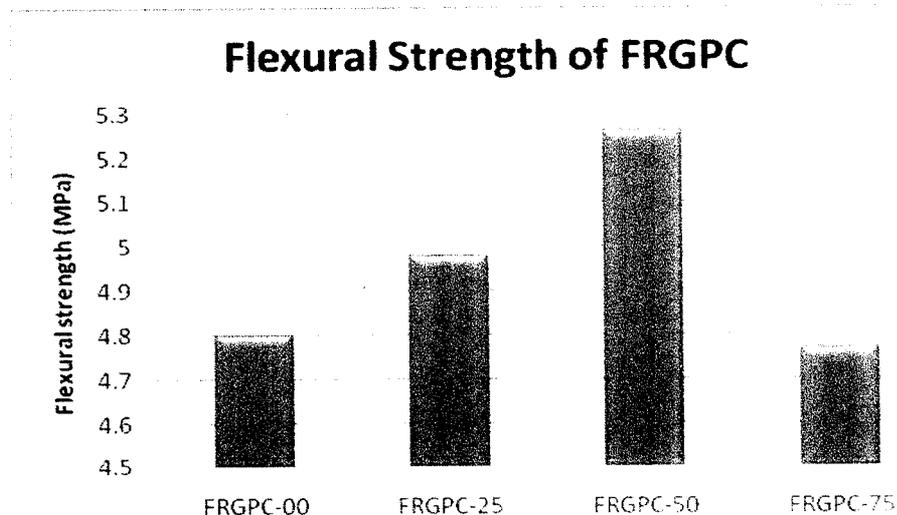


Fig 4.14 Flexural Strength of FRGPCs

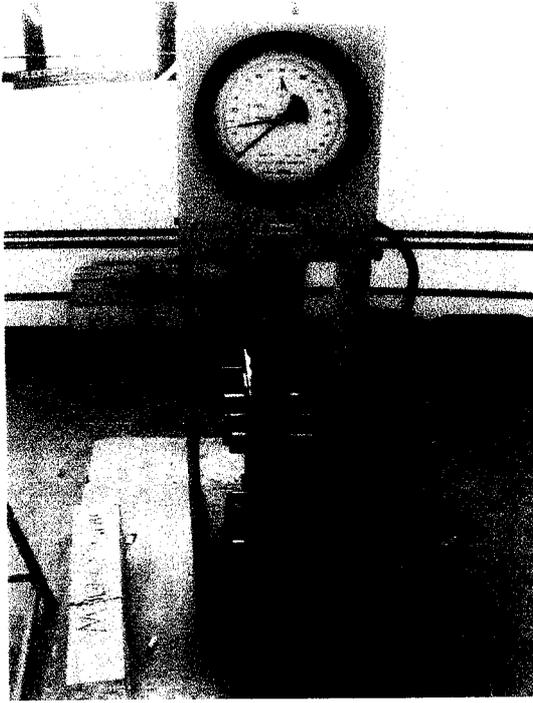


Fig 4.10 ASTM test set up for determining flexural strength (Third point loading)

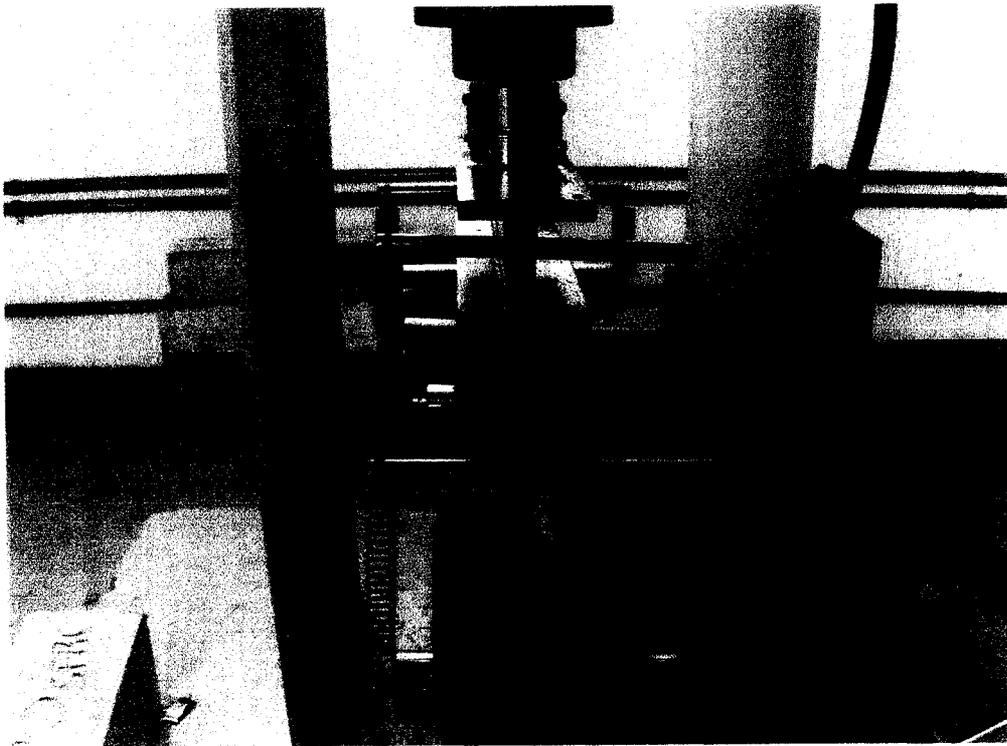


Fig 4.11 Close up loading the beam for determining flexural strength (Third point loading)

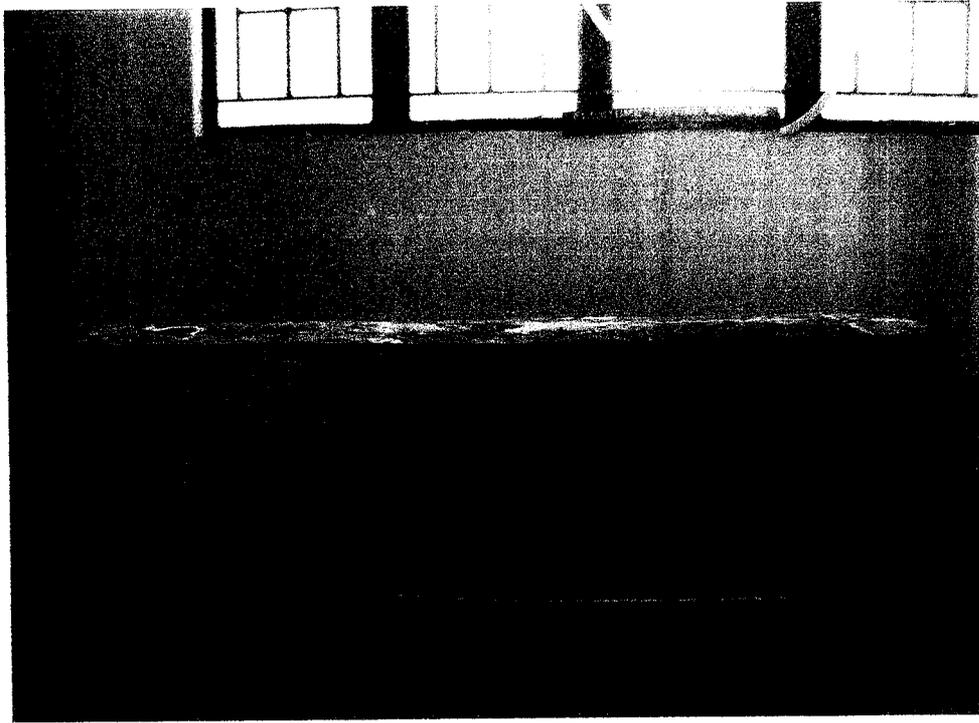


Fig 4.12 Crack pattern for FRGPC-50

4.2.5 Toughness index of FRGPCs

Fiber reinforced Geopolymer concrete (FRGPC) is a composite material in which steel, glass, polypropylene or other tension materials are incorporated to improve the tensile strength and other properties of concrete. The stress-strain variation of high-strength concrete submitted to axial compression shows hardly any strain-softening response as the descending branch after peak stress is almost vertical (ACI 363-R (1984)).

Explosive type of failure occurs when the peak stress is reached in high-strength concrete due to increase in the brittleness. Moreover, the failure is sudden and catastrophic in structures subject to earthquake, blast, or suddenly applied loads. Adding fibers to a plain concrete matrix have little effect on its pre-cracking behaviour but does substantially enhance its post-cracking response, which leads to a greatly improved ductility and toughness (Fanella and Naaman (1985)).

The toughness is defined as the area under the stress-strain or stress-crack mouth opening displacement curve. Magnification of the toughness of fiber reinforced Geopolymer concrete has been measured using toughness index with reference to the no reinforced control concrete matrix. The toughness index (TI) is the ratio of the toughness

of the fiber reinforced matrix to that of reference plain concrete matrix, $T_f, frc/T_f, pc$ (Fanella and Naaman (1985)). This parameter measures the relative increase in the ductility of the fiber reinforced concrete with respect to the control mix. The specific toughness is the toughness of fiber reinforced concrete per unit strength (FT/C or T).

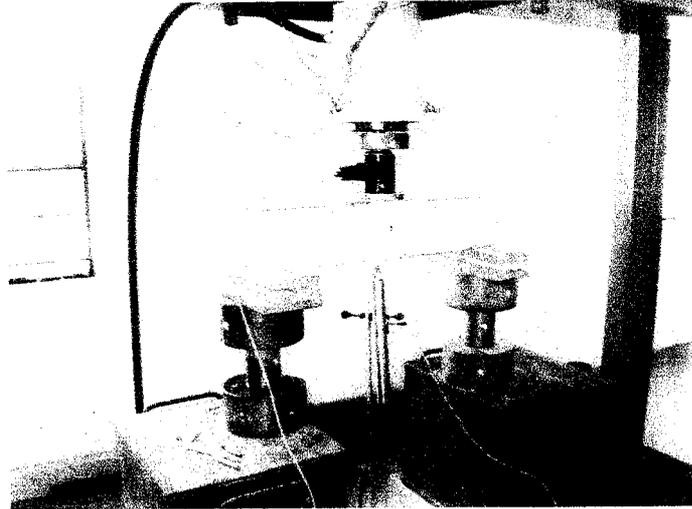


Fig 4.13 Close up of Set up to find load Vs deflection of beam

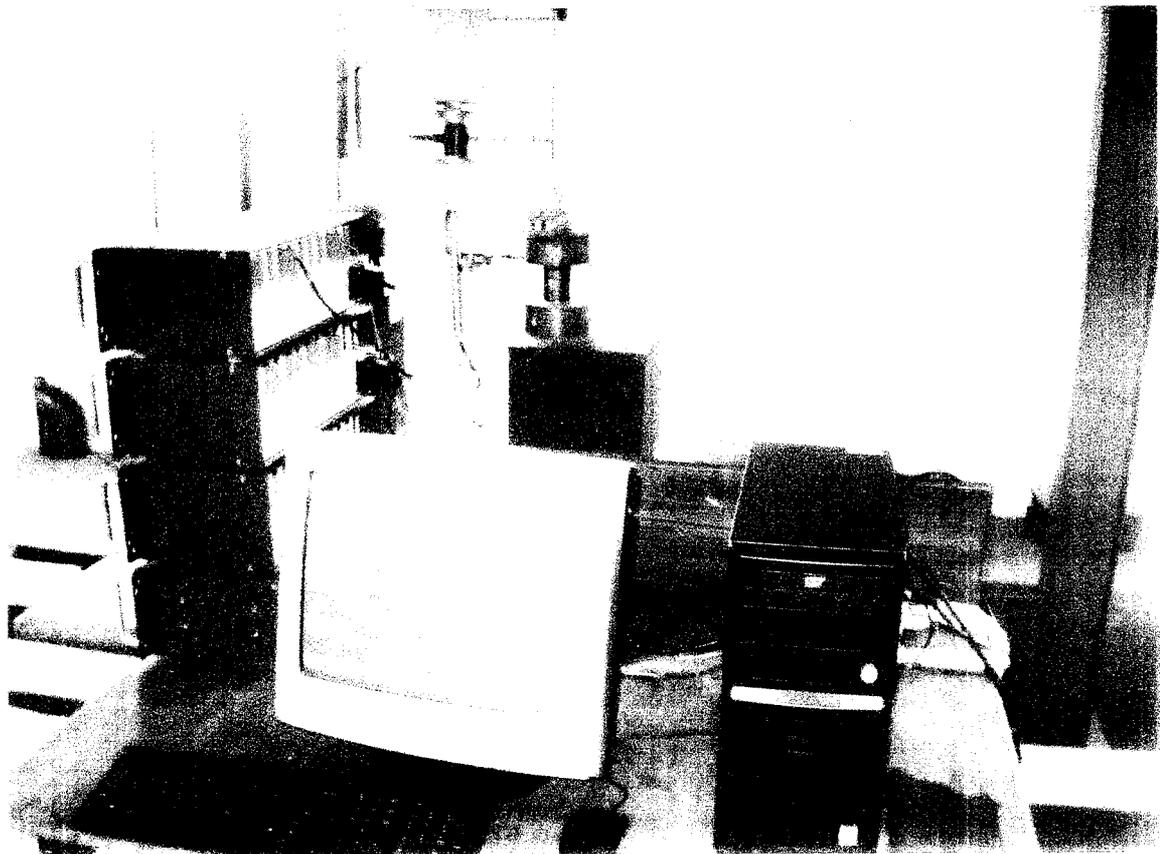


Fig 4.14 Entire Set up of Data Logger

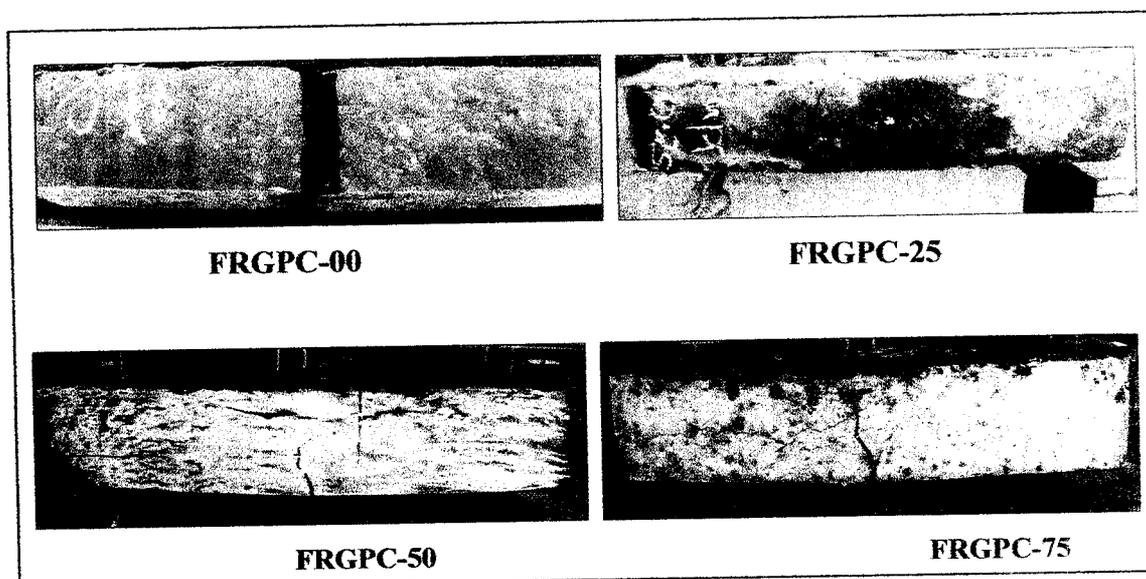


Fig 4.15 Crack pattern

Table 4.8 Fracture Properties of FRGPC

| MIX | FRGPC-00 | FRGPC-25 | FRGPC-50 | FRGPC-75 |
|---|----------|----------|----------|----------|
| Compressive strength C | 37.00 | 35.50 | 34.00 | 32.00 |
| Tensile strength T | 2.21 | 2.31 | 2.52 | 2.69 |
| Fracture Toughness FT N-m | 42.75 | 71.50 | 390.00 | 63.75 |
| Specific Toughness Compression (STC) | 1.16 | 2.01 | 11.47 | 2.00 |
| Specific Toughness tension (STT) | 19.34 | 30.95 | 154.76 | 23.70 |
| Toughness Index (TI) | 1 | 1.67 | 9.12 | 1.49 |

Fracture Toughness (FT) = Area under Load Displacement curve up to maximum load.

Specific Toughness Compression (STC) = C / FT

Specific Toughness tension (STT) = T / FT

Toughness Index (TI) = $FT / \text{Reference FT (ie FRGPC-00)}$

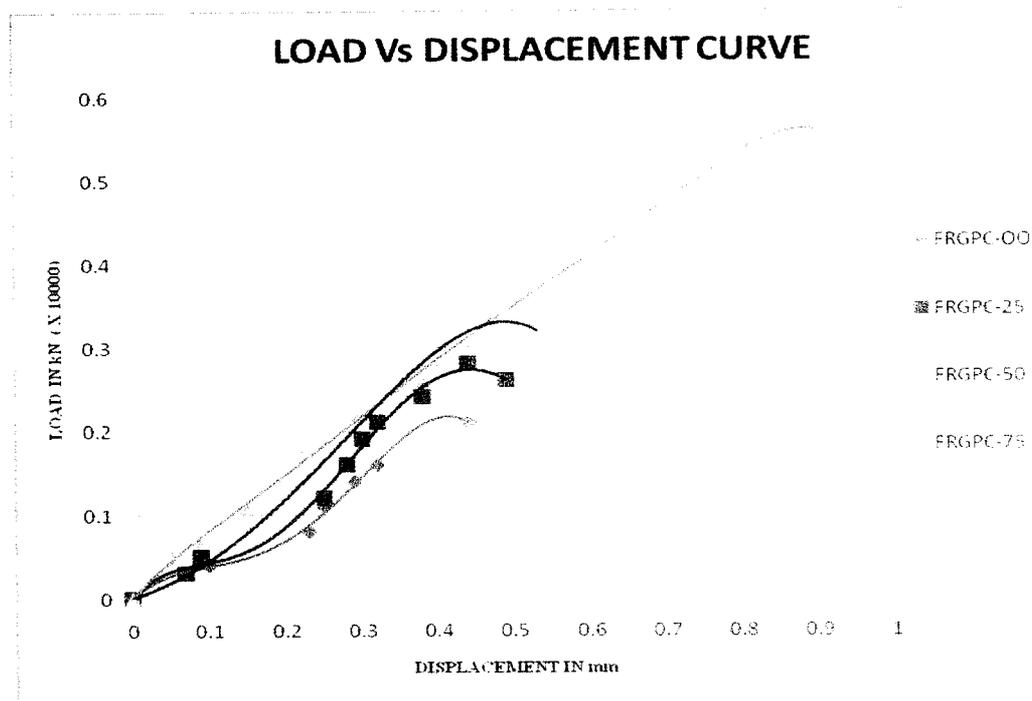


Fig 4.21 Load Vs Displacement curves of FRGPCs to find out toughness

From the above graph we conclude that the Load-Displacement (Deflection) curve is very much similar to Load-Displacement curve of conventional concrete. The Load-Displacement curve relation is shown as given in equation obtained from the graph.

For FRGPC-00

$$y = 807.9x^5 - 928.3x^4 + 374.2x^3 - 60.82x^2 + 3.586x + .000008$$

$$R^2 = 0.998$$

For FRGPC-25

$$y = 91.89x^5 - 142.1x^4 + 71.32x^3 - 12.87x^2 + 1.143x - 0.000$$

$$R^2 = 0.993$$

For FRGPC-50

$$y = -13.84x^6 + 35.40x^5 - 34.42x^4 + 15.80x^3 - 3.527x^2 + 1.034x + 0.000$$

$$R^2 = 0.998$$

For FRGPC-75

$$y = -4.187x^5 - 1.871x^4 + 0.416x^3 + 1.511x^2 + 0.292x + 0.001$$

$$R^2 = 0.998$$

Where x = Displacement

y = Load

4.3 DURABILITY TEST OF CONCRETE

4.3.1 Water absorption test

In a study conducted, water absorption test based on ASTM C 642-82 were used to evaluate surface treatments for concrete. The 100mm cubes used in the tests were cast from a mixture proportioned to produce FRGPC with a relatively high permeability. The concrete was mixed and the cubes were cast and compacted in accordance with standard concreting and fabricating practices. The cubes were cured in the hot air oven for 24 hr and cooled in a moist curing room (100 percent humidity and 73 ± 3 'F) and then stripped. These cubes were used as both test and control specimens.

The cured specimens were cleaned by light sandblasting, dried at 225 ± 5 'F for 24 hr, and cooled overnight. Surface treatments were applied to the cubes. After drying at 73 ± 3 'F in laboratory air for 7 days, the cubes were weighed to the nearest 0.1 g to establish initial weight. Following this procedure, specimens and controls were immersed in 73 ± 3 'F water. A minimum of 200mm of water covered the specimens at all times. At 5, 7, 14, 21, and 28 days, each cube was removed, blotted with a paper towel to dry the surface, weighed to the nearest 0.1 g, and returned to the soaking tank. The percent of water absorbed was determined by calculations based on the initial weight of the concrete and the weight after submersion.

Table 4.8 Water absorption test results

| | Percentage of water absorbed (%) | | | | |
|----------|----------------------------------|--------|---------|---------|---------|
| | 5 Days | 7 Days | 14 Days | 21 Days | 28 Days |
| FRGPC-00 | 1.88 | 2.62 | 2.66 | 2.82 | 2.82 |
| FRGPC-25 | 2.25 | 2.72 | 2.72 | 2.80 | 2.80 |
| FRGPC-50 | 2.30 | 2.88 | 2.92 | 2.97 | 2.97 |
| FRGPC-75 | 2.44 | 2.92 | 2.96 | 3.00 | 3.00 |

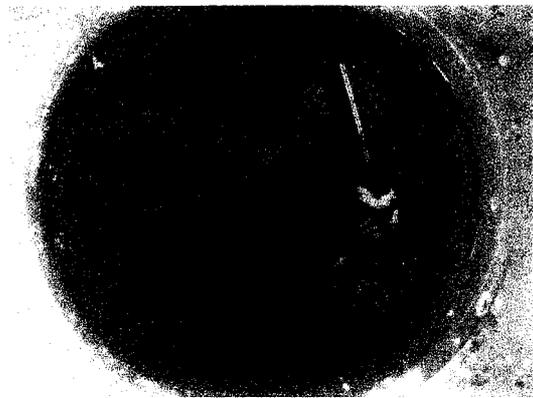


Fig 4.22 Specimens kept for water absorption test

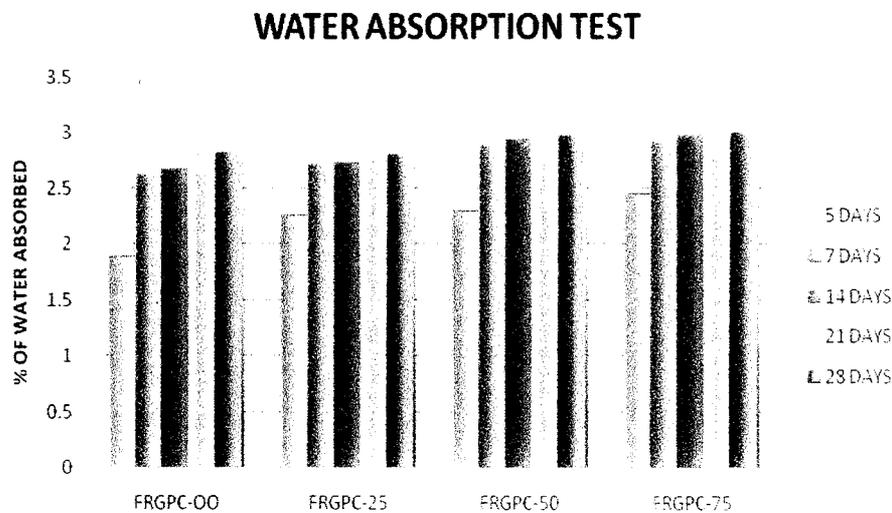


Fig 4.23 Water absorption test results

As per ASTM C 642-82 concrete with water absorption less than 3% is considered as good concrete. All the FRGPCs have water absorption less than 3% except for FRGPC-75, which exactly have water absorption of 3%. So GPC and FRGPC is good in durability aspect when water absorption is considered.

4.3.2 Acid resistance test

Acid resistance test was conducted on geopolymer concrete. Because no universal or widely accepted standard procedures for acid resistance test exist, the type and concentration of the acid solution to which the specimens were exposed varied. Sulfuric acid is one type of acid solution that is frequently used to simulate the acid attack in sewer pipe systems. In such systems, sulfuric acid attack is a particular problem as it is generated bacterially from hydrogen sulfide. To test the acid resistance of geopolymer

concrete, Hime (2003) suggested that the specimens be exposed to sulfuric acid solution with a concentration of pH = 1. This value of pH was also used by Gourley & Johnson (2005) to simulate the acid attack on sewer pipes. Mehta (1985) and Li and Zhao (2003) used 1% and 2% sulfuric acid concentration to simulate the sulfuric acid attack on concrete. Based on those past studies, to evaluate the acid resistance of fly ash-based geopolymer concrete, the specimens were soaked in sulphuric acid solution with concentration of 5% with the measured pH ranges from about 0.9 to 2.1, up to 28 days of exposure. The test specimens were immersed in sulphuric acid solution in a container. The solution was stirred every week and replaced when pH level changes. The acid resistance of geopolymer concrete was then evaluated based on the change in compressive strength and the change in mass after acid exposure. The test specimens for acid resistance test on geopolymer concrete were 100x100x100mm cubes for both the compressive strength test and the change in mass test. For compressive strength test, the specimens were tested in saturated-surface-dry (SSD) condition. On the day of test, the specimens were removed from the acid solution container and wiped clean before testing. Specimens for change in mass test were also removed from the acid solution container and wiped clean prior to the measurement. Immediately after mass measurement using a laboratory scale, the specimens were returned to the acid solution container.

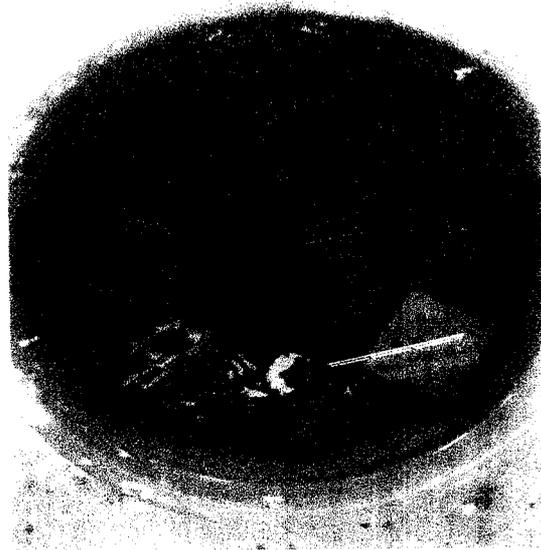
Table 4.9 Acid resistance test results

| | Percentage of loss of weight (%) | | | | Compressive strength - MPa | |
|----------|----------------------------------|---------|---------|---------|----------------------------|---|
| | 7 Days | 14 Days | 21 Days | 28 Days | After 24 hrs of curing | After 28 days immersion in H ₂ SO ₄ |
| FRGPC- | 0.33 | 0.77 | 1.34 | 1.83 | 37.00 | 33.00 |
| FRGPC-25 | 0.35 | 0.84 | 1.41 | 1.89 | 35.50 | 30.50 |
| FRGPC-50 | 0.44 | 0.93 | 1.64 | 2.26 | 34.00 | 27.00 |
| FRGPC-75 | 0.53 | 1.37 | 2.26 | 2.69 | 32.00 | 23.00 |

The acid resistance test is accelerated by increasing the concentration of sulphuric acid to 5%. The deterioration of concrete is very less when compared to conventional concrete, obtained from previous studies. The compressive strength is also satisfied though it decreases. Hence GPC and FRGPCs are good in aggressive environments too. The percentage loss in compressive strength for FRGPC-00, FRGPC-25, FRGPC-50 and FRGPC-75 is about 10%, 14%, 20% and 28% respectively.



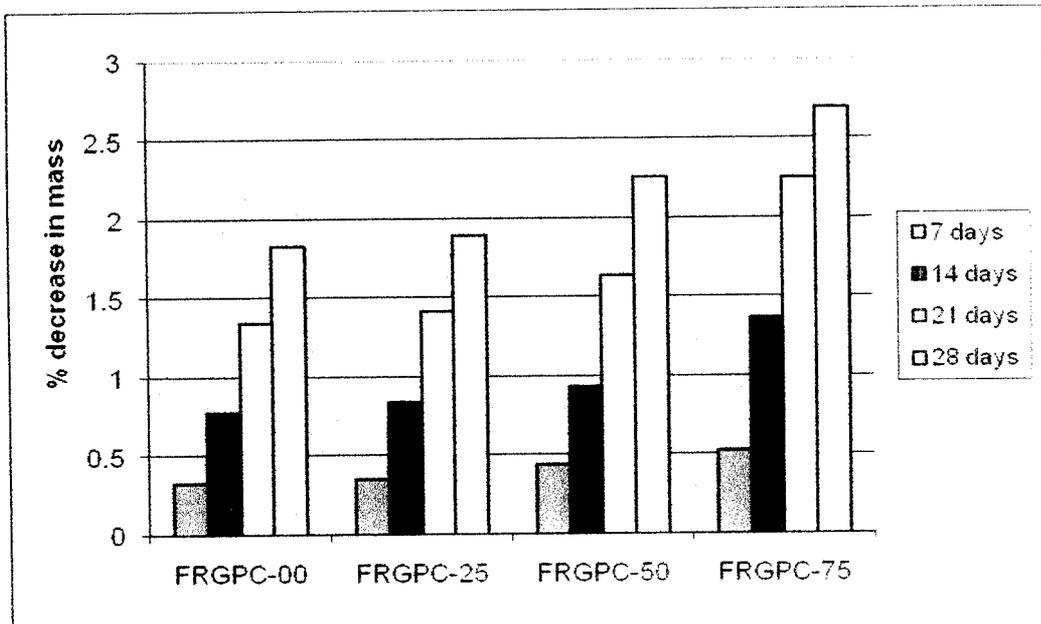
Fig 4.17 Sulphuric acid-98.08% purity



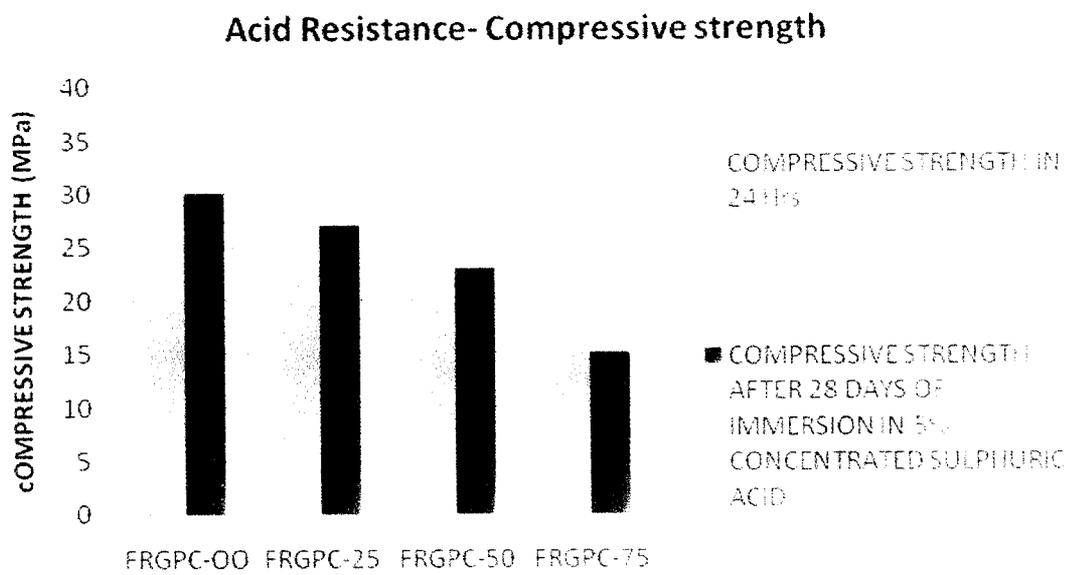
**Fig 4.18 Cubes immersed in H_2SO_4
(5% concentration)**



Fig 4.19 Cubes after 28 days of immersion in 5% concentrated sulphuric acid



Graph 4.9 Acid resistance tests - % change in mass



Graph 4.10 Acid resistance tests – Compressive strength

CONCLUSIONS

CHAPTER 5

CONCLUSIONS

The following conclusions were drawn within the limitation of experimental investigation.

5.1 GENERAL CONCLUSION

1. There is no substantial gain in the compressive strength of heat-cured fly ash based geopolymer concrete with age.
2. The GPC made from locally available sodium silicate is found to be cheaper than the conventional concrete.
3. Fly ash-based geopolymer concrete cured in the laboratory ambient conditions gains compressive strength with age. The 7th day compressive strength of ambient-cured specimens depends on the average ambient temperature during the first week after casting; higher the average ambient temperature higher is the compressive strength.
4. Fly ash-based geopolymer concrete has less workability and when fibers are added to it the workability further decreases with increase in fiber content. Hence proper vibration should be provided during the time of casting.
5. Fly ash-based Fiber reinforced geopolymer concrete has comparatively less strength than ordinary geopolymer concrete. It should be taken care of that compression members shouldn't be casted using FRGPCs.
6. The stress strain curve and tensile strength of FRGPCs were very much similar to the conventional concrete.
7. Exposure to sulphuric acid solution damages the surface of heat-cured fiber reinforced geopolymer concrete test specimens and causes a mass loss of about 2% after 28 days of exposure in 5% concentrated sulphuric acid solution. The severity of the damage depends on the acid concentration. The steel fibers embedded in the concrete was not much effected by sulphuric acid.
8. The test results demonstrate that heat-cured fly ash-based geopolymer concrete has an excellent resistance to water absorption. All the FRGPCs had water absorption percentage less than 3%.
9. From the results obtained, FRGPC-50 has better physical and structural properties when compared with other FRGPCs. So we conclude that for this particular mix and

grade of GPC, 0.5% of fiber is the optimum value steel fibers that can be added to obtain better results.

10. The sulphuric acid attack also causes degradation in the compressive strength of heat-cured geopolymer concrete. The extent of degradation depends on the concentration of the acid solution and the period of exposure. However, the sulphuric acid resistance of heat-cured geopolymer concrete is significantly better than that of Portland cement concrete as reported in earlier studies.

11. As there are no codes that specify standards for geopolymer concrete, the mixes should be designed, experimented and then used, as the quality of fly ash used plays very important role in it.

5.2 SPECIFIC CONCLUSION

5.2.1 Test on fresh FRGPCs

From the results obtained from flow table test and compaction factor test its found that the workability for GPC is comparatively low and with the increase in fiber percentage, workability decreases. Super plasticizers can be used up to 6% of the fly ash. For mixes with lesser water binder ratio results in stiffer mixes, which accounts for higher dosage of super plasticizer.

5.2.2 Test on hardened FRGPCs

Compression strength test

The compression test results show that GPC without fiber has strength of 37MPa and it decreases with increase in fiber content. The previous studies conducted say that the decrease in strength is due to the difference in thermal coefficient of GPC and steel fibers.

Split tensile strength test

The split tensile strength test results show that FRGPCs has good split tensile strength and it increases with increase in fiber content. FRGPC-00 has split tensile strength of 2.21MPa and increases to 2.69MPa for FRGPC-75.

Stress strain characteristics

Young's modulus of elasticity for FRGPCs were satisfactory and FRGPC-50 showed better result of 31,955 MPa. The stress strain curve is also similar to FRC stress strain curves.

Flexural strength

Flexural strength for FRGPCs ranges from 4.80MPa to 5.6MPa and FRGPC-50 showed better result of 5.26 MPa.

Toughness index

Toughness index for FRGPC-50 when compared with FRGPC-00 is 9.12, and is the optimum toughness obtained. The load Vs displacement curve for FRGPCs was similar to FRCs.

5.2.3 Durability test on FRGPCs**Water absorption**

According to IS specifications concrete with water absorption less than 3% is considered as good concrete. All FRGPCs had water absorption less than 3%.

Acid resistance test

FRGPCs have better acid resistance when compared to conventional concrete. The percentage decrease in mass increased with increase in fiber percentage. There was about 10 percent decrease in compressive strength for FRGPC-00 and 20 percent decrease for FRGPC-50.

SCOPE FOR FUTURE WORK

The future scope of work is as followed

- Study on GPC reinforced with glass fibers, polypropylene fibers and hybrid fibers.
- Study on characteristics of GPC and FRGPC beams.
- Study on characteristics of GPC and FRGPC slabs.
- Study on high strength GPC mix.
- Study on Flyash based GPC using quarry dust.
- Study on behavior of GPC and FRGPC in fire.

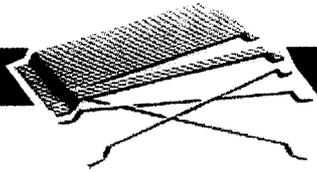
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APPENDIX



Dramix®



Description: Dramix® fibres are filaments of wire, deformed and cut to lengths, for reinforcement of concrete, mortar and other composite materials. Dramix® RC-80/60-BN is a cold drawn wire fibre, with hooked ends, and glued in bundles.



Applications:

- jointless floors
- suspended ground slabs
- jointless floors on vibrocompacted piles
- industrial floors
- slabs on vibro-compacted piles
- liquid tight floors
- overlays
- pavements
- segmental linings
- compression layers
- cellar walls
- precast

Geometry:

Length (l)
60 mm

Diameter (d)
0,75 mm

80
Performance class: 80
Aspect ratio (= l/d): 80

4600 fibres/kg

Approvals:

Conforms to **ASTM A820**

Product **Belgium**
ATG 04/1857

The Netherlands
22702

Turkey
TS 10513

Czech Republic
C.070-021415

Quality System in Belgian, Brazilian, Czech, Turkish and Chinese plants
ISO 9001

Product **Poland**
AT-15-2117/2001

Romania
007-01/068-2003

Germany
Z-3.71-1745

Slovak Republic
1402A/02/0771/1/C/C04

Tensile strength:

- on the wire: minimum 1050 N/mm²
- low carbon conforms to EN 10016-2 - C9D

Coating: None

Technical data:

For industrial floors, floors on vibrocompacted piles, jointless floors... ask for specialized documentation.

1 Equivalent flexural strength

- $f_{ctm,eq,300} / f_{ctk,eq,300}$ = average and characteristic equivalent flexural strength to a deflection of 1,5 mm according to NBN B 15-238, 239, JSCE-SF4 and CUR35.
- $f_{ctm,eq,150} / f_{ctk,eq,150}$ = average and characteristic equivalent flexural strength to a deflection of 3 mm according to NBN B 15-238, 239, JSCE-SF4 and CUR35.

Dramix® RC-80/60-BN

| f _{ctm,f} (1) | 3,7 (C20/25) (2) | | 4,3 (C25/30) | | 4,8 (C30/37) | | 5,3 (C35/45) | | 5,8 (C40/50) | |
|------------------------|-------------------------|-------------------------|-------------------------|-------------------------|-------------------------|-------------------------|-------------------------|-------------------------|-------------------------|-------------------------|
| | f _{ctm,eq,300} | f _{ctm,eq,150} |
| 20 | 2,7 | 1,9 | 2,4 | 2,2 | 2,5 | 2,6 | 3,0 | 2,8 | 3,2 | 3,0 |
| 25 | 2,5 | 2,2 | 2,5 | 2,7 | 3,2 | 3,0 | 3,5 | 3,2 | 3,7 | 3,3 |
| 30 | 2,8 | 2,7 | 3,5 | 3,1 | 3,6 | 3,3 | 3,9 | 3,5 | 4,1 | 3,6 |
| 35 | 3,2 | 3,0 | 3,6 | 3,2 | 3,9 | 3,6 | 4,2 | 3,8 | 4,4 | 3,9 |
| 40 | 3,5 | 3,3 | 3,8 | 3,5 | 4,2 | 3,9 | 4,4 | 4,1 | 4,6 | 4,2 |
| 45 | 3,7 | 3,4 | 4,0 | 3,6 | 4,3 | 4,0 | 4,6 | 4,2 | 4,8 | 4,3 |
| 50 | 3,9 | 3,5 | 4,2 | 3,7 | 4,4 | 4,1 | 4,8 | 4,3 | 5,0 | 4,4 |

(1) f_{ctm,f} = mean flexural tensile strength of plain concrete (N/mm²).
 (2) Concrete class corresponding with f_{ctm,f} according to EN 1992-1-1. Boxed value [0.5] is replaced by the value 0.6 in formula (3.1).

f_{ctk,eq,300} = 0.7 x f_{ctm,eq,300} According to Dramix® guideline unless more specific data available.
 f_{ctk,eq,150} = 0.7 x f_{ctm,eq,150}

2 Equivalent axial tensile strength

- Equivalent axial tensile strength = 0,37 x equivalent flexural strength.

Trade Name: **N^o Sodium Silicate Solution**
Date Prepared: **06/13/06**

Page: 1 of 5

1. CHEMICAL PRODUCT AND COMPANY IDENTIFICATION

Product name: N^o Sodium silicate solution
Product description: A 3.22 weight ratio sodium silicate, 37.5% solution in water
Manufacturer: PQ Corporation
P. O. Box 840
Valley Forge, PA 19482 USA
Telephone: 610-651-4200
In case of emergency call: 610-651-4200
For transportation emergency
Call CHEMTREC: 800-424-9300

2. COMPOSITION/INFORMATION ON INGREDIENTS

| <i>Chemical and Common Name</i> | <i>CAS Registry Number</i> | <i>Wt. %</i> | <i>OSHA PEL</i> | <i>ACGIH TLV</i> |
|---|----------------------------|--------------|-----------------|------------------|
| Water | 7732-18-5 | 62.5% | Not Established | Not Established |
| Silicic acid, sodium salt; Sodium silicate | 1344-09-8 | 37.5% | Not Established | Not Established |

3. HAZARDS IDENTIFICATION

Emergency Overview: Clear to hazy, colorless, odorless, thick liquid. Causes moderate eye, skin, and digestive tract irritation. Spray mist causes irritation to respiratory tract. Due to high pH of product, release into surface water is harmful to aquatic life. Noncombustible. Spills are slippery. Reacts with acids, ammonium salts, reactive metals and some organics.

Eye contact: Causes moderate irritation to the eyes.
Skin contact: Causes moderate irritation to the skin.
Inhalation: Spray mist irritating to respiratory system.
Ingestion: May cause irritation to mouth, esophagus, and stomach.
Chronic hazards: No known chronic hazards. Not listed by NTP, IARC or OSHA as a carcinogen.

Physical hazards: Dries to form glass film which can easily cut skin. Spilled material is very slippery. Can etch glass if not promptly removed.

4. FIRST AID MEASURES

Eye: In case of contact, immediately flush eyes with plenty of water for at least 15 minutes. Get medical attention.

Skin: In case of contact, immediately flush skin with plenty of water. Remove contaminated clothing and shoes. Get medical attention.

Inhalation: Remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical attention.

Ingestion: If swallowed, **DO NOT** induce vomiting. Get medical attention immediately. If victim is fully conscious, give a cupful of water. Never give anything by mouth to an unconscious person.

5. FIRE FIGHTING MEASURES

Flammable limits: This material is noncombustible.

Extinguishing Media: This material is compatible with all extinguishing media

Hazards to fire-fighters: See Section 3 for information on hazards when this material is present in the area of a fire.

Fire-fighting equipment: The following protective equipment for fire fighters is recommended when this material is present in the area of a fire: chemical goggles, body-covering protective clothing, chemical resistant gloves, and rubber boots.

6. ACCIDENTAL RELEASE MEASURES

Personal protection: Wear chemical goggles, body-covering protective clothing, chemical resistant gloves, and rubber boots. See section 8.

Environmental Hazards: Sinks and mixes with water. High pH of this material is harmful to aquatic life, see Section 12. Only water will evaporate from a spill of this material.

Small spill cleanup: Mop up and neutralize liquid, then discharge to sewer in accordance with federal, state and local regulations or permits.

Large spill cleanup: Keep unnecessary people away; isolate hazard area and deny entry. Do not touch or walk through spilled material. Stop leak if you can do so without risk. Prevent runoff from entering into storm sewers and ditches which lead to natural waterways. Isolate, dike and store discharged material, if possible. Use sand or earth to contain spilled material. If containment is impossible, neutralize contaminated area and flush with large quantities of water.

CERCLA RQ: There is no CERCLA Reportable Quantity for this material. If a spill goes off site, notification of state and local authorities is recommended.

7. HANDLING AND STORAGE

Handling: Avoid contact with eyes, skin and clothing. Avoid breathing spray mist. Keep container closed. Promptly clean residue from closures with cloth dampened with water. Promptly clean up spills.

Storage: Keep containers closed. Store in clean steel or plastic containers. Separate from acids, reactive metals, and ammonium salts. Storage temperature 0-95° C. Loading temperature 45-95° C. Do not store in aluminum, fiberglass, copper, brass, zinc or galvanized containers.

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

| | |
|--------------------------------|--|
| <i>Engineering controls:</i> | Use with adequate ventilation. Keep containers closed. Safety shower and eyewash fountain should be within direct access. |
| <i>Respiratory protection:</i> | Use a NIOSH-approved dust and mist respirator where spray mist occurs. Observe OSHA regulations for respirator use (29 C.F.R. §1910.134) |
| <i>Skin protection:</i> | Wear body-covering protective clothing and gloves. |
| <i>Eye protection:</i> | Wear chemical goggles. |

9. PHYSICAL AND CHEMICAL PROPERTIES

| | |
|-----------------------------|--|
| <i>Appearance:</i> | Thick liquid. |
| <i>Color:</i> | Clear to hazy white. |
| <i>Odor:</i> | Odorless or musty odor. |
| <i>pH:</i> | Approximately 11.3 |
| <i>Specific gravity:</i> | 1.39 g/cm ³ (20°C), 41° Bé, 11.62 lbs/gal |
| <i>Solubility in water:</i> | Miscible. |

10. STABILITY AND REACTIVITY

| | |
|--|--|
| <i>Stability:</i> | This material is stable under all conditions of use and storage. |
| <i>Conditions to avoid:</i> | None. |
| <i>Materials to avoid:</i> | Gels and generates heat when mixed with acid. May react with ammonium salts resulting in evolution of ammonia gas. Flammable hydrogen gas may be produced on contact with aluminum, tin, lead, and zinc. |
| <i>Hazardous decomposition products:</i> | Hydrogen. |

11. TOXICOLOGICAL INFORMATION

| | |
|-------------------------|--|
| <i>Acute Data:</i> | <p>When tested for eye and skin irritation potential, a similar material caused moderate irritation to the eyes and moderate irritation to the skin. Human experience indicates that skin irritation occurs, particularly, when sodium silicates get on clothes at the collar, cuffs or other areas where contact and abrasion may occur.</p> <p>The acute oral toxicity of this product has not been tested. When sodium silicates were tested on a 100% solids basis, their single dose acute oral LD₅₀ in rats ranged from 1500 mg/kg to 3200 mg/kg. The acute oral lethality resulted from nonspecific causes. This product contains approximately 37.5% sodium silicate.</p> |
| <i>Subchronic Data:</i> | <p>In a study of rats fed sodium silicate in drinking water for three months, at 200, 600 and 1800 ppm, changes were reported in the blood chemistry of some animals, but no specific changes to the organs of the animals due to sodium silicate administration were observed in any of the dosage groups. Another study reported adverse effects to the kidneys of dogs fed sodium silicate in their diet at 2.4g/kg/day for 4 weeks, whereas rats fed</p> |

Special Studies:

the same dosage did not develop any treatment-related effects. Decreased numbers of births and survival to weaning was reported for rats fed sodium silicate in their drinking water at 600 and 1200 ppm. Sodium silicate was not mutagenic to the bacterium E. Coli when tested in a mutagenicity bioassay. There are no known reports of carcinogenicity of sodium silicates. Frequent ingestion over extended periods of time of gram quantities of silicates is associated with the formation kidney stones and other siliceous urinary calculi in humans. Sodium silicate is not listed by IARC, NTP or OSHA as a carcinogen.

12. ECOLOGICAL INFORMATION

Eco toxicity:

The following data is reported for sodium silicates on a 100% solids basis: A 96 hour median tolerance for fish (*Gambusia affinis*) of 2320 ppm; a 96 hour median tolerance for water fleas (*Daphnia magna*) of 247 ppm; a 96 hour median tolerance for snail eggs (*Lymnea*) of 632 ppm; and a 96 hour median tolerance for Amphipoda of 160 ppm. This product contains approximately 37.5% sodium silicate.

Environmental Fate:

This material is not persistent in aquatic systems, but its high pH when undiluted or unneutralized is acutely harmful to aquatic life. Diluted material rapidly depolymerizes to yield dissolved silica in a form that is indistinguishable from natural dissolved silica. It does not contribute to BOD. This material does not bioaccumulate except in species that use silica as a structural material such as diatoms and siliceous sponges. Where abnormally low natural silica concentrations exist (less than 0.1 ppm), dissolved silica may be a limiting nutrient for diatoms and a few other aquatic algal species. However, the addition of excess dissolved silica over the limiting concentration will not stimulate the growth of diatom populations; their growth rate is independent of silica concentration once the limiting concentration is exceeded. Neither silica nor sodium will appreciably bioconcentrate up the food chain.

Physical/Chemical:

Sinks and mixes with water. Only water will evaporate from this material.

13. DISPOSAL CONSIDERATIONS

Classification:

Disposed material is not a hazardous waste.

Disposal Method:

Dispose in accordance with federal, state and local regulations and permits.

14. TRANSPORT INFORMATION

DOT UN Status:

This material is not regulated hazardous material for transportation.

Trade Name: **N[®] Sodium Silicate Solution**
Date Prepared: **06/13/06**

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15. REGULATORY INFORMATION

| | |
|------------------------|--|
| <i>CERCLA:</i> | No CERCLA Reportable Quantity has been established for this material. |
| <i>SARA TITLE III:</i> | Not an Extremely Hazardous Substance under §302. Not a Toxic Chemical under §313. Hazard Categories under §§311/312: Acute |
| <i>TSCA:</i> | All ingredients of this material are listed on the TSCA inventory. |
| <i>FDA:</i> | The use of sodium silicate is authorized by FDA as a boiler water additive for the production of steam that will contact food pursuant to 21 CFR §173.310; as a component of zinc-silicon dioxide matrix coatings on food contact surfaces pursuant to 21 CFR §175.390(c); as a GRAS substance when migrating from cotton fabric used in dry food packaging pursuant to 21 CFR §182.70; and as a GRAS substance when migrating to food from paper and paperboard products pursuant to 21 CFR §182.90. |

16. OTHER INFORMATION

Prepared by: **John G. Blumberg**
Supersedes revision of: **03/28/06**

THE INFORMATION ON THIS SAFETY DATA SHEET IS BELIEVED TO BE ACCURATE AND IT IS THE BEST INFORMATION AVAILABLE TO PQ CORPORATION THIS DOCUMENT IS INTENDED ONLY AS A GUIDE TO THE APPROPRIATE PRECAUTIONS FOR HANDLING A CHEMICAL BY A PERSON TRAINED IN CHEMICAL HANDLING. PQ CORPORATION MAKES NO WARRANTY OF MERCHANTABILITY OR ANY OTHER WARRANTY, EXPRESS OR IMPLIED WITH RESPECT TO SUCH INFORMATION OR THE PRODUCT TO WHICH IT RELATES, AND WE ASSUME NO LIABILITY RESULTING FROM THE USE OR HANDLING OF THE PRODUCT TO WHICH THIS SAFETY DATA SHEET RELATES. USERS AND HANDLERS OF THIS PRODUCT SHOULD MAKE THEIR OWN INVESTIGATIONS TO DETERMINE THE SUITABILITY OF THE INFORMATION PROVIDED HEREIN FOR THEIR OWN PURPOSES.

CERTIFICATE



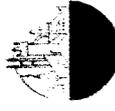
COIMBATORE INSTITUTE OF TECHNOLOGY

COIMBATORE, TAMILNADU, INDIA

DEPARTMENT OF CIVIL ENGINEERING

International Conference on

**INNOVATIVE AND SMART STRUCTURAL SYSTEMS
FOR SUSTAINABLE HABITAT (INSHAB 2008)**



INSHAB 2008

CERTIFICATE

This is to certify that Prof./Dr/Mr/Ms**ANIL P. JOSE**.....

..... has participated/presented a paper in the International Conference on

INNOVATIVE AND SMART STRUCTURAL SYSTEMS FOR SUSTAINABLE HABITAT (INSHAB 2008)

during 3rd,4th & 5th January 2008.

Title of the paper.....**DEVELOPMENT OF FLY ASH BASED FIBRE REINFORCED GEOPOLYMER CONCRETE**

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