UGC MAJOR RESEARCH PROJECT

DEVELOPMENT OF GEOPOLYMER CONCRETE AND TESTING OF ELEMENTS

FINAL PROJECT REPORT

Submitted by

PRINCIPAL INVESTIGATOR

Dr. S.THIRUGNANASAMBANDAM
Professor

DEPARTMENT OF CIVIL & STRUCTURAL ENGINEERING

ANNAMALAI UNIVERSITY

FACULTY OF ENGINEERING AND TECHNOLOGY
ANNAMALAI NAGAR

2015 - 2018

FINAL REPORT OF THE WORK DONE ON THE MAJOR PROJECT SUBMITTED TO UGC

1)	Project report	: Final
2)	UGC reference	: No. 43-265/2014(SR), dated 22.08.2015
3)	Period of report	: 01.07.2015 to 30.06.2018
4)	Title of the Project	: Development of Fly Ash Based Geopolymer Concrete and Testing Elements
5)	(a) Name of the Principal Investigator	: Dr. S. Thirugnanasambandam
	(b) Department and University	: Department of Civil and Structural Engineering, Annamalai University.
6)	Effective date of starting the project	: 01.07.2015
7)	Grant approved and expenditure incurred during the period of report:	
	(a) Total amount approved	: Rs. 6, 75, 000/-
	(b) Total Expenditure	: Rs. 6, 74, 422/- Balance amount Rs. 578/-
8)	Report of the work done	: Enclosed

Report of the work done:

a) Brief Objectives of the project

The objectives of the project are:

i) To develop different grades of Geopolymer concrete using fly ash, sand, coarse aggregate and alkaline solution.

ii) To determine the short term mechanical properties of Geopolymer concrete viz. strength characteristics and elastic modulus,

iii) To establish the durability characteristics for different exposure conditions and assessment of geopolymer concrete against current durability performance criteria.

iv) To cast Geopolymer concrete beams, pre-stressed concrete beams, sleepers.

Work done so far and results achieved and publications, resulting from the work

b) Year wise plan of work:

Year	Work Done so far
I	1.Literature Survey 2.Preliminary Studies: ❖ Identification of source material, alkaline solutions, and other ingredients. ❖ Determining the material characterization of ingredients, such as particle size, LoI, and chemical composition, 3. Development of Geopolymer concrete formulation with Different curing methods.
II	1. Mix design for Geopolymer Concrete 2. Casting and testing of Geopolymer Concrete with different grades. 3. Studies on short-term and long-term mechanical properties, 4. Studies on durability characteristics, 3. Development of geopolymer concrete elements
III	1. Development of geopolymer concrete products like sleepers, Ferrogeopolymer slabs, domes, pipes, beams, channels. 2. Testing of Geopolymer elements in the laboratory. 3. Submission of Journal Papers form these results. 4. Preparation and Submission of Report

CHAPTER 1

INTRODUCTION

Project Title:

DEVELOPMENT OF GEOPOLYMER CONCRETE AND TESTING OF ELEMENTS

• Origin of the research problem

Concrete made with Portland cement is the most widely used material on earth. The concrete industry is the largest user of natural resources in the world. Significant increases in cement production have been observed and are anticipated to increase due to the massive increase in infrastructure and industrialization in India. The emissions generated by Portland cement productions are principal contributors to the greenhouse gas (GHG) effect. For instance, the production of Portland cement for concrete accounts for an estimated 5 percent of global anthropogenic carbon dioxide. Recent estimates of the emissions from cement production reveals that 377 million metric tons of carbon was generated in 2007; this indicates that emissions have more than the doubled since the mid 1970s from fossil-fuel burning and cement production. Whilst measures may be undertaken to reduce the generation of carbon dioxide from cement kilns, carbon dioxide emission is still in the order of 600 kg of carbon dioxide per ton of cement of which 400 kg per tone is the result of the calcination of limestone.

In view of the serious impact of carbon dioxide on the environment and the continued anticipated growth of industrialization and urbanization, there is a need to redirect the building industry away from its overwhelming reliance on Portland cement by developing alternative binder systems. The two options which have attracted attention as alternative binders are (i) the partial replacement of cement by industrial byproducts like fly ash and slag and (ii) the use of geopolymer binders. The first alternative has been widely researched and abundant information on the fresh and hardened properties of concrete with partial replacement of cement has led to the use of such blended cements. The second alternative, geopolymer binders, is an emerging area of technology. **Davidovits** first proposed that an alkaline liquid could be used to react with the silicon (Si) and aluminum (Al) in a source material of geological origin or in by-product materials such as fly ash and rice husk ash to produce cementitious binders. Because the chemical reactions that takes place in this case is a polymerization process and the source materials are of geological origin, he coined the term 'geopolymer' to represent these binders. Geopolymers are members of the family of inorganic polymers. The polymerization process involves a substantially fast chemical reaction under alkaline condition on Si-Al minerals that result in a three-dimensional polymeric chain and ring structure consisting of Si-O-Al-O bonds. According to Davidovits, geopolymers have a wide range of applications determined by the chemical structure in terms of the atomic ratio Si: Al.

Review of Research and Development in the Subject:

- **International status**

Lloyd and Rangan conducted a study on geopolymer concrete with fly ash. For their study, they used low calcium (ASTM Class F) fly ash as their base material. The observations are made withthe effect of water – geopolymer solids. They concluded that geopolymer possess excellent properties and is well suited to manufacture precast concrete products that are needed in rehabilitation and retrofitting of structures after disaster. The price of fly ash based geopolymer concrete is estimated about 10 to 30percent cheaper than Portland cement concrete.Heat-cured low-calcium fly ash-based geopolymer concrete offers several economic benefits over Portland cement concrete.

Vijaya Rangan, Djwantoro Hardjito studied fly ash based Geopolymer Concrete. The material used waslow calcium ASTM class F dry fly ash obtained from power station. The calcium content of the fly ash was about 2percent about by mass. They observed the compressive strength datas and they concluded that fly ash geopolymer concrete has good compressive strength and is suitable for structural application. The fly ash based geopolymer concrete also showed excellent resistance to sulphate attack and the elastic properties of hardened concrete and the behaviour and the strength of reinforced structural members are similar to the Portland cement concrete.

Djwantoro Hardjito et al discussed on the development of fly ash based geopolymer concrete. The fresh geopolymer concrete was easily handled upto 120 minutes without any sign of setting. The addition of high range water reducing admixture improved the workability of concrete. They concluded that higher concentration of sodium hydroxide solution and curing temperature in the range of 30ºc to 90ºc results in a higher compressive strength of geo polymer concrete.

Fernandez et al carried out work in microstructure development of alkali activated fly ash cement. The study was conducted on class F fly ash with the following composition, SiO_2=53.09percent, Al_2O_3=24.8percent, Fe_2O_3=8.01percent, CaO=2.24percent.Ash was mixed with 8M solution of NaoH. The paste obtained was cured at 85°C for 5 hours. It was concluded that, when flyash is activated with alkaline solution, the interaction between the particles increased and thus results in good compaction.

Kunalkupwade – patil and Erez Allouche conducted test on the effect of alkali silica reaction in Geopolymer concrete. In their study, alkali silica reaction occurs due to chemical reactions between hydroxyl ions in the pore water within the concrete matrix and certain forms of silica.

- **National Status**

A very few works have been carried out in India since the quality and chemical composition of coal varies with the geological region of formation of coal, the chemical composition of fly ash also varies.

- **Significance of the study**

In this technology, **100% cement is replaced by fly ash** with alkaline solution. Low calcium Fly ash is a by-product from the coal industry, which is widely available in the world. Fly ash is rich in silicate and alumina, hence it reacts with alkaline solution to produce alumina silicate gel that binds, the aggregate to produce a good concrete.

CHAPTER 2
M 20 GRADE GEOPOLYMER CONCRETE

1.0 GENERAL

The experimental test program consisting of casting and testing of concrete cube specimens (150mm x 150mm x 150mm) and geopolymer concrete cube specimens (100mm x 100mm x 100mm) are made to determine the compressive strength for cubes. The specimens are cast using **M20 grade concrete** and ordinary Portland cement 53 Grade, natural river sand and the crushed stone of maximum size 20 mm were used. Each three numbers of specimens are made to take the average value for every curing period of 7 and 28 days.

2.0 MATERIALS USED AND THEIR PROPERTIES

2.1 Cement

Ordinary Portland cement of 53 grades, available in market was used in the investigation. The cement used for all tests is from the same batch. The cement has been tested for various properties as per IS: 4031-1988 and found to be confirming to various specifications of IS: 12269-1987.

Specific Gravity of Cement= 3.15

2.2 Coarse Aggregate

Crushed stone aggregates (locally available) of 20mm are used throughout the experimental study. The coarse aggregate should be in Saturated Surface Dry (SSD) condition. The cleaned coarse aggregates are chosen.

Specific Gravity of Fine Aggregate = 2.71

2.3 Fine Aggregate

The locally available river sand was used as a fine aggregate in the present investigation. The fine aggregate was tested for various properties such as specific gravity, sieve analysis, fineness modulus etc. in accordance with IS: 2386-1963. The size of sieves used for the purpose of grain size distribution analysis ranges from 4.75mm to 75µ and pan at the bottom. The sieve analysis helps to determine the zone, to which, the fine aggregate belongs to. The specific gravity test is used to determine the Quality and the eligibility of the material to be used for the concrete mix.

Specific Gravity of Fine Aggregate = 2.69

The fineness modulus of fine aggregate is 2.57. The grading zone obtained for fine aggregate is zone III and it is suitable for making concrete.

2.4 Fly Ash and GGBS

Class F (low-calcium) dry fly ash conforming to IS 3812-2003 obtained from Mettur Power Station of Tamilnadu from southern part of India was made use of in this casting of the specimens. The fly ash (Figure 1a) should be rich in aluminium and silicon. The fly ash is more finer than cement. It reduces the porosity of the concrete and increases the specific surface area. Since it is a pozzolanic material, the heat of hydration will be less. It will reduce the amount of initial cracks developed in a concrete comparatively.

Fig.1a Fly Ash

Specific gravity of Fly Ash= 2.41

GGBS is a partial replacement of fly ash for the Geopolymer concrete. It increases the engineering proprieties of the material. GGBS is shown in Fig.1b. GGBS is a byproduct from iron. The blast furnaces used to make iron. Test operates at a temperature of about $1500\,^{\circ}C$. The iron ore is reduced to iron and remaining materials from slag. The use of GGBS for concrete material contributes to the saving the natural resources and energy in cement manufacturing process and to reducing CO_2 emissions and environment impact.

Fig. 1b GGBS

2.5 Sodium Silicate

Sodium silicate is also known as water glass or liquid glass, available in liquid (gel) form. In present investigation sodium silicate 20 is used. The figure of sodium silicate with its components is shown in Figure 2. The components of sodium silicate used are given in Table 1.

Fig. 2 Sodium Silicate

Table 1 Specifications of Sodium Silicate*

Chemical formula	Na_2O X SiO_2(colourless)
Na_2O	15.9%
SiO_2	31.4%
H_2O	52.7%
Appearance	Liquid(gel)
Colour	Light yellow liquid(gel)
Boiling point	102^0C for 40% aqueous solution
Molecular weight	184.04
Specific gravity	1.6

*** supplied by the manufacturer**

The alkaline solution prepared is shown in the Figure 3.

Fig. 3 Alkaline solution

2.6 Sodium Hydroxide

Generally, sodium hydroxides are available in solid state by means of pellets and flakes. The cost of the sodium hydroxide is mainly varied according to the purity of the substance. For an economical geo-polymer concrete, it is recommended to use the lowest cost possible i.e. up to 94% to 96% purity. In this investigation the sodium hydroxide pellets of 8 molar concentrations were used (Figure 4). The properties of sodium hydroxide are given in Table 2.

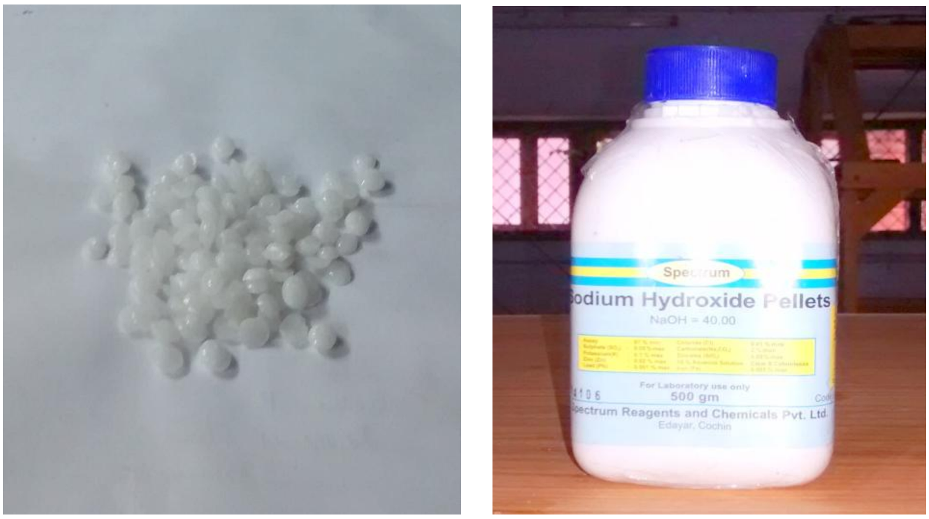


Fig. 4 Sodium Hydroxide

Table 2 Properties of Sodium Hydroxide

COMPONENTS	**CONCENTRATION**	**RANGE**
Assay	97%	MIN
Na_2CO_3	2%	MAX
Chloride(Cl)	0.01%	MAX
Sulphate(SO_2)	0.05%	MAX
Lead (Pb)	0.001%	MAX
Iron(Fe)	0.001%	MAX
Potassium(k)	0.1%	MAX
Zinc(Zn)	0.02%	MAX

2.7 Water

Fresh and clean water is used for casting the specimens in the present study. The water is relatively free from organic matter, silt, sugar, oil, chloride and acidic matter as per Indian standard.

3.0 MIX DESIGN

Mix design can be defined as the process of selecting suitable ingredients of concrete such as cement, aggregate, water, ground granulated blast furnace slag, and determining their relative proportions with the object of producing concrete of required strength, workability and durability as economically as possible. The purpose of designing can be seen from the above definition. The first objective is to achieve the stipulated strength and durability. The second objective is to make the concrete in most economical manner. The grade of concrete used in the present investigation was M 20. The mix was designed using IS 10262-2009.

4.0 CASTING OF SPECIMENS

4.1 Conventional Cubes

Based on the Mix design for M 20 grade concrete, the concrete mix is prepared. Since it is M 20 grade, there is no need for addition of admixtures to improve the workability. The slump cone test is made for checking the workability of the mix. And the mix is placed inside the mould and proper damping with damping rod (Figure 5). The mould is left for 24 hours at room temperature and demoulded. The specimen is allowed to cure for 28 days in water and tested.

Fig. 5 Casting of Conventional Concrete Cubes

4.2 Geopolymer Cubes

The mix ratio derived from the M 20 grade conventional concrete is used for preparation of mix design for geopolymer concrete mix. The materials used are fly ash, sodium silicate, sodium hydroxide, aggregates and water. The alkaline solution is obtained by mixing sodium hydroxide and sodium silicate as shown in Figure 6. The mixed solution is kept for one day and used for making geopolymer concrete. The Moulds of cubes of size 100mm x100mm x 100mm are used. The prepared concrete mix is poured inside the mould (Figure 6) vibrated on vibrating table. The Mould is kept in ambient curing for seven days.

a. Activator Solution Raw materials

b.Mixing of NaOH Pellets with Water

c.Mixing of NaOH & Na_2SiO_3

d.Mixing of Raw Materials in Pan Mixer

e.Geopolymer Concrete in Moulds

Fig. 6 Casting of Geopolymer Concrete Cubes

4.3 COMPRESSIVE STRENGTH TEST

In the case of cubes, the specimen is placed in the machines such a manner that the load is applied to opposite sides of the cubes as cast. The axis of the specimen is carefully aligned with the centre of thrust of the spherically seated plate. No packaging is used between the face of the test specimens and the steel plate of the testing machine. A spherically seated block is brought to bear on the specimens; the movable portion is rotating gently by hand so that uniform seating may be obtained. The load applied without shock and increased continuously until the resistance of the specimen increasing load can be sustained. The maximum load to the specimens is then recorded. The strength of the cube is calculated by dividing the maximum load by the cross-sectional area of the cube i.e. the plane perpendicular to axis of the load (Figure 7). The same experimental pattern is applied for the geopolymer concrete cubes and the maximum load is noted. Their experimental values are compared to determine the suitability of geopolymer concrete in place of conventional concrete.

Fig. 7 Compressive Strength Test Set up

4.4 COMPRESSIVE STRENGTH OF CUBES

The concrete cube is demoulded after 24 hours. The compressive strength of both conventional concrete cubes (150mm x 150mm x 150mm) and geopolymer concrete cubes (100mm x 100mm x 100mm) are tested after respective days of curing. The compressive strength of these cubes after 7 days and 28 days of curing are given in following Table 3 and 4. The compressive strength of geopolymer cubes made of 100% fly ash and that of geopolymer cubes made of 50% fly ash and 50% GGBS are given in Tables 5 and 6.

Table 3 Compressive Strength of Control Concrete Cubes after 7 days

CUBE	WEIGHT in Kg	AREA in mm^2	LOAD in kN	STRENGTH in N/mm^2
1	8.475	22500	376	16.71
2	8.495	22500	388	17.24
3	8.339	22500	352	15.64

Average Compressive Strength = 16.53 N/mm^2

Table 4 Compressive Strength of Control Concrete Cubes after 28 days

CUBE	WEIGHT in kg	AREA in mm^2	LOAD in kN	STRENGTH in N/mm^2
1	8.632	22500	651	28.9
2	8.731	22500	693	30.8
3	8.362	22500	629	27.9

Average Compressive Strength = 29.2 N/mm^2

Table 5 Compressive Strength of Geopolymer Concrete Cubes (100% FLY ASH)

CUBE	WEIGHT in kg	AREA in mm^2	LOAD in kN	STRENGTH in N/mm^2
1	2.260	10000	124	12.4
2	2.155	10000	186	18.6
3	2.140	10000	143	14.3

Average Compressive Strength = 15.1 N/mm^2

Table 6 Compressive Strength of Geopolymer Concrete Cubes (50% Fly ash + 50% GGBS)

CUBE	WEIGHT in kg	AREA in mm^2	LOAD in kN	STRENGTH in N/mm^2
1	2.260	10000	312	31.2
2	2.155	10000	295	29.5
3	2.140	10000	286	28.6

Average Compressive Strength = 29.77 N/mm^2

From the above results, GPC mix was fixed by using 50% GGBS and 50% fly ash

4.5 MODULUS OF ELASTICITY OF CONCRETE FOR CONTROL AND GPC SPECIMENS

The cylindrical specimens of size 150 mm diameter and 300 mm height are cast and tested. The testing of cylinder is shown in Figure 8.

Fig. 8 Test set up for Modulus of Elasticity for Concrete

The Modulus of Elasticity of Concrete for Control Specimens Theoretical value is 22360 N/mm^2 and the Experimental value of cement concrete is 23170 N/mm^2 and GPC concrete is 22745 N/mm^2. Modulus of Elasticity for control the concrete and GPC concrete is obtained from the graph as shown in Figure 9 and Figure 10 respectively.

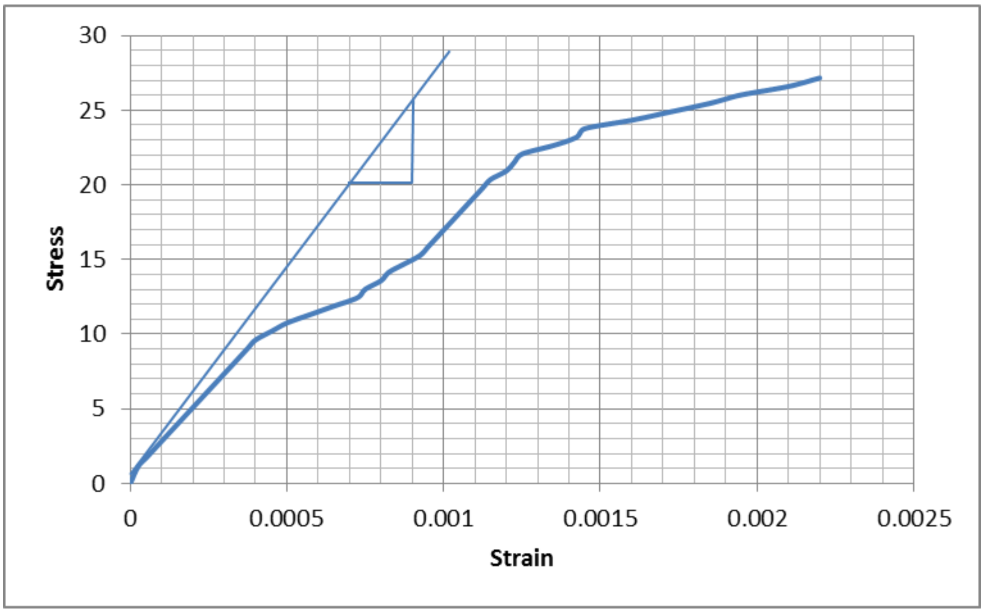


Fig. 9 Stress Strain Curve for Control Concrete Cylinder

Stress = 5.7 MPa ; Strain = 2.46 X 10^{-4} ; E = 23170 N/mm^2

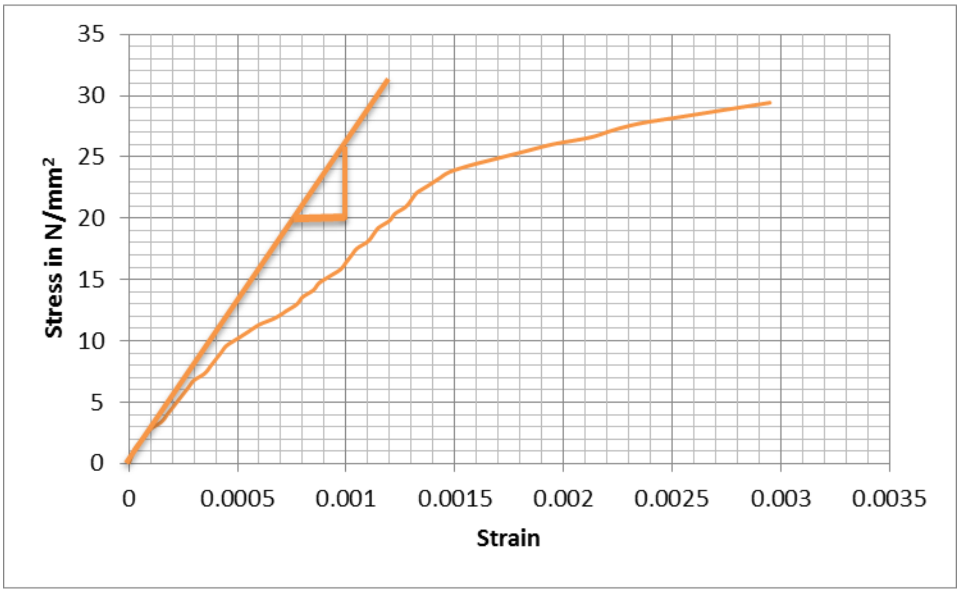


Fig.10 Stress Strain Curve for Geopolymer Concrete Cylinder

Stress = 5.8 MPa ; Strain = 2.55 X 10^{-4}; E = 22745 N/mm^2

4.6 MODULUS OF ELASTICITY FOR STEEL

The test for Modulus of elasticity of steel is conducted with the 12 mm dia steel rebar with a gauge length of 600mm. The test is conducted in the Universal Testing Machine (UTM). The test set up for modulus of elasticity for steel rod is shown in the Figure 11.

Fig. 11 Tension Test of Steel Rod

The test results were obtained. The load Vs displacement curves (Figure 12) and stress-strain curves for steel rod (Figure 13) is plotted. The yield stress for steel is 524.3 N/mm^2. The yield stress values are obtained from the graph as shown in the Figure 13.

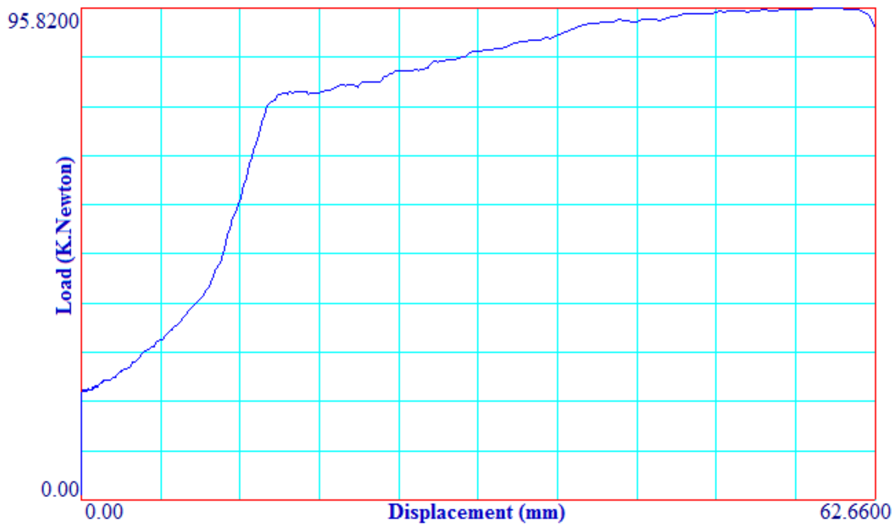


Fig.12 Load Vs Displacement Curve for Steel Rod

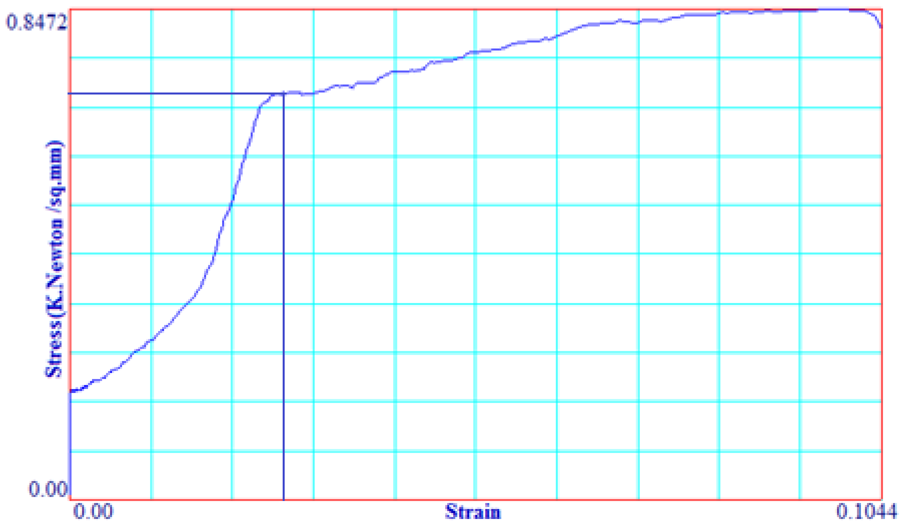


Fig.13 Stress Strain Curve for Steel Rod

4.7 BEHAVIOUR OF BEAMS UNDER FLEXTURE

4.7.1 Casting and Curing of Beams

The test program consists of casting and testing of beams of size 125 mm wide, 250 mm deep and 3200 mm long. Control concrete beams for M 20 Grade and geopolymer concrete beams of same grade are cast. High yield strength deformed bars of 10, and 12 mm diameter are used as longitudinal reinforcement and 8 mm diameter mild steel two legged vertical stirrups are provided at 150 mm spacing as shear reinforcement in all the beams as shown in Figure 14. The reinforcement made of steel rebars is shown in Figure 15. Casting of specimen of specimen is shown in Figure 16.

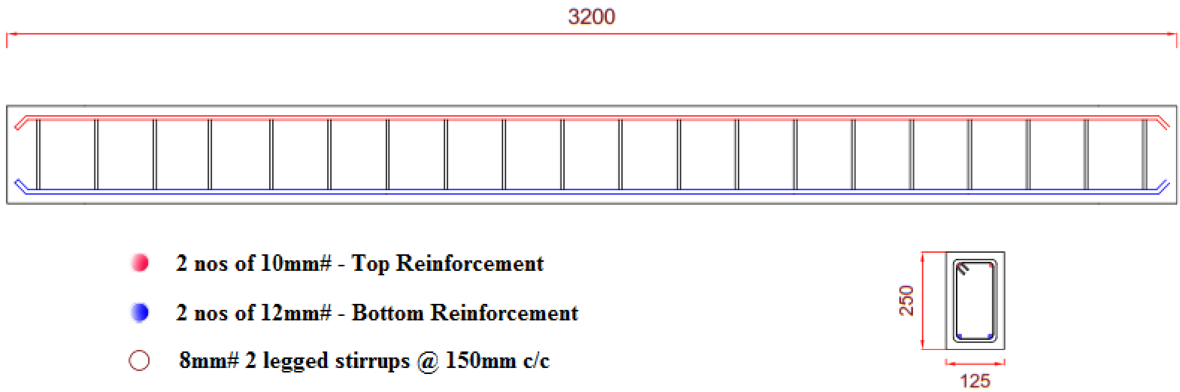


Figure 14 Reinforcement Details

Figure 15 Reinforcement Grill for Beams

Figure 16 Casting of Beams

4.7.2 TESTING OF BEAMS

4.7.2.1 Test Setup

The test setup for flexural test is shown in Figure 17. The test specimen is mounted in a beam testing frame of 300 kN capacity. The beams are simply supported over a span of 3000 mm, and subjected to two concentrated loads placed symmetrically on the span. The distance between the load points is 1000 mm. The load is applied on two points each 500 mm away from the center of the beam towards the support. Dial gauges of 0.001 mm least count is used for measuring the deflections under the load points and at mid span for measuring the deflection. The dial gauge readings are recorded at different loads. The strain in concrete is measured using a demec gauge. An automatic data acquisition unit is used to collect the data during test. The load is applied at intervals of 25 kN. The first crack loads are obtained by visual examination. The test set up for testing of beam is shown in Figure 17 and testing of beam is shown in Figure18.

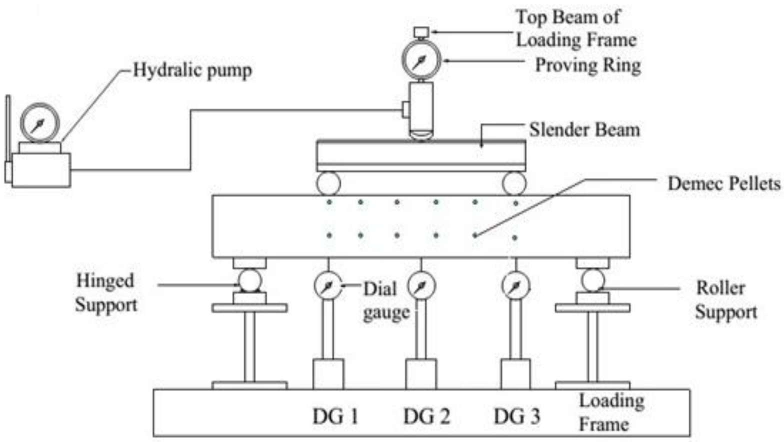


Figure 17 Test setup

Figure 18 Testing of Beam under Two Point Loading

4.7.2.2 Flexural Behaviour of Control Beams

The static behaviour of beams includes studying the structural behaviour aspects such as deflection, crack propagation and ultimate load carrying capacity of the beam under monotonic conditions. Hence the beams are tested monotonically with simply supported boundary conditions.

These beams are loaded up to failure and deflections are measured for a load increment of 2.5kN and these load deflection values are used as base values for other beams. The ultimate load of control beam was noted and be Pu. The load deflection curves obtained for the control of Control beam from the monotonic test is shown in Figure 19.

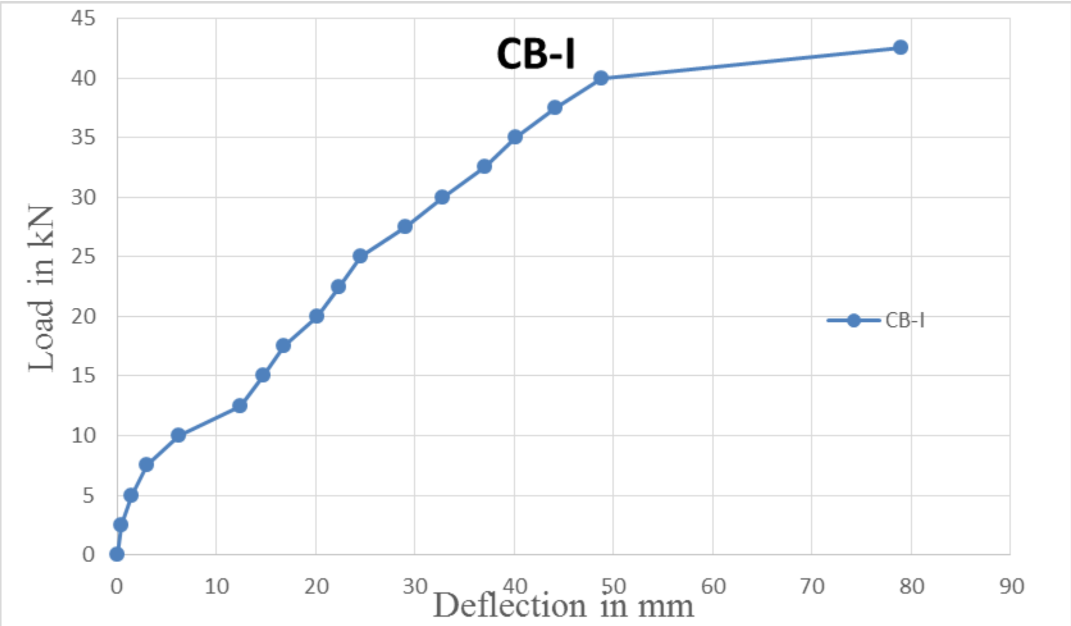


Figure 19 Load Deflection Behaviour of Control Beam

While testing the load deflection behaviour of control beams at initial stage of loading, the concrete behaves in a linear elastic manner. When the load increases, the extreme fibre stresses in bending increase up to the tensile strength of concrete and the first crack appears in the middle of constant bending moment region. Then several flexural cracks develop with the increasing of load on the beam. The tension steel reinforcement carries the maximum amount of bending moment and at the same time rotation of beams increases further causing increase in steel stress. Due to the stress in steel reaches yield value, the overall stiffness of beam gets reduced. Further, flexural cracks extend vertically upwards with increasing crack width. Then, cracks appear in the support reaction in inclined direction. The final failure of the beam takes place with increasing in deflection with constant ultimate load.

4.7.2.3 Flexural Behaviour of GPC Beams

Then, GPC beams with steel reinforcements were tested. All the GPC beams were tested as per the procedure explained earlier for the control beams. The experimental load deflection curves for GPC beams along with those of control beam is shown in Figure 20. When the load increases, the extreme fibre stresses in bending increase up to the tensile strength of concrete and the first crack appears in the middle of constant bending moment region. Then several flexural cracks develop with the increasing of load on the beam. The tension steel reinforcement carries the maximum amount of bending moment and at the same time rotation of beams increases further causing increase in steel stress. The final failure of the beam takes place with increasing in deflection with constant ultimate load.

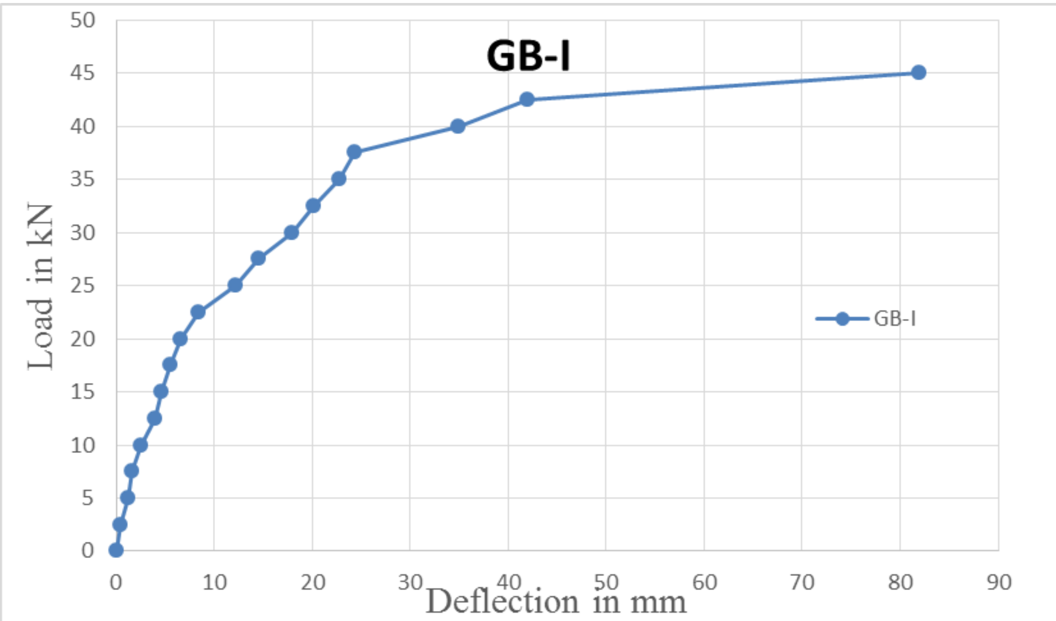


Figure 20 Load Deflection Behaviour of GPC Beam

4.7.3 Cyclic Behaviour of Control and Geopolymer Beams

When the beam is given compressive cyclic loading, the behaviour of control beams and geopolymer beams are noted. The testing of beam under compressive cyclic loading is shown in the following Figure 21.

Figure 21 Test Setup for Beam Testing under Compression Cyclic Loading

The load deflection curve for control beam and GPC beam is shown Figures 22 and 23. The compression cyclic load is given at the increment of every 10kN. In the first cycle the load is applied upto 10 kN and released to zero and the next cycle the load is increased from zero to 20kN and released to zero. This incremental loading is applied upto failure of beam. The load increment and the corresponding deflections are automatically measured and recorded in the computer system as shown in Figures 22 and 23.

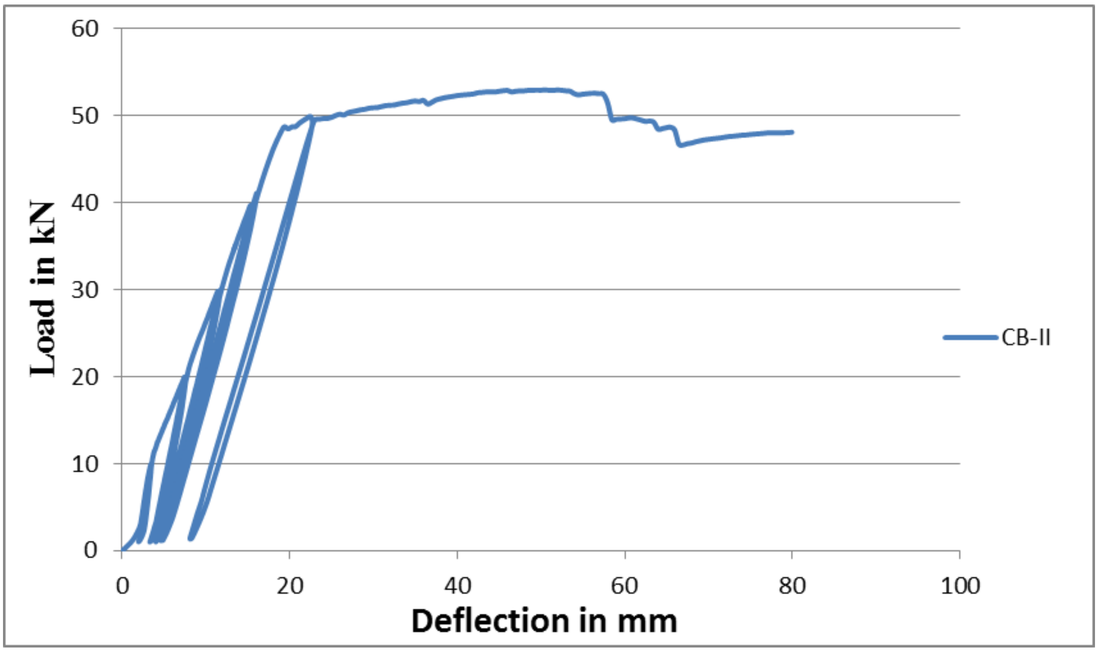


Figure 22 Load Deflection Behaviour of Control Beam under Cyclic Loading

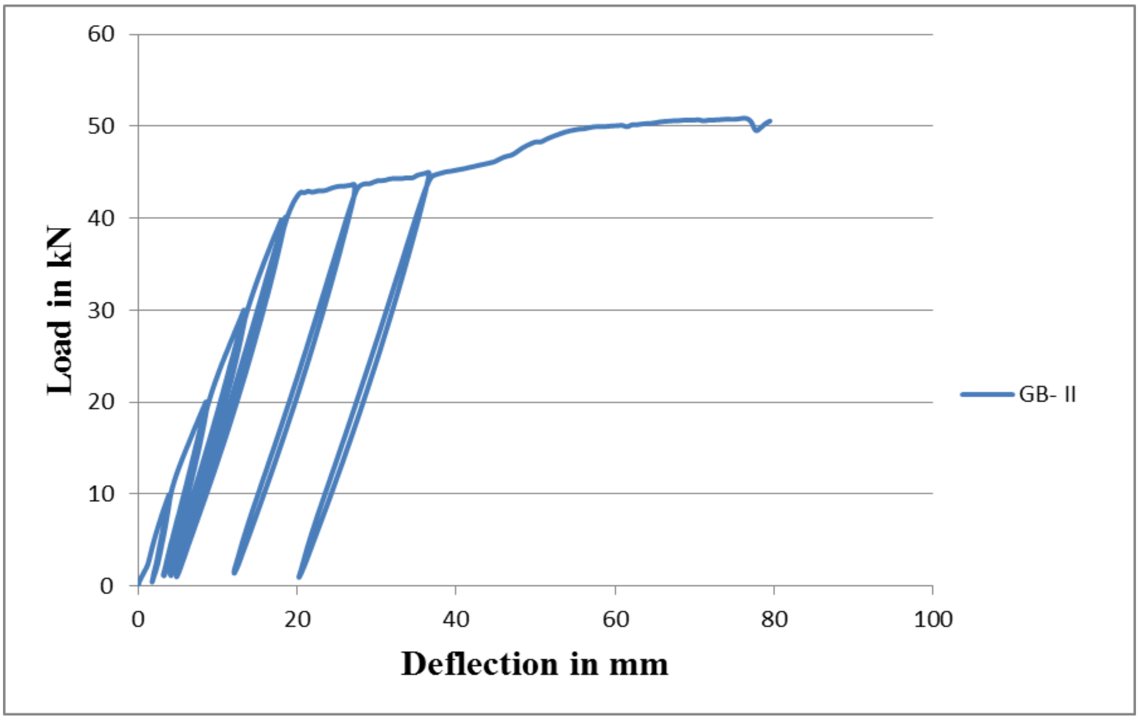


Figure 23 Load Deflection Behaviour of GPC Beam under Cyclic Loading

4.7.4 Crack Pattern and Failure Mode

The photographs of crashed concrete in control beam and geopolymer concrete beams under static and cyclic loading are shown in Figures 24 to 27.

Figure 24 Cracking Pattern of Control Beam Under Static loading

Figure 25 Cracking Pattern of Control beam Under Cyclic loading

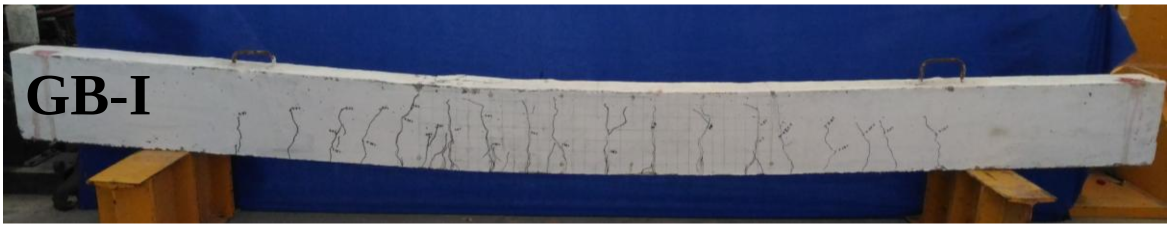


Figure 26 Cracking Pattern of GPC beam Under Static loading

Figure 27 Cracking Pattern of GPC beam Under Cyclic loading

The flexure cracks are initiated in the pure bending zone. As the load increases, existing cracks propagate and new cracks develop along the span. In the case of beams with larger tensile reinforcement ratio some of the flexural cracks in the shear span turn into inclined cracks due to the effect of shear force. The width and the spacing of cracks vary along the span. In all, the crack patterns observed for geopolymer concrete beams are similar to those reported in the control beams. The cracks at the mid-span open widely near failure. Near peak load, the beams deflected significantly, thus indicating that the tensile steel must have yielded at failure. The final failure of the beams occur when the concrete in the compression zone is crushed, accompanied by buckling of the compressive steel bars. The failure mode is typical of that of an under-reinforced concrete beam. During the test, the first crack patterns in the beams are measured using crack deflection microscope and the crack patterns are closely analyzed.

5.0 BEHAVIOUR OF BEAMS UNDER STATIC LOADING

The ratio of M20 grade of concrete is 1:1.67:3.01. The beams were cast and tested under two point Static and Cyclic loading. The comparison of test results for all beams under static loading is given in the Table 7.

Table 7 Static Loading of Beams at Different Stages

Sl. No.	Beam Designation	Load at Different Stage (kN)		
		First Crack	Yield	Ultimate
1	**CB-I**	10	25	42.5
2	**GB-I**	12.5	27.5	45

The deflection of beam specimens at different loads is given in the Table 8.

Table 8 Deflection of Beam Specimens at different Stages of Static Loading

Sl. No.	Beam Designation	Deflection at Different Stage (mm)		
		First Crack	Yield	Ultimate
1	**CB-I**	6.2	22.4	79
2	**GB-I**	4	24.6	82

6.0 BEHAVIOUR OF BEAMS UNDER CYCLIC LOADING

The test result of all beams under cyclic loading is given in the Table 9. The deflection of beam specimens at different loads is given in the Table 10.

Table 9 Cyclic Loading of Beams at Different Stages

Sl. No.	Beam Designation	Load at Different Stage (kN)	
		Yield	Ultimate
1	**CB-II**	48.73	52.5
2	**GB-II**	43.43	50.5

Table 10 Deflection of Beam Specimens at different Stages of Cyclic Loading

Sl. No.	Beam Designation	Deflection at Different Stage (mm)	
		Yield	Ultimate
1	**CB-II**	20.54	57.54
2	**GB-II**	36.28	77.08

7. CONCLUSIONS

1. Mix design for conventional concrete grade of M20 was carried out as per IS 10262:2009 and obtained as the ratio of 1:1.67:3.01 with w/c ratio 0.5. The concrete specimens were cured in water for 28 days. The compressive strength of conventional concrete was obtained as 29.2 N/mm^2.
2. The GPC was made with same mix ratio of conventional concrete with 100% replacement of cement by 50% each of fly ash and GGBS. The ratio of fly ash and GGBS to alkaline solution is 0.5. The GPC specimens were kept cured in ambient condition for five days. The GPC was cured in atmosphere temperature for seven days. The seventh day compressive strength of GPC is 29.76 N/mm^2.
3. The ultimate load carrying capacity of geopolymer concrete beam with steel rebars is 45 kN and the same in conventional concrete beam is 42.5 kN. Hence GPC beam takes 5.6% more load when compared with conventional beam. The geopolymer concrete beam with steel rebars was found an ultimate deflection of 82mm when compared to conventional concrete beam as 79mm.
4. The conventional concrete beam with steel rebars takes 52.5 kN at ultimate stage when compared to GPC beam with steel rebars of 50.5 kN under compression cyclic load. The GPC beam show a decrease of 3.8% load carrying capacity when it is subjected to cyclic loading.
5. The geopolymer concrete beam obtains a max deflection of 77.08 mm when compared to conventional concrete beam of 57.54 mm under cyclic loading and it is shown that geopolymer beam has more ductility when compared to conventional concrete beam.

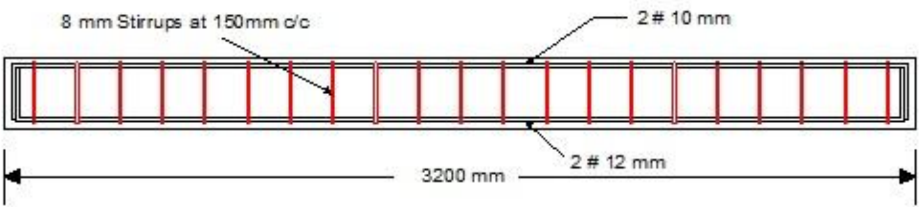
CHAPTER 3

M 40 GRADE GEOPOLYMER CONCRETE

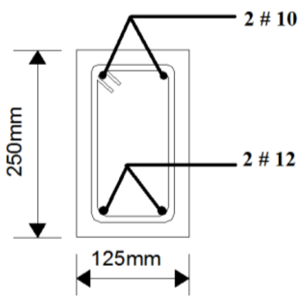
a) Reinforcement Grill

b) After casting of beam

Fig. 1 Casting of Conventional Concrete Beams



Longitudinal Section



Cross Section

Fig. 2 Beam Specimen Detaling

Fig. 3 Ambient curing of Geopolymer Concrete Beam

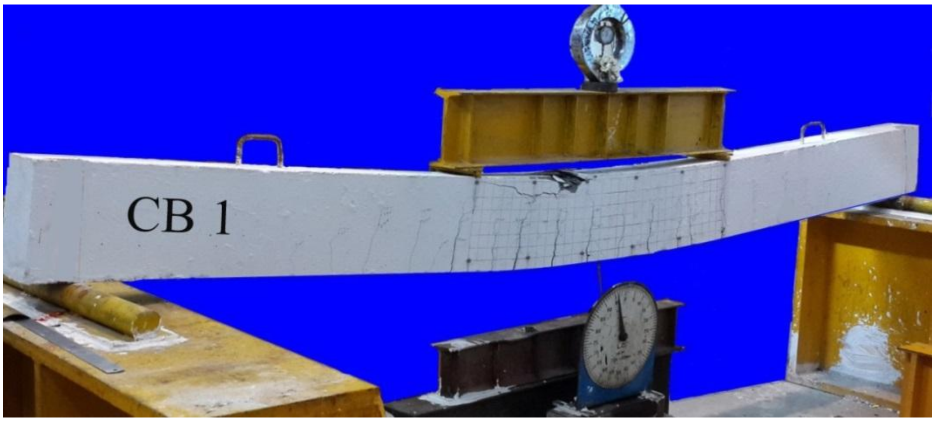


Fig. 4 Failure of Beam at Ultimate Load (CB1)

Fig. 5 Failure of Beam at Ultimate Load (GPC1)

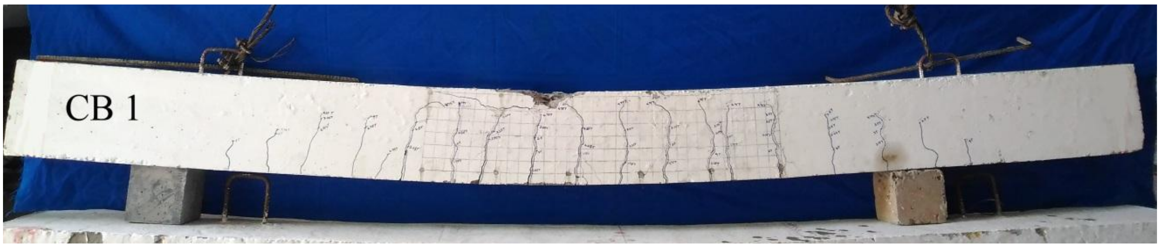


Fig. 6 Crack Pattern of CB1

Fig. 7 Crack Pattern of GPC1

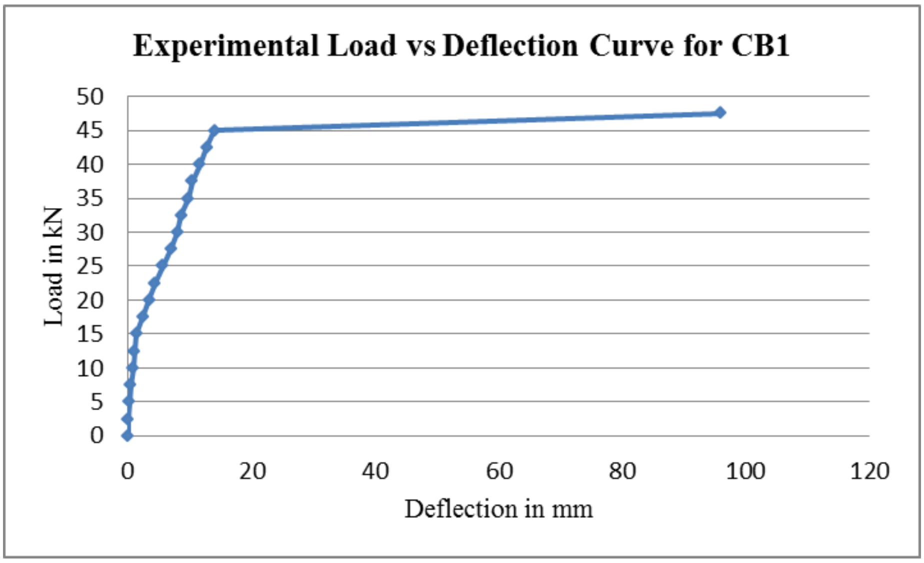


Fig. 8 Static Load vs Deflection for Conventional Concrete (CB1)

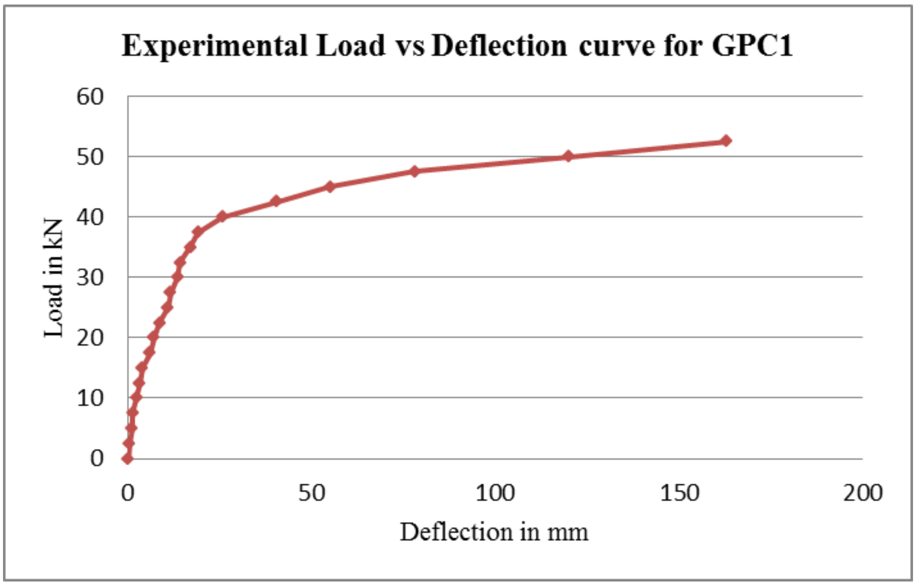


Fig. 9 Static load vs deflection for Geopolymer Concrete (GPC1)

Table 1 Static Flexure Test Results of Beams

Conventional Concrete Beam (CB1)				Geopolymer Concrete Beam (GPC1)			
First Crack Load in kN	Ultimate Deflection in mm	Yield load in kN	Ultimate Load in kN	First Crack Load in kN	Ultimate Deflection in mm	Yield load in kN	Ultimate Load in kN
17.5	96	45.3	47.5	10	163	42	52.5

Fig. 10 Failure of Beam at Ultimate Load (CB2)

Fig. 11 Failure of Beam at Ultimate Load (GPC2)

Fig. 12 Crack Pattern of CB2

Fig. 13 Crack Pattern of GPC2

Table 2 Experimental Results from Compression Cyclic test

Conventional Concrete Beam (CB2)				Geopolymer Concrete Beam (GPC2)			
First Crack Load in kN	**Ultimate Deflection in mm**	**Yield load in kN**	**Ultimate Load in kN**	**First Crack Load in kN**	**Ultimate Deflection in mm**	**Yield load in kN**	**Ultimate Load in kN**
15.5	79.7	36.8	45.48	16	79.85	37.3	41.49

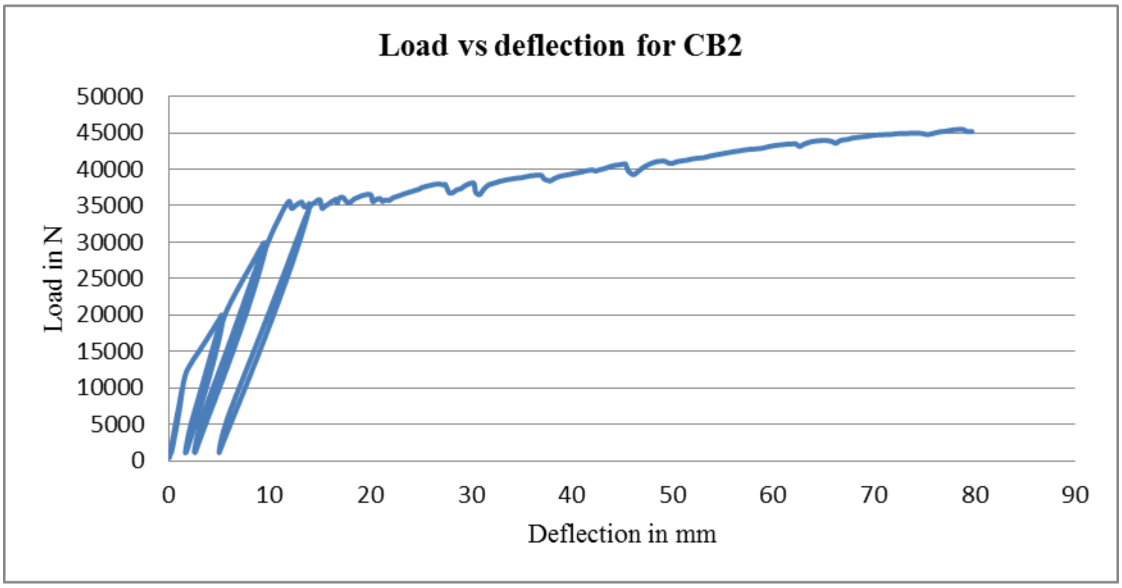


Fig. 14 Cyclic Load vs Deflection for Conventional Concrete

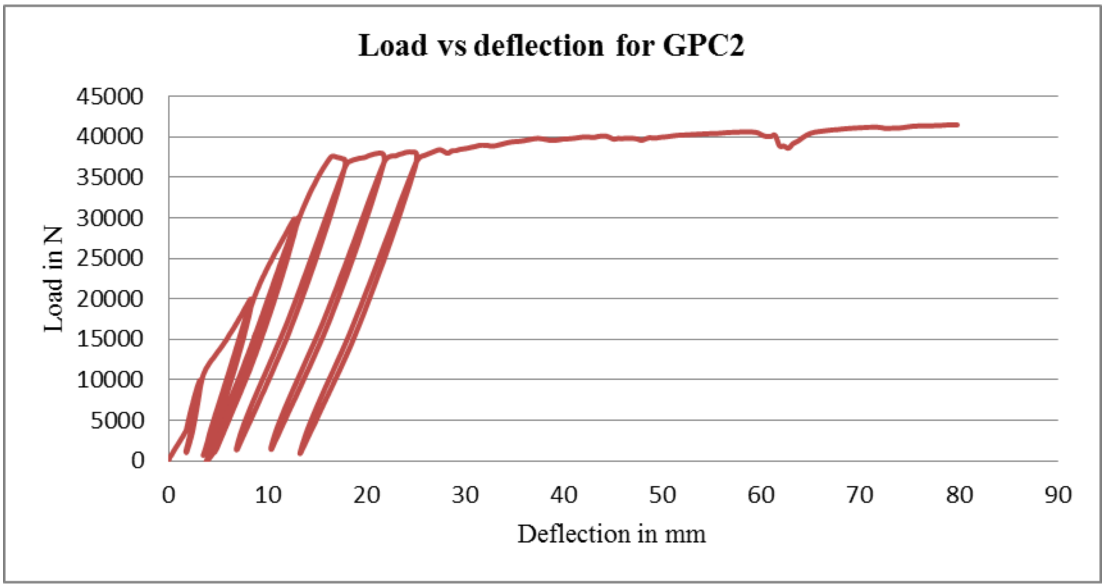


Fig. 15 Cyclic Load vs Deflection for Geopolymer Concrete

CONCLUSIONS:

Based on the experimental work, the following conclusions are drawn.

1. Mix design for conventional concrete grade of M40 was carried out as per IS 10262:2009 and obtained as the ratio of 1:1.83:2.19 with w/c ratio 0.38.the concrete specimens were cured in water for 28 days. The compressive strength of conventional concrete was obtained as 52.03 N/mm^2.
2. The GPC was made with same mix ratio of conventional concrete with 100% replacement of cement by 50% each of fly ash and GGBS. The ratio of fly ash and

GGBS to alkaline solution is 0.45.the GPC specimens were kept cured in ambient condition for five days. The compressive strength of GPC is 56.77 N/mm^2. The GPC was cured in atmosphere temperature for three days.

3. The ultimate load carrying capacity of geopolymer concrete beam is 52.5 kN and the same in conventional concrete beam is 47.5 kN. Hence GPC beam takes 9.5% more load when compared with conventional beam
4. The geopolymer concrete beam was found an ultimate deflection of 163 mm when compared to conventional concrete beam as 96mm, it is shown that geopolymer beam has more ductility when compared to conventional concrete beam.
5. The conventional concrete beam takes 45.48 kN at ultimate stage when compared to GPC beam of 41.49 kN under compression cyclic load. The GPC beam show a decrease of 9.6% load carrying capacity when it is subjected to cyclic loading.
6. The geopolymer concrete beam obtains a max deflection of 79.85 mm when compared to conventional concrete beam of 79.7 mm and it is shown that geopolymer beam has more ductility when compared to conventional concrete beam.
7. It is recommended that the GPC can be used for making RC beams for structural applications since it possess the same behaviour in flexure when compared to conventional concrete beams.

CHAPTER 4

M 60 GRADE GEOPOLYMER CONCRETE

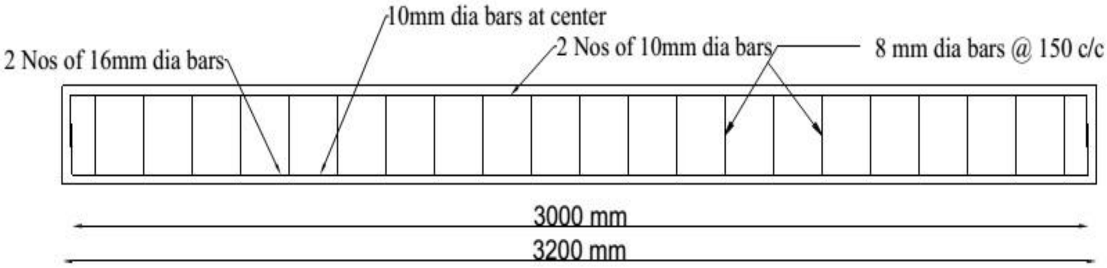


Fig. 1 Beam Specimen Detailing

Fig. 2 Casting of Conventional Concrete Cubes and Cylinders

Fig.3 Casting of Conventional Concrete Beams

Fig. 4 Casting of Geopolymer Concrete Beams

Fig.5 Failure of Beam at Ultimate Load CB1

Fig.6 Failure of Beam at Ultimate Load GB1

Fig.7 Crack Pattern of CB1

Fig.8 Crack Pattern of GB1

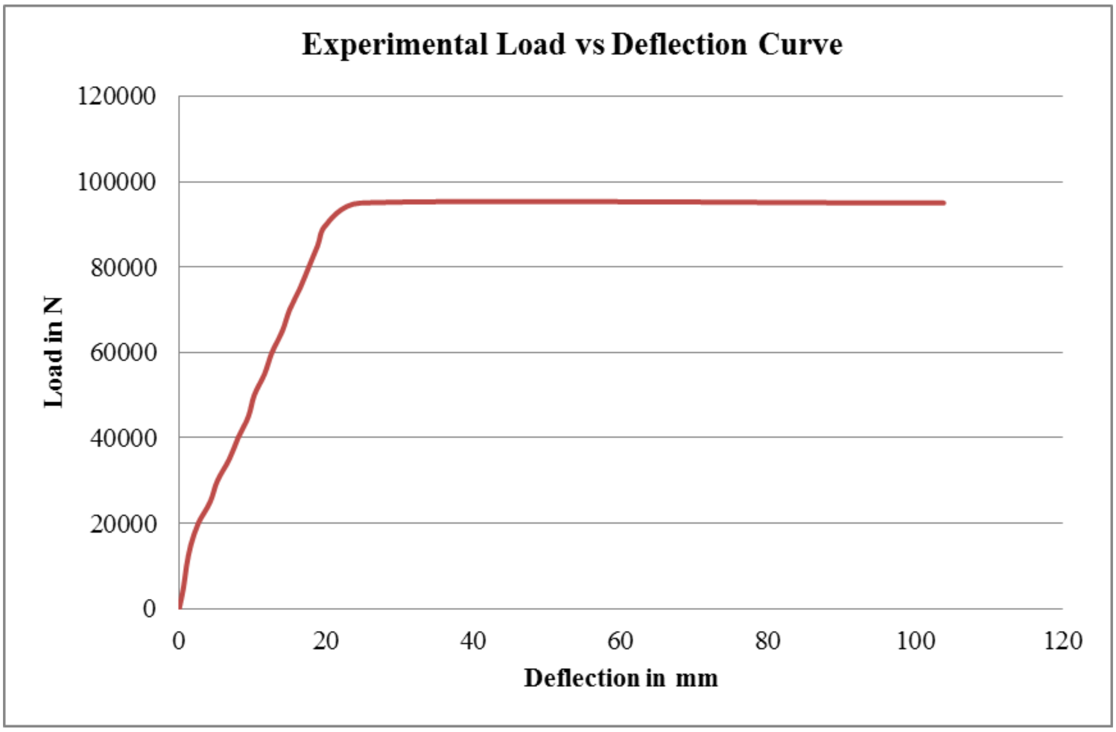


Fig.9 Static Load vs Deflection for CB1

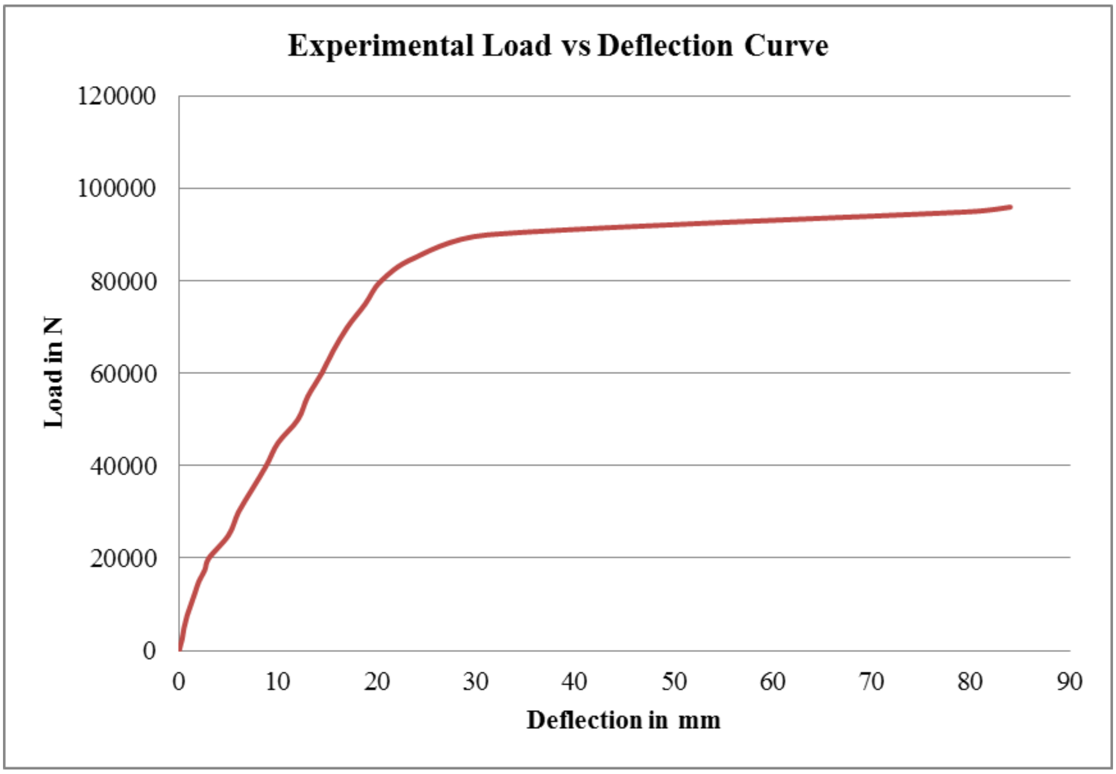


Fig.10 Static Load vs Deflection for GB1

Deflection Pattern under Cyclic Loading:

Fig.11 Failure of Beam at Ultimate Load CB2

Fig.12 Failure of Beam at Ultimate Load GB2

Crack Pattern

Fig.13 Crack pattern of CB2

Fig.14 Crack Pattern of GB2

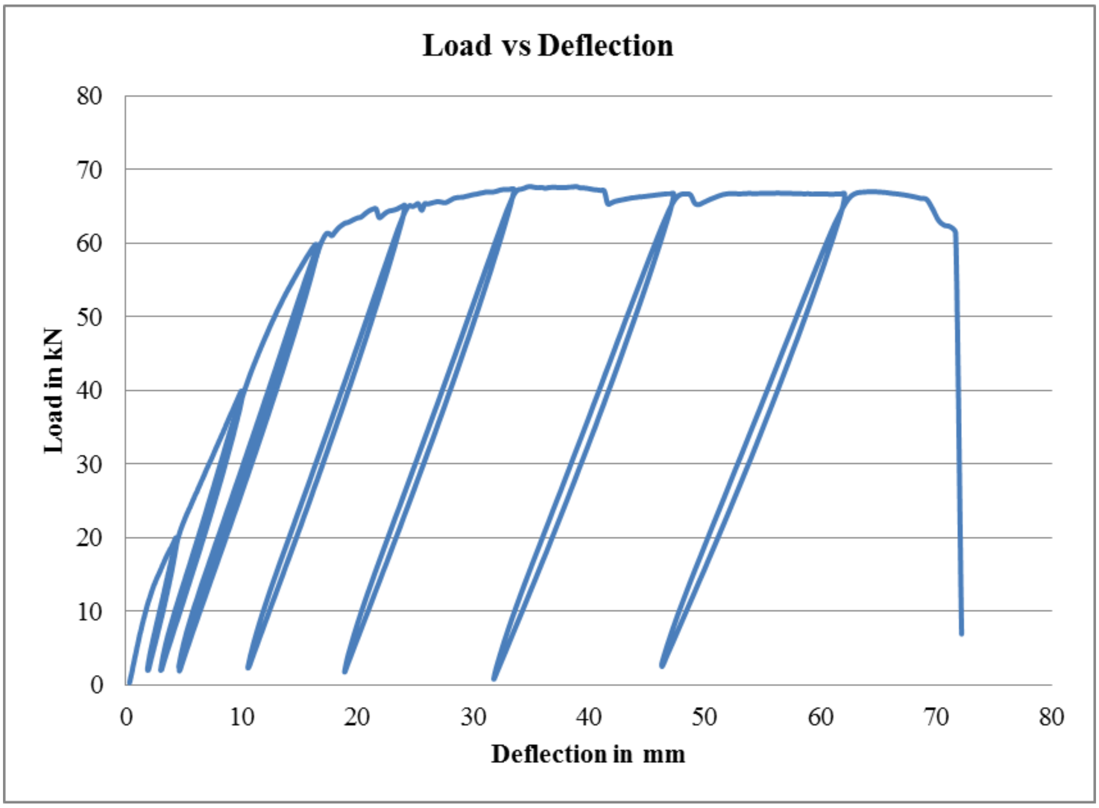


Fig.15 Compression Cyclic Load vs Deflection for CB2

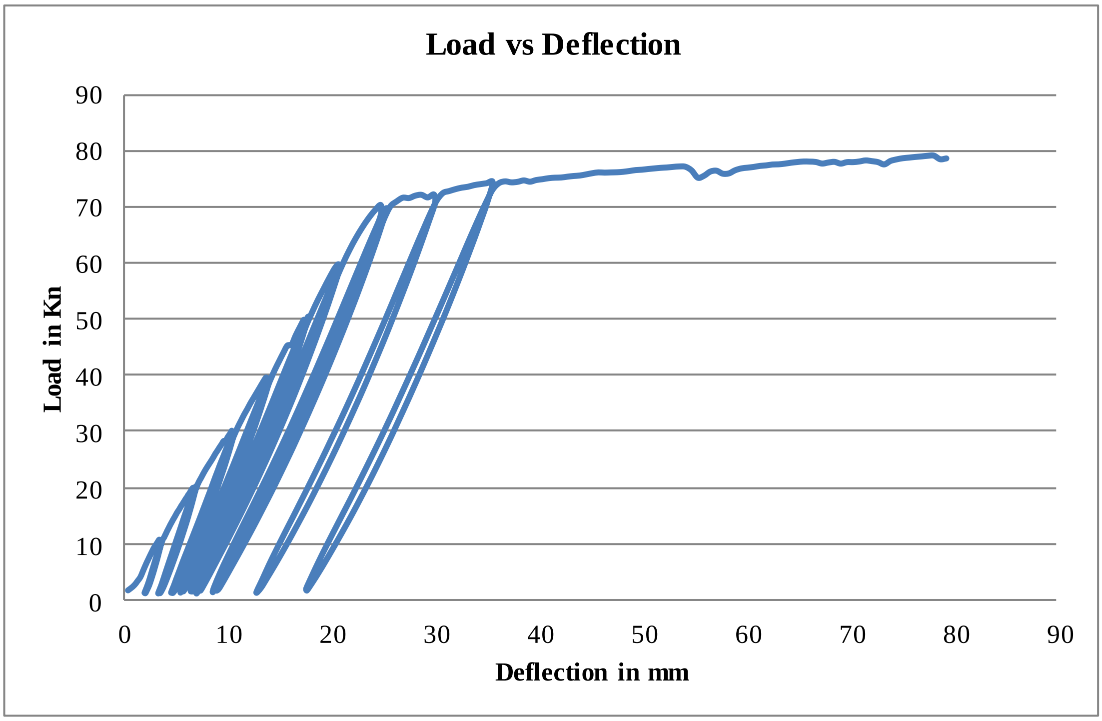


Fig.16 Compression Cyclic Load vs Deflection for GB2

CONCLUSIONS:

Based on the experimental work, the following conclusions are drawn.

1. Mix design for conventional concrete grade of M 60 was carried out as per ACI Code and obtained as the ratio of 1:1.36:1.75 with w/c ratio 0.30. The compressive strength of conventional concrete was obtained as 70.52 N/mm^2
2. The same mix ratio was adopted for GPC with 100% replacement of cement by 100% of GGBS. The ratio of GGBS to alkaline solution is 0.45. The compressive strength of GPC is found as 72.87 N/mm^2 . The GPC was cured in atmospheric temperature.
3. The ultimate load carrying capacity of geopolymer concrete beam is 96 kN and the same in conventional concrete beam is 95 kN.
4. The geopolymer concrete beam deflection of 85 mm when compared to conventional concrete beam of 104 mm and it is shown that geopolymer beam has more ductility when compared to conventional concrete beam.

CHAPTER 5

RAILWAY SLEEPERS

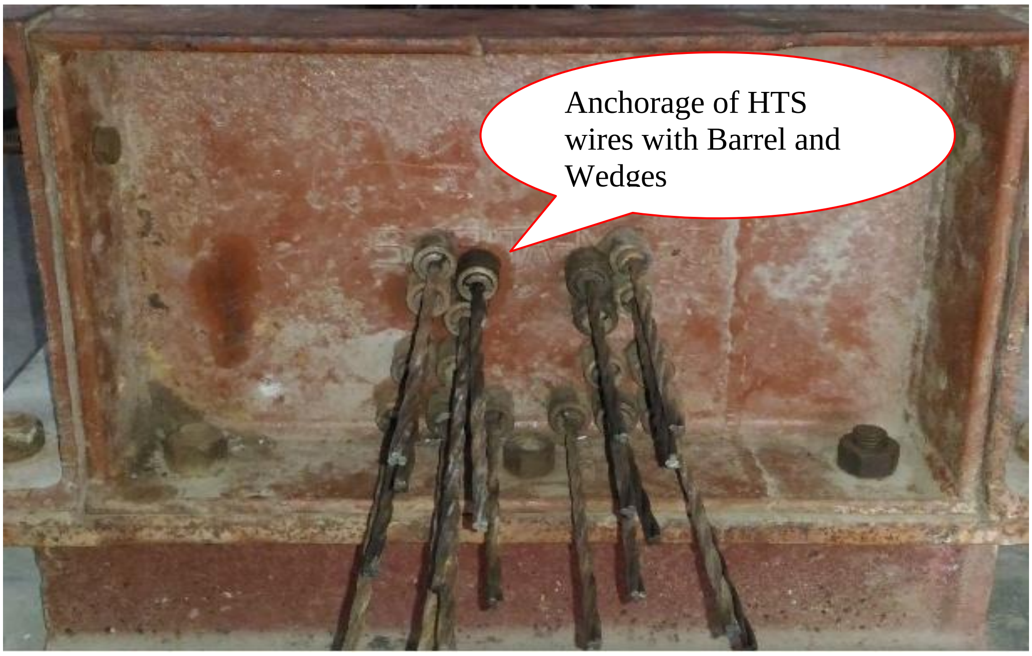


Fig.1 Anchored in HTS Strands with Barrels and Wedges

Fig.2 Pre tensioning of Strands

Fig. 3 Before pre tension of Strands

Fig.4 After pre tensioning of Strand

Fig.5 Casting of OPC Sleeper

Fig.6 De Tensioning of Strands

Fig.7 Curing of OPC Sleeper **Fig.8 Ambient curing of GPC Sleeper**

Fig.9 Experimental Setup of the Sleeper

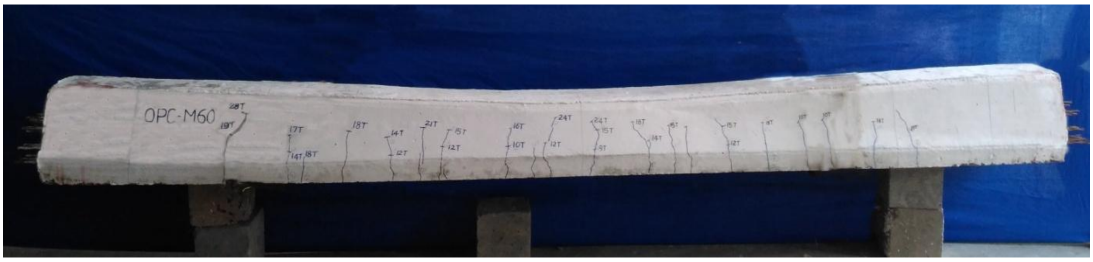


Fig.10 Crack pattern of OPC Sleeper

Fig.11 Crack pattern of GPC sleeper

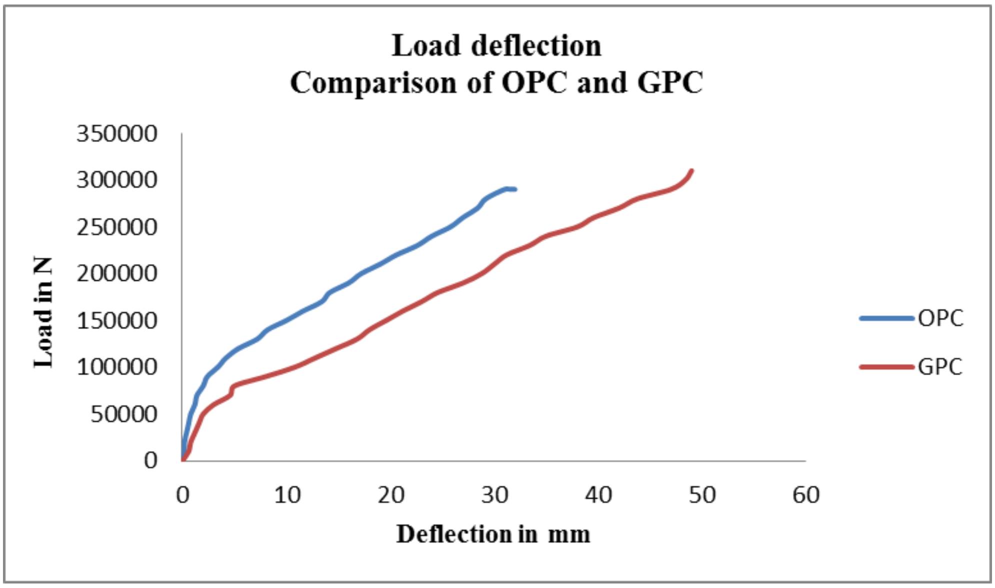


Fig.12 Comparison of load deflection curve for OPC and GPC

Table 1 Experimental Results

OPC				GPC			
First crack Load in kN	Yield Load in kN	Ultimate stage		First Crack Load in kN	Yield Load in kN	Ultimate stage	
		Load in kN	Deflection in mm			Load in kN	Deflection in mm
90	123	290	32	60	182	320	49

Table 2 Crack details of OPC and GPC

OPC		GPC	
Crack width	**Cracks**	**Crack width**	**Cracks**
12 mm	24	17 mm	27

CONCLUSIONS:

Based on the experimental investigations of prestressed conventional and GPC sleepers, the following conclusions are drawn:

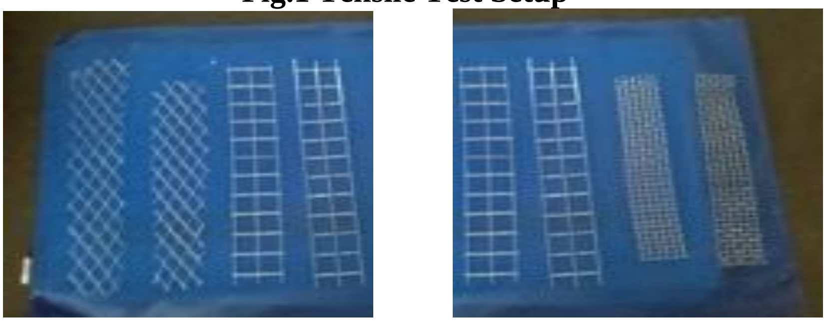
1. Sleepers were cast using conventional and GPC of grade M60. The conventional concrete compressive strength is 72.13 N/mm^2 and GPC compressive strength is 73.95 N/mm^2.
2. Both conventional and GPC sleepers are prestressed with 18 numbers of 6mm dia high tensioned strands having a yield stress of 2942 N/mm^2.
3. The conventional concrete of M60 grade pre stressed sleeper obtained the ultimate load of 290 kN.
4. The GPC of M60 grade prestressed sleeper obtained the ultimate load of 320 kN. the load carrying capacity increased by 10%.
5. At ultimate load level, 34% increase in deflection was observed in geopolymer pre tensioned concrete sleeper compared to conventional pre tensioned concrete sleeper.
6. The crack distribution and width are found increase in GPC pre tensioned concrete sleeper with respect to conventional pre tensioned concrete sleeper.
7. Ambient curing temperature (40°C) is found adequate for curing of GPC sleepers.
8. From the studies carried out on low calcium fly ash based geopolymer concrete, it is concluded that the geopolymer sleepers show an encouraging result in strength point of view.
9. From the experimental results, GPC sleepers perform well in all aspects when compared with conventional concrete.

CHAPTER 6

FERROGEOPOLYMER BOX BEAMS

TENSILE STRENGTH TEST

Fig.1 Tensile Test Setup



A: Welded and Expended Wire Mesh **B: Welded and Woven Wire Mesh**

Fig. 2 Types of Wire Meshes

Table 1 Tensile Strength of Wire Mesh

S.NO	TYPES OF WIRE MESH	TENSILE STRENGTH N/mm^2
1	Welded wire mesh	534
2	Woven wire mesh	261
3	Expended wire mesh	250

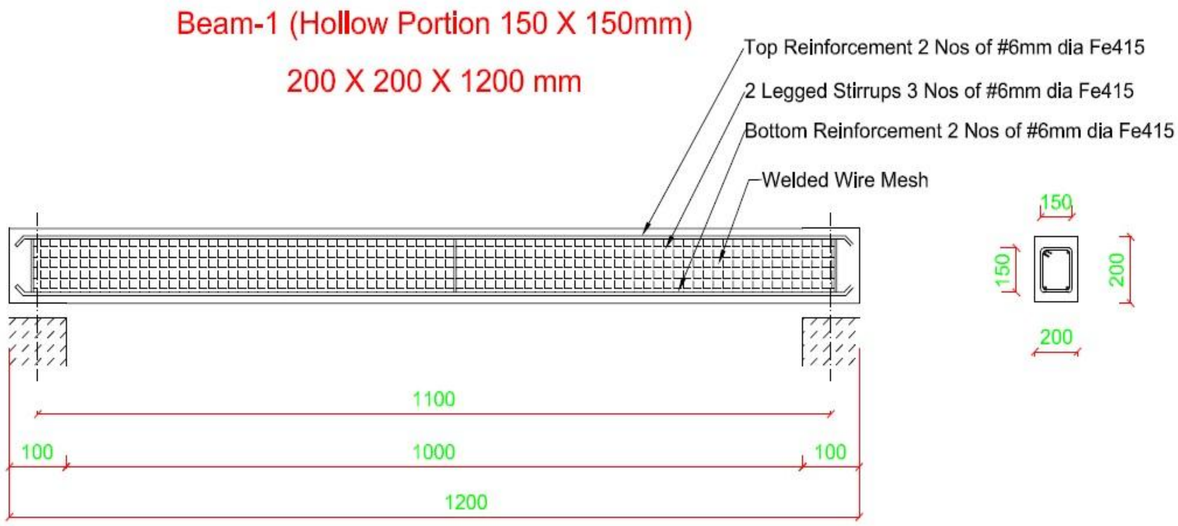


Fig. 3 Control and Ferrogeopolymer Beam Mesh A Details

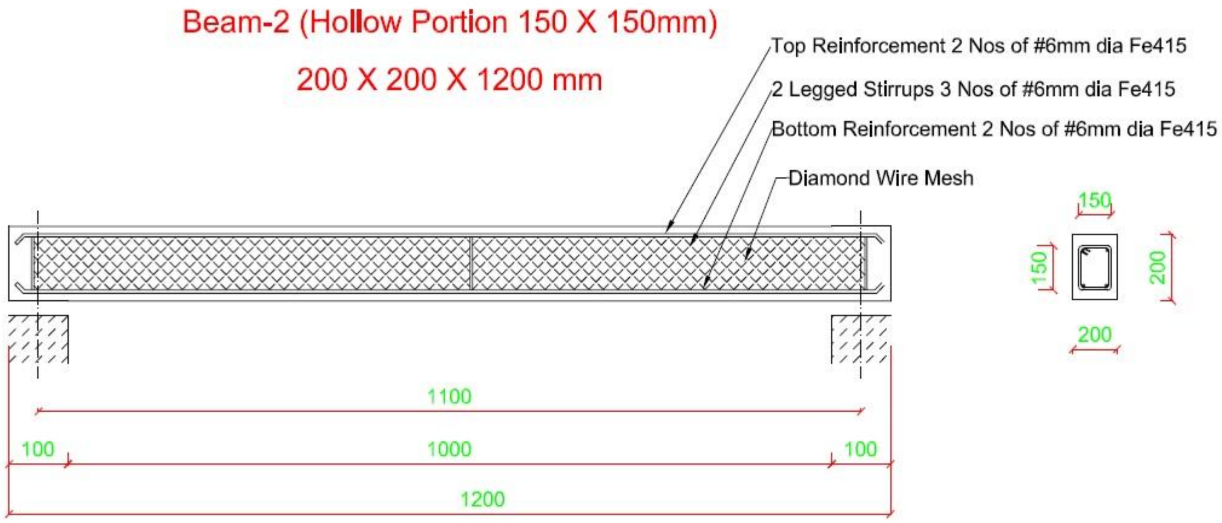


Fig. 4 Control and Ferrogeopolymer Beam Mesh B Details

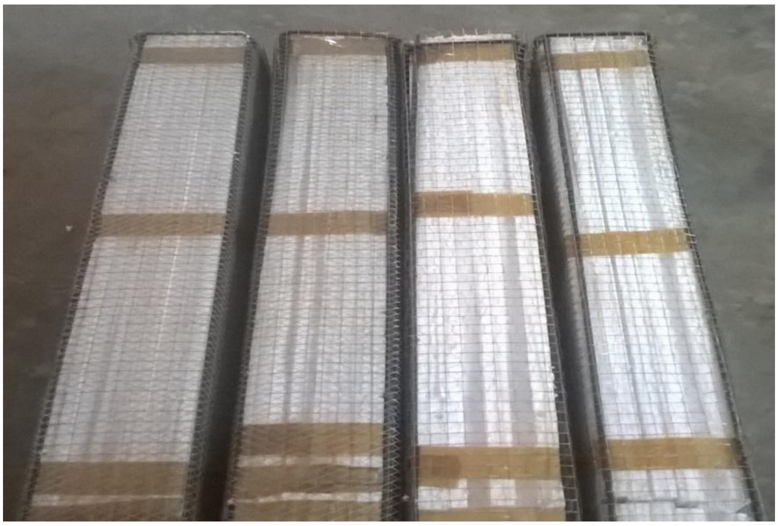


Fig.5 Wire Mesh Reinforcement A and B Type

Table 2 Beam Designation

S.NO	Beam Identification	Description	Reinforcement
1	CB A	Cement mortar	Welded and Woven
2	CB B	Cement mortar	Welded and Expended
3	GB A	Geopolymer	Welded and Woven
4	GB B	Geopolymer	Welded and Expended

Fig.6 Curing of Ferrocement Box Beams

Fig.7 Curing of Ferrogeopolymer Beam (Ambient curing)

Fig.8 Test Setup

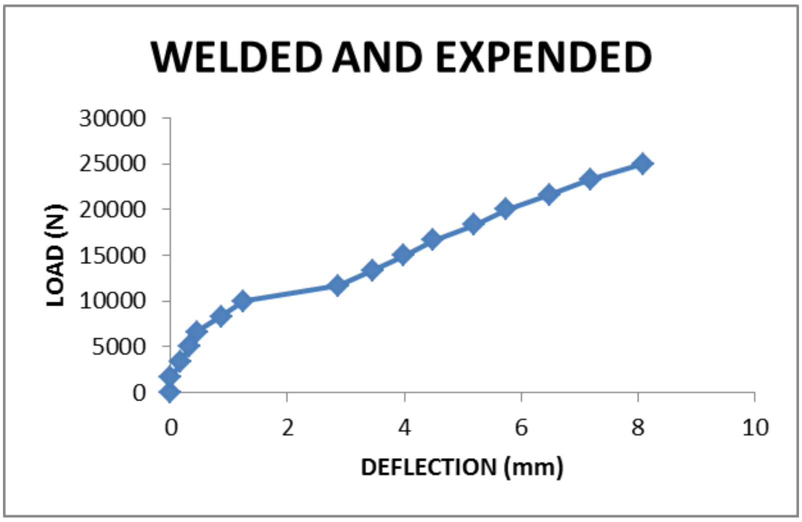


Fig.9 Load-Deflection behavior of Control Beam A

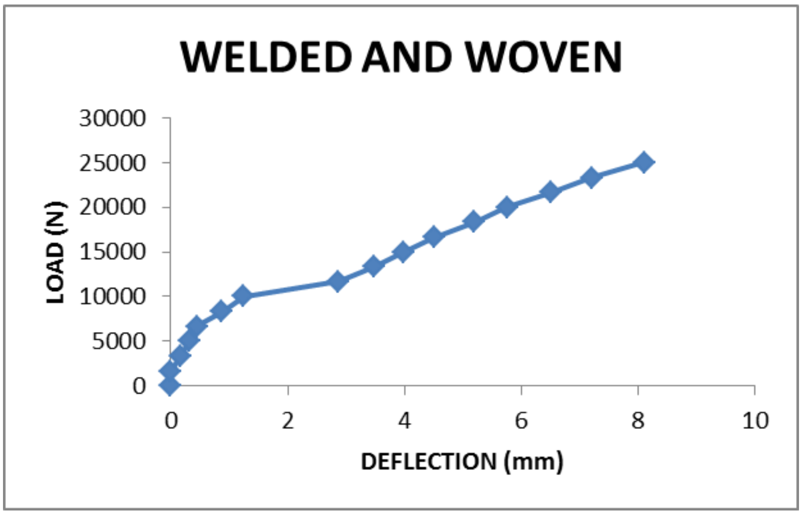


Fig.10 Load-Deflection Behavior of Control Beam B

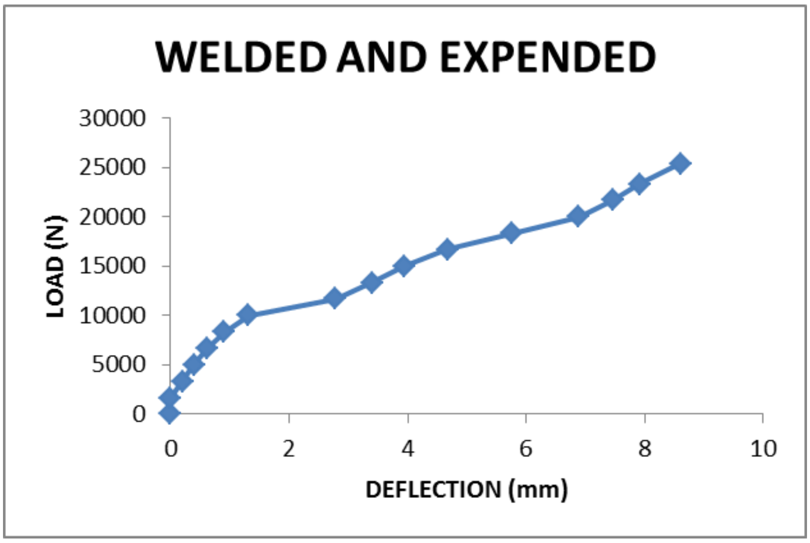


Fig.11 Load-Deflection behavior of Ferrogeopolymer Beam A

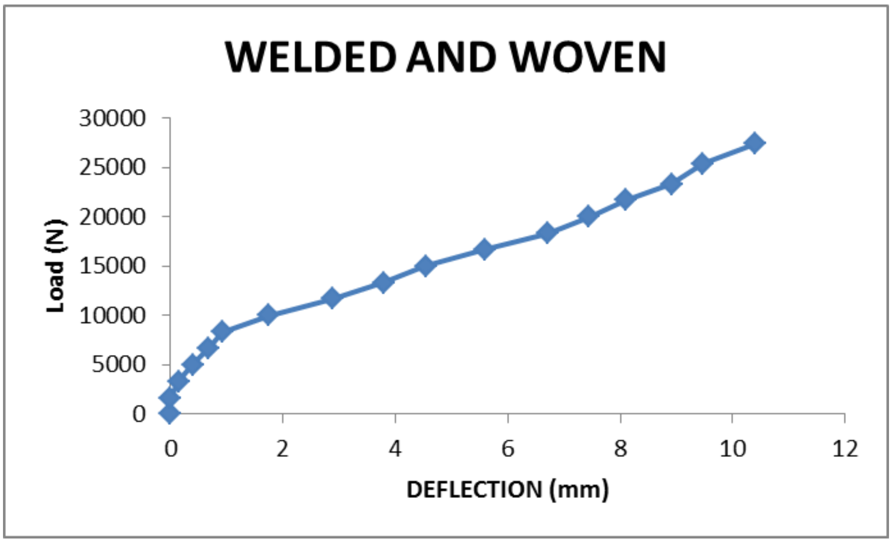


Fig.12 Load-Deflection behavior of Ferrogeopolymer Beam B

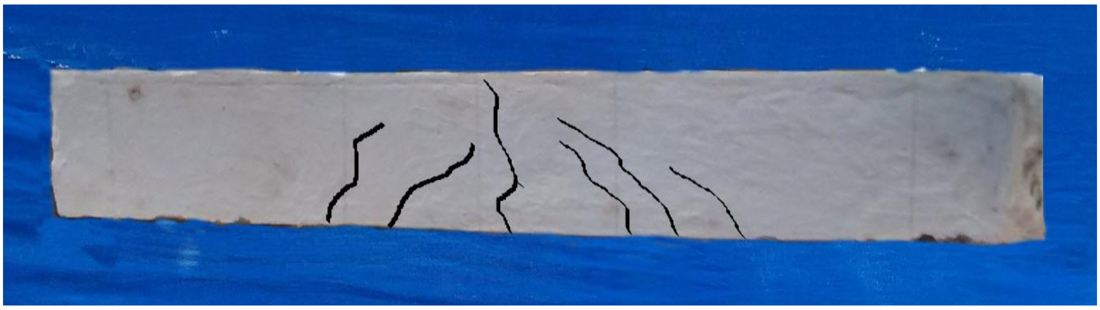


Fig.13 Crack Pattern of Beam (CB A)

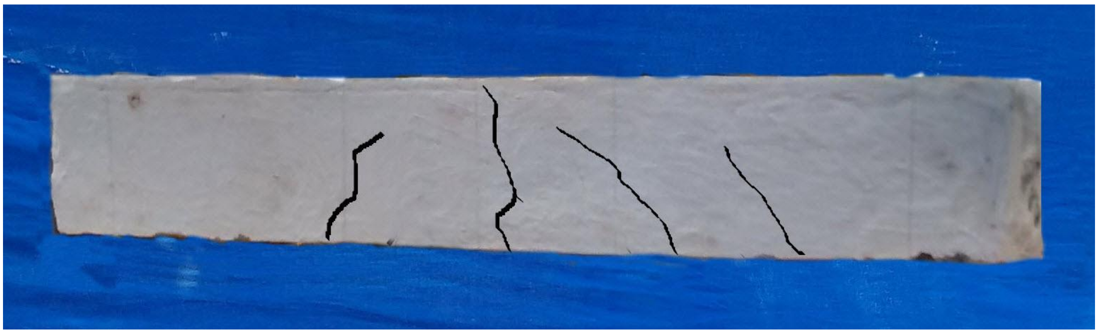


Fig.14 Crack Pattern of Beam (CB B)

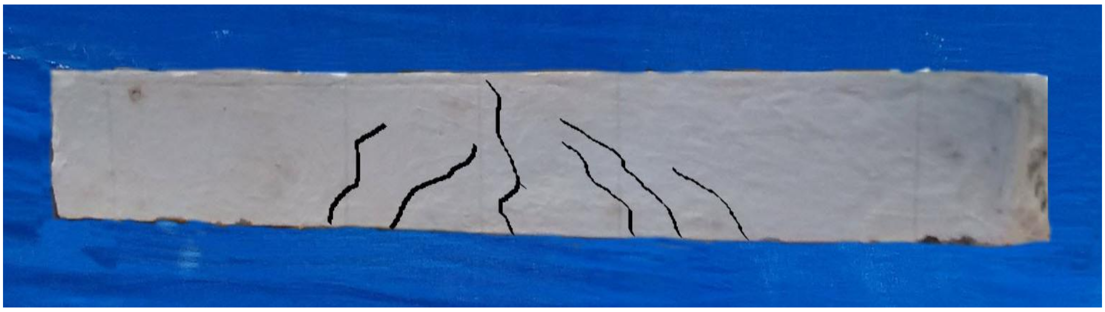


Fig.15 Crack Pattern of Beam (GB A)

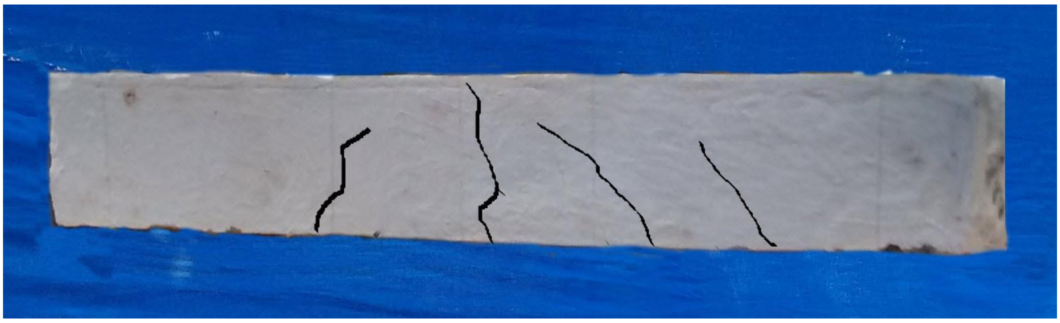


Fig.16 Crack Pattern Beam (GB B)

Table 3 Test Result of Ferrocement and Ferrogeopolymer Beams

S.NO	BEAM	YIELD LOAD (T)	ULTIMATE LOAD (T)	YIELD DEFLECTION (mm)	ULTIMATE DEFLECTION (mm)
1	CB A	1.75	2.5	5.7	8.6
2	CB B	2.25	2.75	5.1	8.3
3	GB A	2.25	2.75	7.9	9.3
4	GB B	2.5	3.0	7.4	8.7

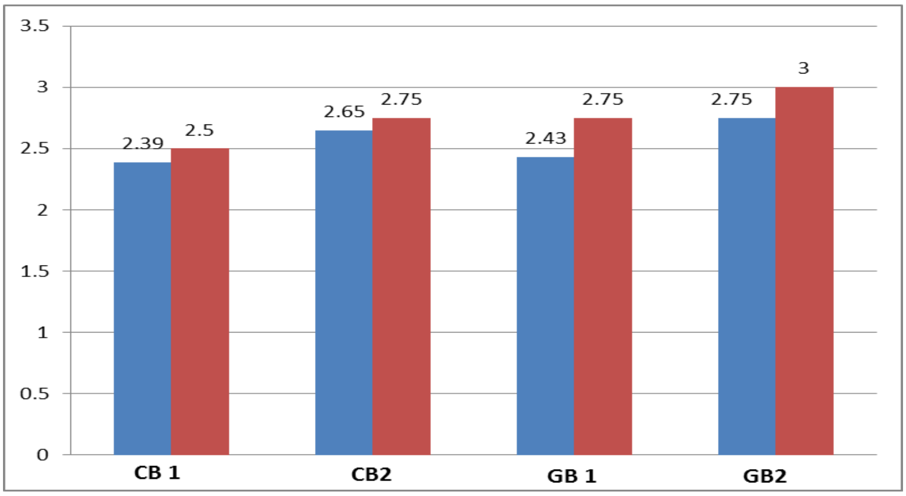


Fig. 17 Comparison of Experimental and Theoretical Loads of All Beams

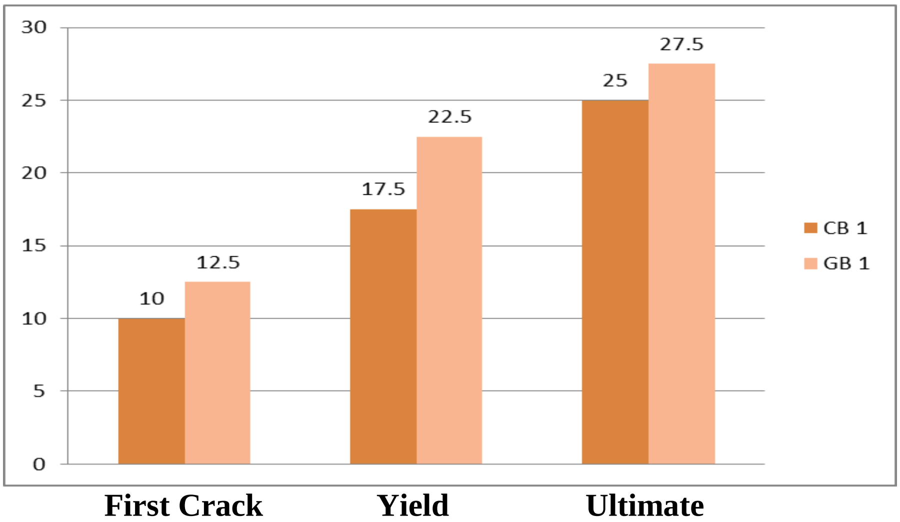
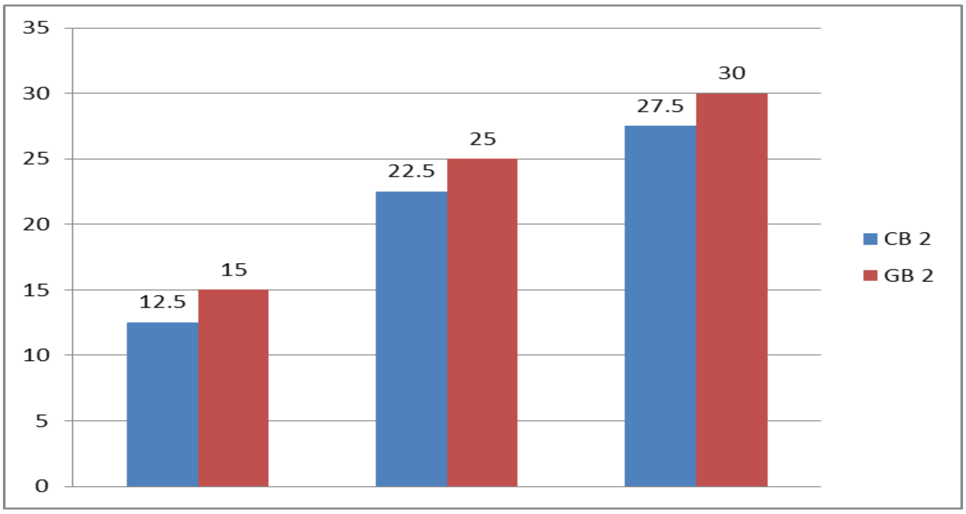
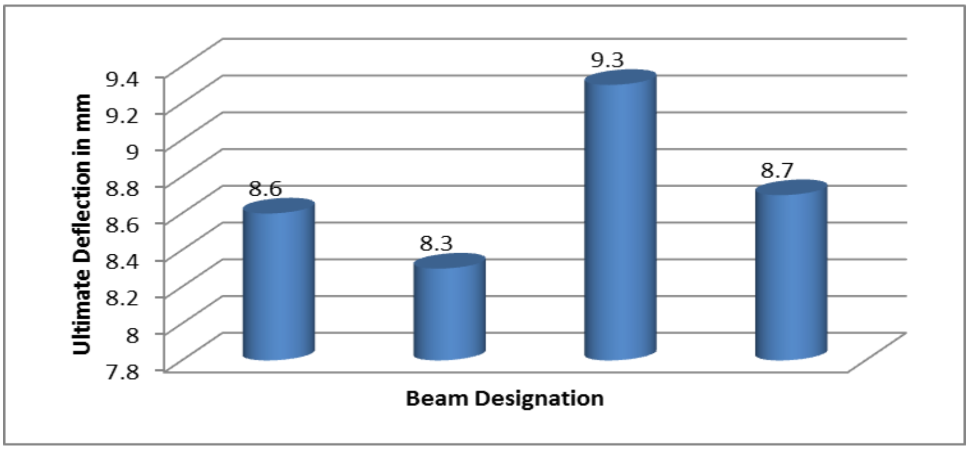


Fig. 18 Comparison of Beams at Different Stages of Loading



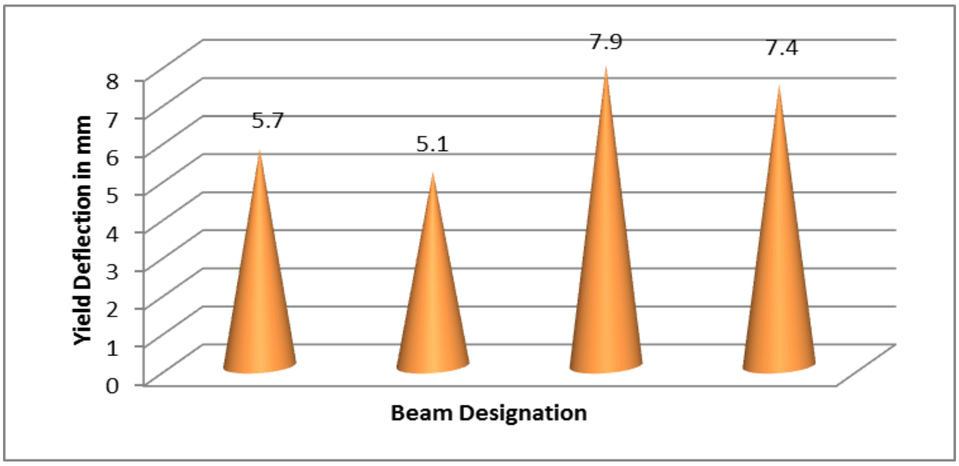
First Crack Yield Ultimate

Fig.19 Comparison of Beams at Different Stages of Loading



CB1 CB2 GB1 GB2

Fig.20 Comparison of Ultimate Deflection at All Beams



CB1 CB2 GB1 GB2

Fig.21 Comparison of Deflection at Yield load All Beams

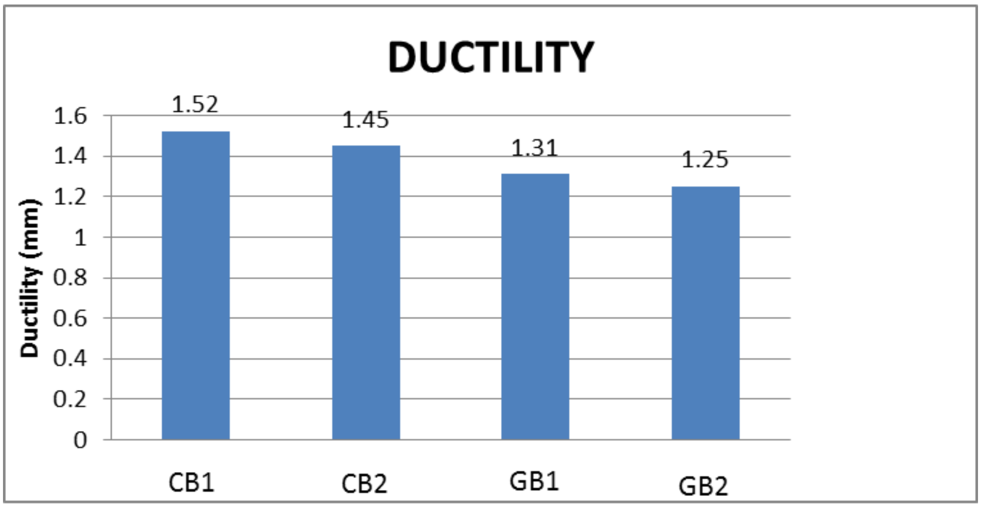


Fig.22 Ductility of all beams

Table 4 Comparison of Theoretical and Experimental Values

BEAM	P_{cr}(theory) (kN)	P_{cr}(exp) (kN)	W_{av}(theory) (mm)	W_{av}(exp) (mm)	Al_{av}(theory) (mm)	Al_{av}(exp) (mm)
CB1	23.9	25	5.18	4.3	63.29	51.23
CB2	26.5	27.5	2.14	2.6	28.40	32.45
GB1	24.3	27.5	4.70	4.13	52.71	44.51
GB2	26.9	30	3.10	3.47	25.50	31.10

CONCLUSIONS:

Based on the experimental investigation conducted on ferrogeopolymer box beams with two patterns of steel reinforcement and ferrocement box beams, the following conclusions are presented.

- The ferrocement was made with cement mortar 1: 2 with w/c ratio of 0.46. The compressive strength of cement mortar cubes is 54 N/ mm^2.
- The geopolymer mortar was developed with same ratio as used in cement mortar with 100% cement replaced by cementations material containing fly ash (60%) and GGBS (40%). The compressive strength of geopolymer mortar cubes after 7 days cured in atmospheric is 53.6 N/ mm^2.
- The ferrocement hollow beam of size 1200mm x 200mm x 200mm with hollow portion of 150mm x 150mm was made and tested under two points loading.

- The ultimate load and deflection of ferrocement hollow beam made with welded and woven wire mesh reinforcement are 2.5 kN and 9.6 mm respectively.
- The ultimate load and deflection of ferrocement hollow beam made with welded and expended wire mesh reinforcement are 2.7 kN and 8.3 mm respectively.
- The ultimate load and deflection of ferrogeopolymer hollow beam made with welded and woven wire mesh reinforcement are 2.54 kN and 10.4 mm respectively.
- The ultimate load and deflection of ferrogeopolymer hollow beam made with welded and expended wire mesh reinforcement are 2.73 kN and 8.9 mm respectively.
- The ferrogeopolymer box beams (welded and woven mesh) shown, increase of 10% in ultimate load carrying capacity when compared to ferrocement box beams.
- The ferrogeopolymer (welded with expended mesh) beams shown an, increase of 9.5% in ultimate load carrying capacity when compared to ferrocement beam.
- The ferrogeopolymer (welded with woven mesh) beam shows a reduction of 7.6% in ultimate deflection when compared to ferrocement specimens.
- The ferrogeopolymer beam (welded with expended mesh) shows a reduction of 6.7% in ultimate deflection when compared to ferrocement specimens.
- The conventional mesh reinforcement beam exhibit linear elastic behaviour up to the first crack loads, irrespective of the number of layers of mesh reinforcement used and afterwards deviate from linearity.
- All flexural specimens mostly have failed due to flexural cracks; cracks are initiated at the bottom of the mid span which is mostly in flexure zone.
- When the load was increased, additional vertical cracks appeared on beam surface, followed by the formation of diagonal cracks.
- Ferrogeopolymer box beams demonstrate excellent crack control characteristics.

CHAPTER 7

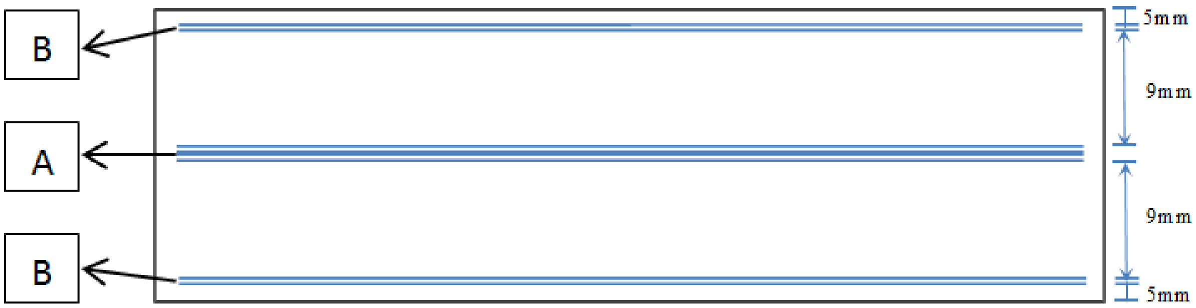
FERROGEOPOLYMER SLABS

REINFORCEMENT DETAILING OF SPECIMENS

Table 1 Designation of Specimens

<table>
<tr><th colspan="2">Type of Specimen</th><th>Ferrocement Slab</th><th>Ferrogeopolymer Slab</th></tr>
<tr><td rowspan="2">Welded and expandable with chicken mesh</td><td>With steel</td><td>CE1</td><td>GE1</td></tr>
<tr><td>Replaced with meshes</td><td>CE2</td><td>GE2</td></tr>
<tr><td rowspan="2">Welded and woven with chicken mesh</td><td>With steel</td><td>CW1</td><td>GW1</td></tr>
<tr><td>Replaced with meshes</td><td>CW2</td><td>GW2</td></tr>
</table>

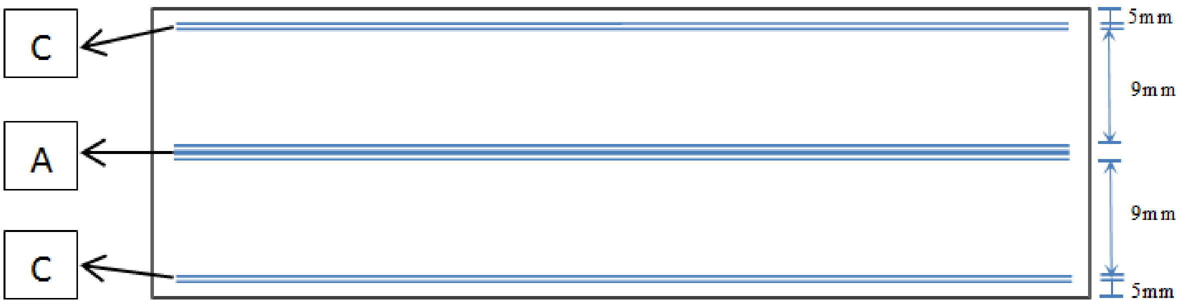
Arrangement of CE1 and GE1



A - Skeletal steel + 2 chicken meshes, B - Welded + Expendable meshes

Fig. 1 Cross Section of Slab Panel (CE1 & GE1)

Arrangement of CW1 and GW1



A - Skeletal steel + 2 chicken meshes, C - Welded + Woven meshes

Fig. 2 Cross Section of Slab Panel (CW1 & GW1)

Arrangement of CE2 and GE2

B -Welded + Expandable, D -Welded + 2 chicken meshes,

E -Expendable + 2chicken meshes.

Fig. 3 Cross Section of Slab panel (CE2 & GE2)

Arrangement of CW2 and GW2

C-Welded + Woven, D -Welded +2 chicken meshes,
F -Woven + 2 chicken meshes.

Fig. 4 Cross Section of Slab panel (CW2 & GW2)

Table 2 Surface area and Volume fraction of Specimens

Type of specimens	Volume fraction (%)	Surface area (mm^2/mm^3)
CE1& GE1	2.44	0.0549
CE2& GE2	2.11	0.1005
CW1 & GE1	2.69	0.0784
CW2 & GW2	2.63	0.1394

Fig.5 Skeletal Steel

Fig.6 Tying of Meshes **Fig.7 Cutting of Mesh**

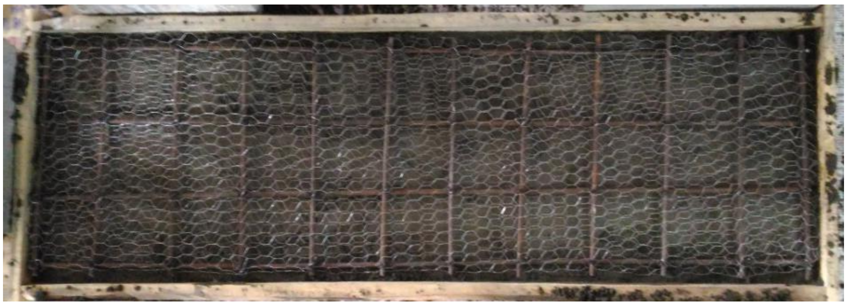


Fig.8 Placing of Skeletal Steel Layer

Fig.9 Applying Cement Mortar and Compaction

Fig.10 Placing of Mesh Layer

Fig.11 Finished Specimen of (CE1)

Casting GE1 and GW1

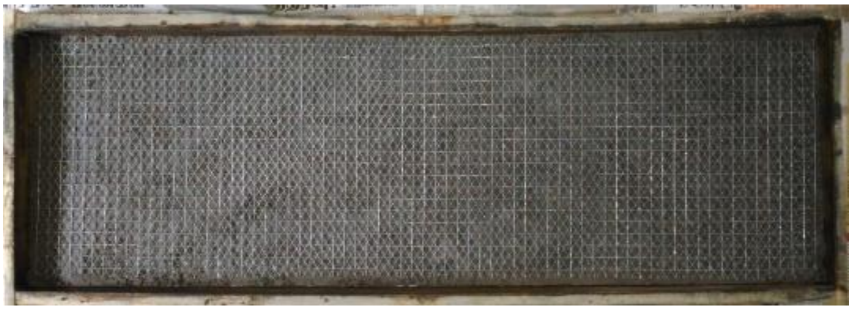


Fig.12 Placing of C Type Mesh

Fig.13 Placing of Skeletal Steel

Fig.14 Mortaring on Skletal Steel

Fig.15 Finishing of Specimen (GW1)

Casting of CE2 & CW2

Fig.16 Cover Layer at Bottom

Fig.17 Applying of Mortar

Fig.18 Placing of D type Mesh

Fig.19 Finished Surface of (CE2)

Casting of GE2 & GW2

Fig.20 Placing Bottom Cover Mortar

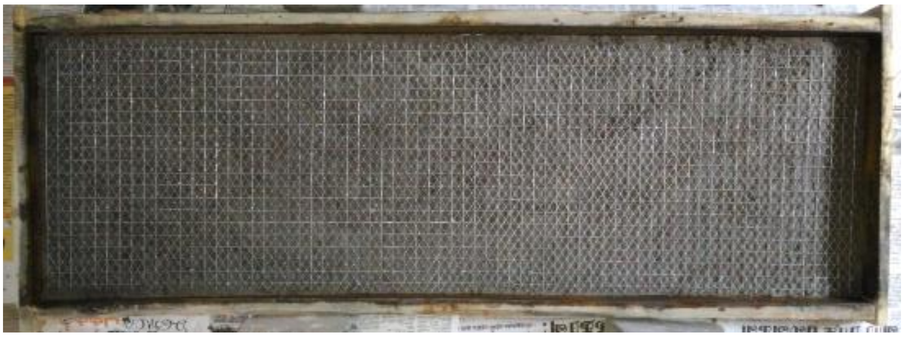


Fig.21 Placing of B Type Layer

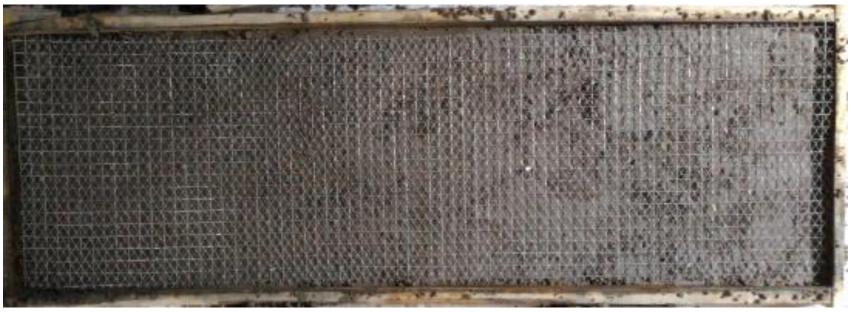


Fig.22 Pacing of E Type Layer

Fig.23 Finished surface of GW2

Curing Ferrocement Slab Panels

Fig.24 Ferrocement Slabs **Fig.25 Covering with Gunny Bag**

Fig.26 Ambient Curing of (GE1)

TESTING OF SLABS

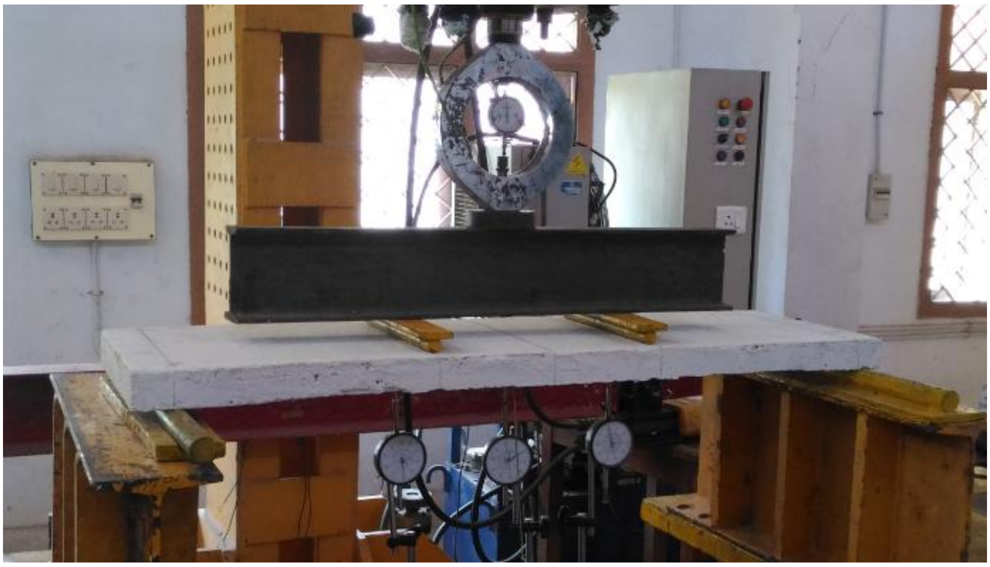


Fig. 27 Test Setup

Fig.28 Deflected Shape @ Ultimate Load (CE1)

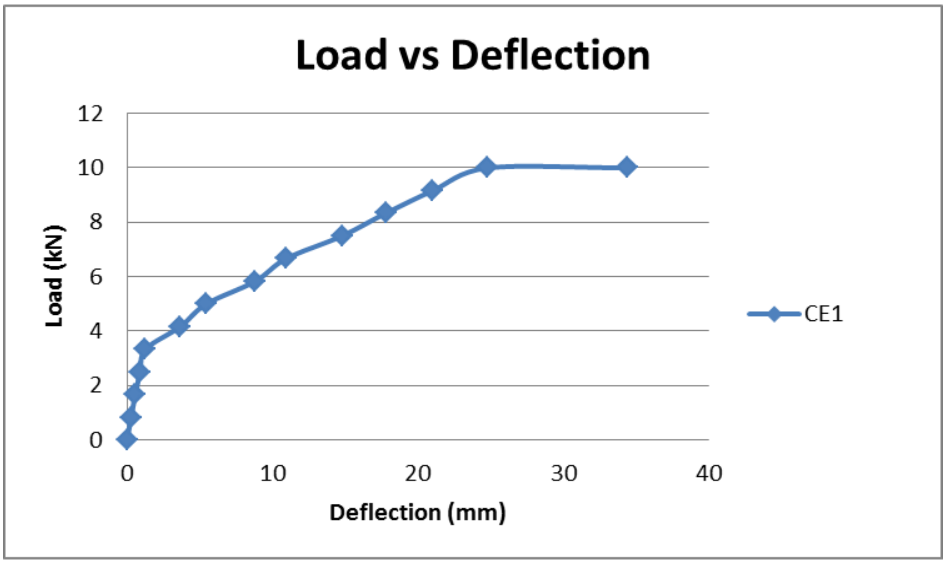


Fig. 29 Load vs Deflection Graph of (CE1)

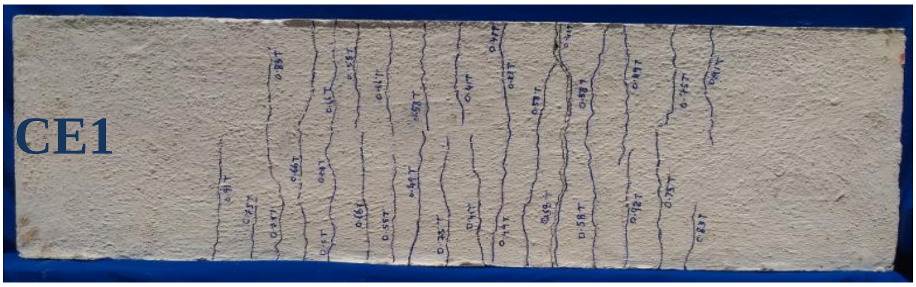


Fig. 30 Crack Patten of (CE1)

Fig.31 Deflected Shape @ Ultimate Load (CE2)

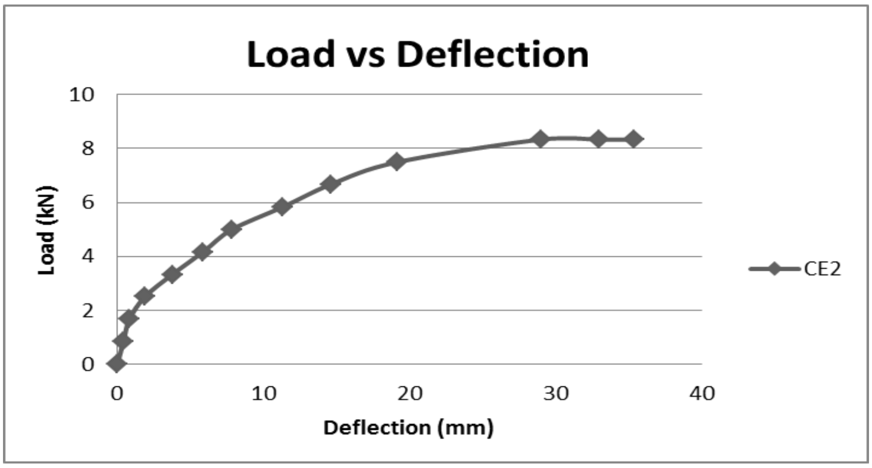


Fig.32 Load vs Deflection Graph of CE2

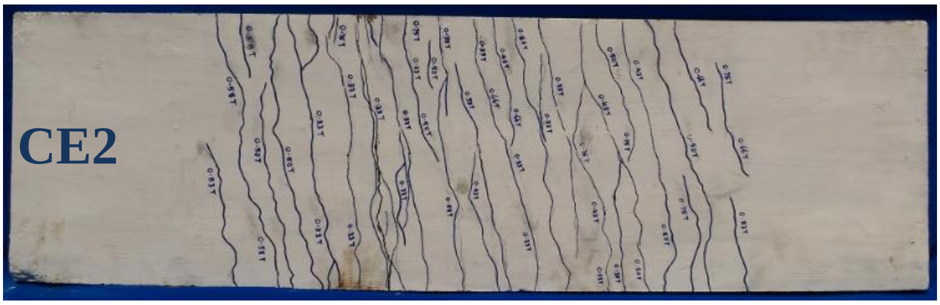


Fig.33 Crack Pattern of CE2

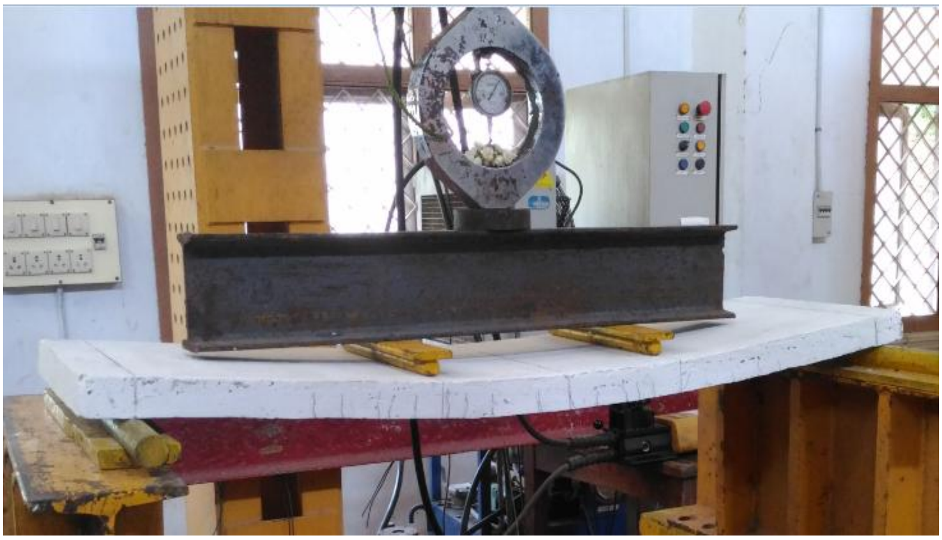


Fig.34 Deflected Shape @ Ultimate Load (CW1)

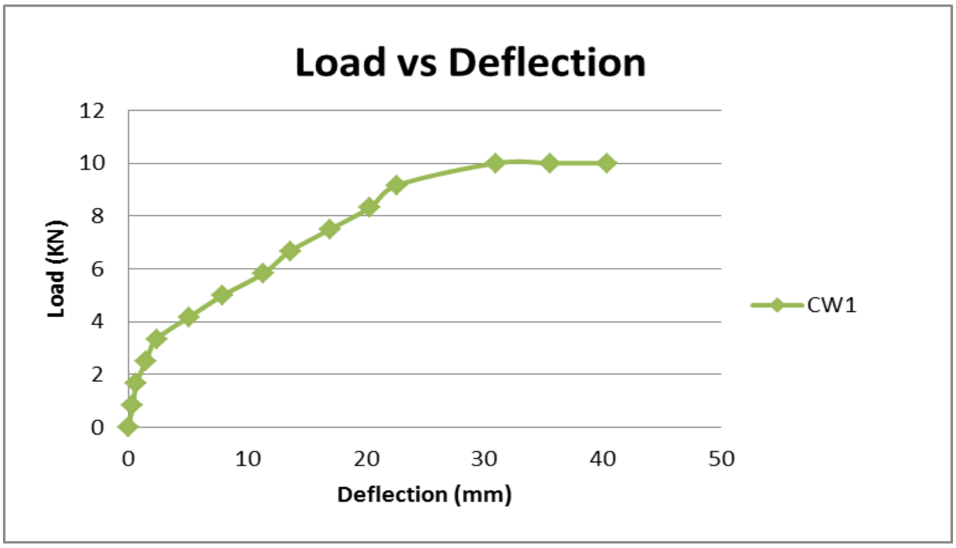


Fig.35 Load vs Deflection of (CW1)

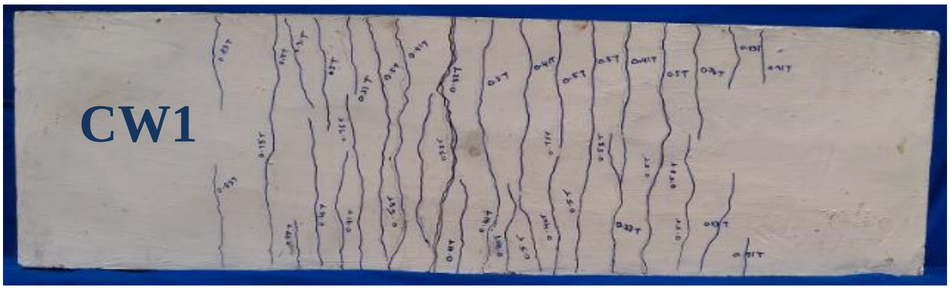


Fig.36 Crack Pattern of (CW1)

Fig.3.7 Deflected Shape @ Ultimate Load (CW2)

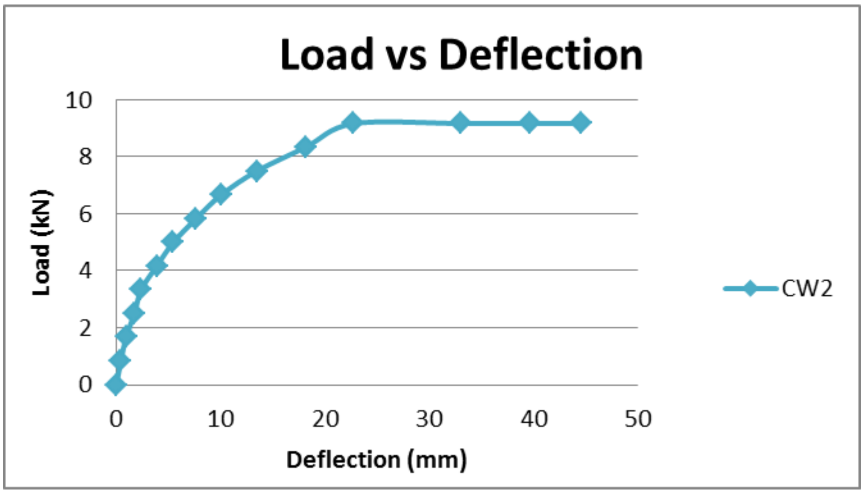


Fig.38 Load vs Deflection of (CW2)

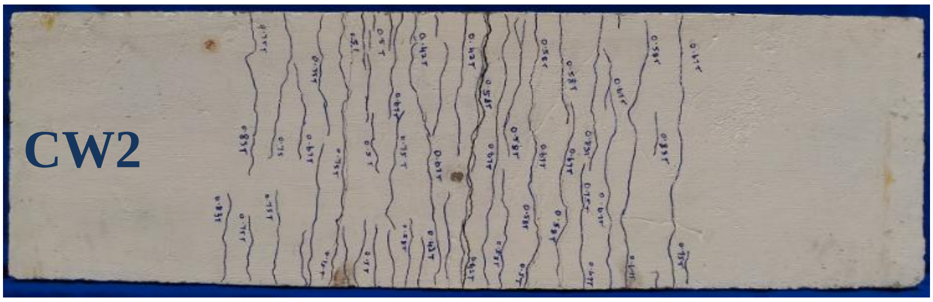


Fig.39 Crack Pattern of (CW2)

Fig.40 Deflected Shape @ Ultimate Load (GE1)

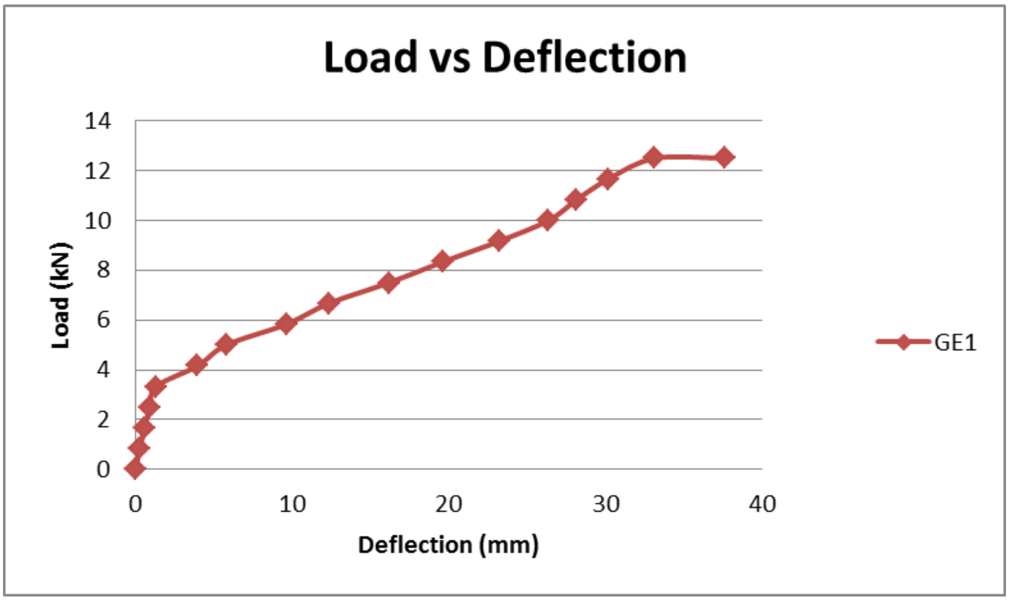


Fig.41 Load vs Deflection of (GE1)

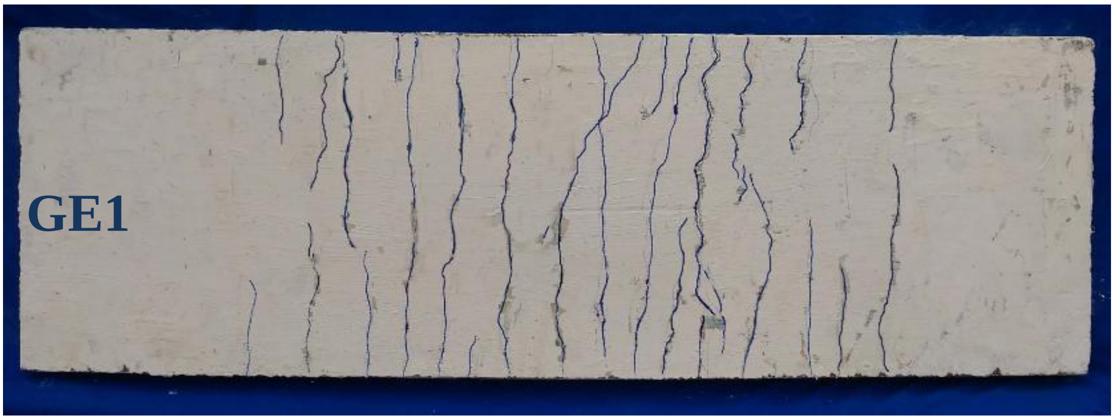


Fig.42 Crack Pattern of (GE1)

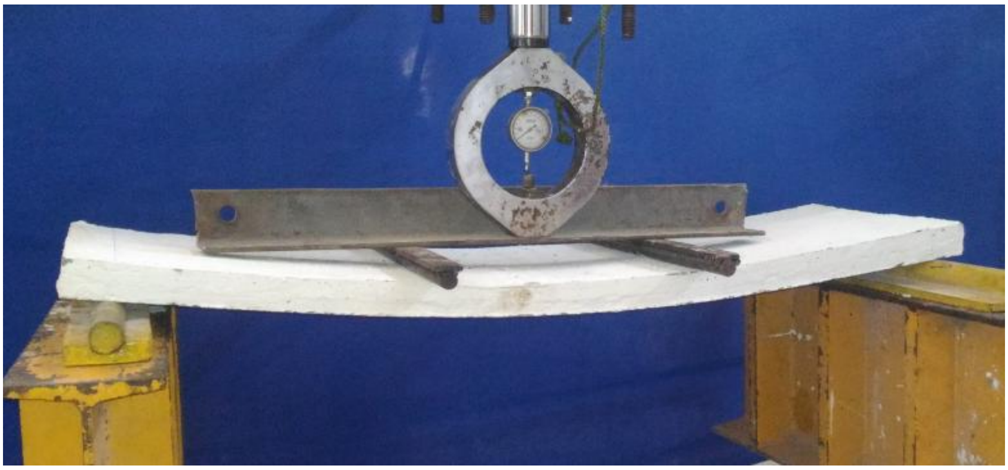


Fig.43 Deflected Shape @ Ultimate Load (GE2)

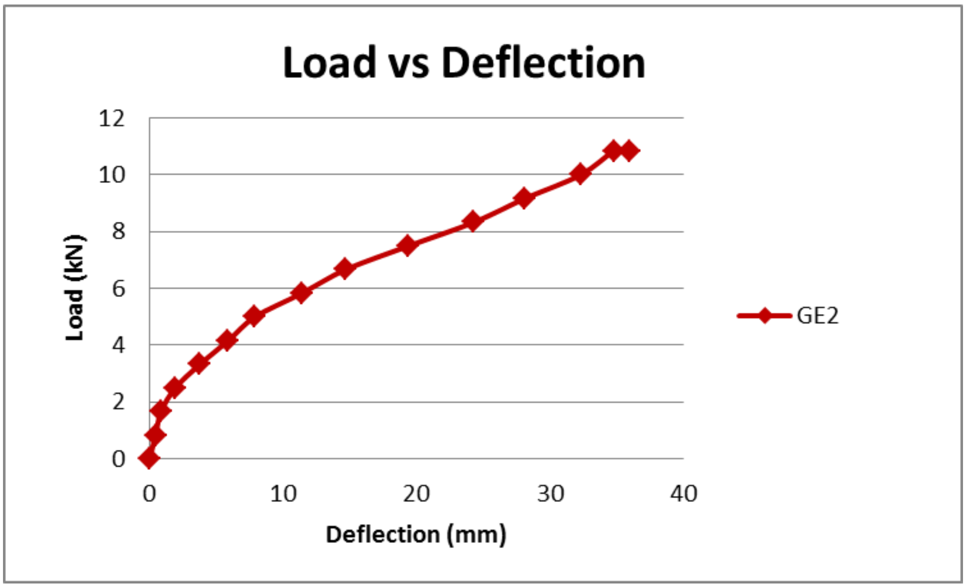


Fig.44 Load vs Deflection of (GE2)

Fig.45 Crack Pattern of (GE2)

Fig. 46 Deflected Shape @ Ultimate Load (GW1)

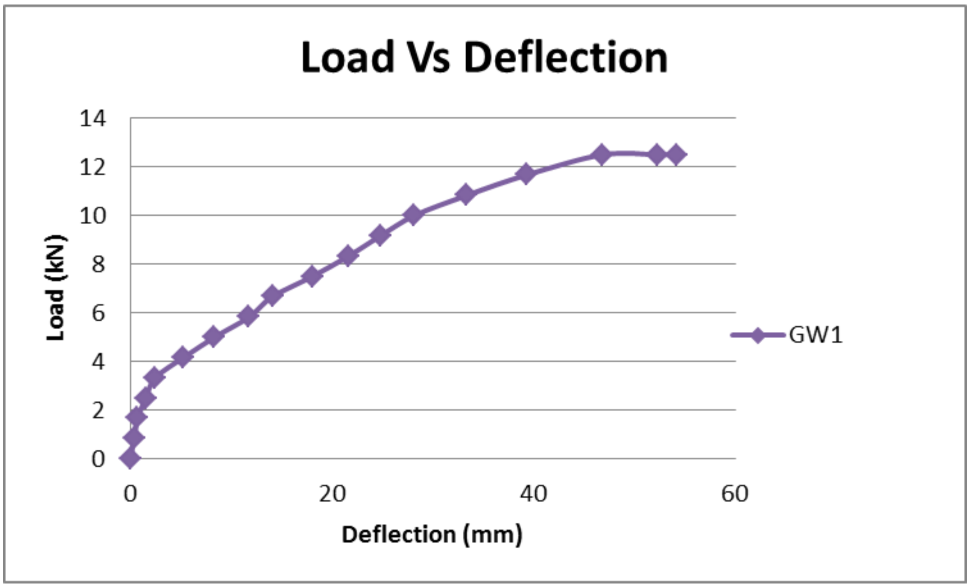


Fig.47 Load vs Deflection of (GW1)

Fig.48 Crack Pattern of (GW1)

Fig.49 Deflected Shape @ Ultimate Load (GW2)

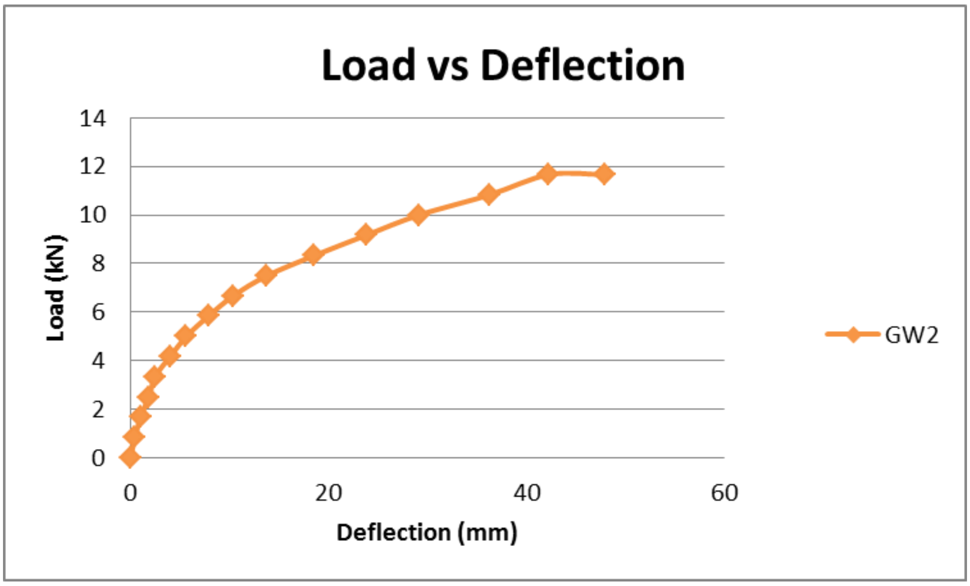


Fig. 50 Load vs Deflection of (GW2)

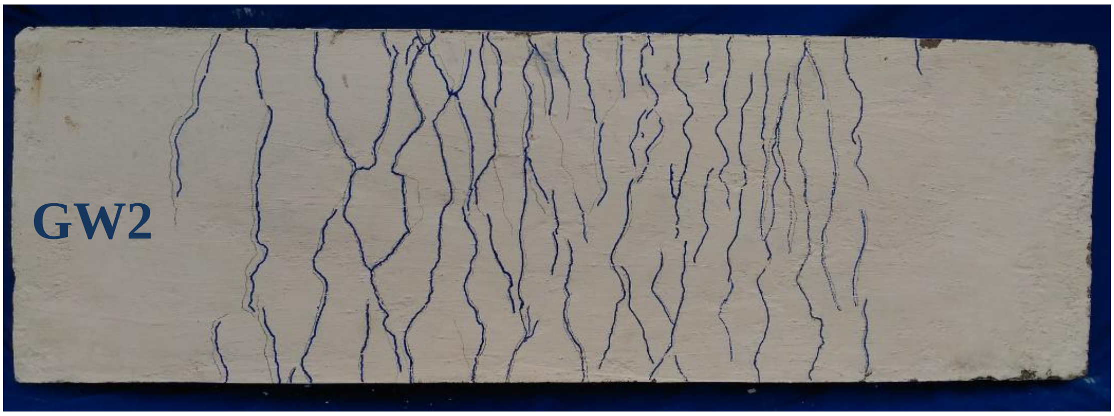


Fig.51 Crack Pattern of (GW2)

CONCLUSIONS:

Based on the experimental investigation of flexural behaviour of ferrocement and ferrogeopolymer slab panels obtained and following conclusion are drawn.

1. Ferrocement of cement mortar 1: 2 with w/c ratio 0.42 was used to cast cement slab panels of size 11000mm x 350mm x 40mm. The cement mortar was tested after 28 days water curing and found as 52.33 n/mm^2
2. The Geopolymer mortar of 60% Flyash and 40% of GGBS with two part of sand was made with alkaline solution of 0.42. The Alkaline solution was a mixture of sodium silicate and sodium hydroxide with the ratio of 2.5.
3. The geopolymer mortar cubes was cast and ambient cured for 7 days and tested. The compressive strength of geopolymer mortar after 7 days of ambient curing was found as 55.62 N/mm^2.
4. The ferrocement slab and ferrogeopolymer slab panels was made with and without steel skeleton containing expanded and woven type meshes.
5. The ferrocement slab with steel skeleton containing expended meshes (CE1) and Woven meshes (CW1) shows 20% and 9% increase in ultimate load carrying capacity when compared to the corresponding ferrocement slabs without Steel Skeleton of (CE2) and (CW2).
6. The ferrogeopolymer slab with steel skeleton containing expended meshes (GE1) and woven meshes (GW1) shows 10.8% and 7.1% increase in ultimate load carrying capacity when compared to the corresponding ferrogeopolymer slabs without Skeletal steel of (GE2) and (GW2).
7. The ferrogeopolymer slab with steel skeleton containing expended meshes (GE1) and Woven meshes (GW1) both shows 25% increase in ultimate load carrying capacity when compared to the corresponding ferrocement slabs of (CE1) and (CW1).

8. The ferrogeopolymer slab without steel skeleton containing expended meshes (GE2) and woven meshes (GW2) shows 30% and 27% increase in ultimate load carrying capacity when compared to the same ferrocement slabs (CE2) and (CW2) respectively.
9. The ferrocement slab with steel skeleton containing expended meshes (CE1) and Woven meshes (CW1) shows 3% and 10.4% decrease in ultimate deflection carrying capacity when compared to the corresponding ferrocement slabs without Steel Skeleton of (CE2) and (CW2).
10. The ferrogeopolymer slab with steel skeleton containing expended meshes (GE1) and woven meshes (GW1) shows 4.6% and 12.9% increase in ultimate deflection carrying capacity when compared to the corresponding ferrogeopolymer slabs without Skeletal steel of (GE2) and (GW2).
11. The ferrogeopolymer slab with steel skeleton containing expended meshes (GE1) and Woven meshes (GW1) shows 9.4% and 34% increase in ultimate deflection carrying capacity when compared to the corresponding ferrocement slabs of (CE1) and (CW1).
12. The ferrogeopolymer slab without steel skeleton containing expended meshes (GE2) and woven meshes (GW2) shows 1.6% and 7.6% increase in ultimate deflection carrying capacity when compared to the same ferrocement slabs (CE2) and (CW2) respectively.
13. From the flexural results obtained from ferrocement and ferrogeopolymer slab, it is recommended that the ferrogeopolymer slab panels can be used in construction since it possess better performance than ferrocement slabs.

CHAPTER 8

FERROGEOPOLYMER ELEMENTS

EXPERIMENTAL INVESTIGATION ON FERROGEOPOLYMER DOMES

DIMENSIONS OF DOME

Diameter = 1000mm

Height = 500mm

Thickness = 50mm

MATERIALS USED

Welded wire mesh of grid size 17mm x 17mm

Expanded metal mesh of size 17mm x 10mm

Steel bars of 6mm dia

Ring direction – 5 numbers

Meridian direction – 16 numbers

Geopolymer mortar 1:2.5 was used

Fly ash and GGBS each 50% is used instead of cement

5 Molarity of NaOH is adopted

Curing condition – Ambient curing

Fig. 1 Steel Rod of 6mm dia

Fig. 2 Tensile Test on Steel Rod

Fig. 3 Test on Expanded Mesh

Fig. 4 Test on Welded Wire Mesh

WELDED WIRE MESH

Peak load	= 2.75 kN
Yield stress	= 413 MPa
Ultimate Tensile stress	= 456 MPa

EXPANDED METAL MESH

Peak load	= 0.400 kN
Yield stress	= 305 MPa
Ultimate Tensile stress	= 400 MPa

Fig. 5 Dome reinforcement

Fig. 6 Mesh on reinforcement

Fig. 7 Application of mortar

Fig. 8 Inner surface of dome

Fig. 9 Test setup

Fig. 10 After testing

Table.1 Specific Gravity Results

Materials	Specific gravity
Cement	3.12
Fine aggregate	2.65
Fly ash	2.24
GGBS	2.82
Sodium Hydroxide	1.47*
Sodium Silicate	1.6*

*Supplied by the Manufacturer

Table.2 Tensile Strength of Steel Results

Diameter of Steel (mm)	Yield Stress (N/mm^2)	Ultimate Stress (N/mm^2)	Breaking Stress (N/mm^2)\
6mm diameter	505.36	631.71	536.95

Table 3 Tensile Strength of Mesh Results

Types of Mesh	Peak Load (kN)	Yield Stress (MPa)	Ultimate Stress (MPa)
Welded Wire Mesh	2.750	413	456
Expanded Metal Mesh	0.400	305	400

Table 4 Compressive Strength of Mortar Cubes at 28 days

Cube No.	Compressive Strength (N/mm^2)	Average Compressive Strength (N/mm^2)
1	44	45
2	45	
3	46	

Table 5 Compressive Strength of Geopolymer Mortar Cubes

Molarity	Cube No.	Compressive strength (7 days) N/mm^2	Average compressive strength (7 days) N/mm^2
5	1	46.14	46.24
	2	46.746	
	3	45.98	
	4	46.10	

The result shows that the compressive strength of geopolymer mortar cubes is 2.7% higher than the compressive strength of cement mortar cubes. The comparison of compressive strength of cement and geopolymer mortar cubes were is shown in Figure 11.

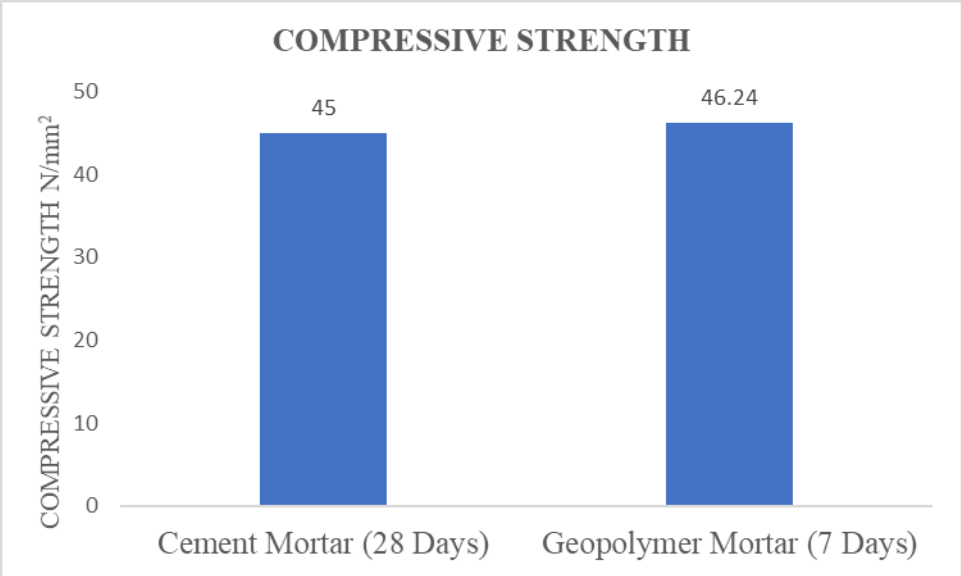


Fig. 11 Comparison of Compressive Strength of Cement Mortar and Geopolymer Mortar

The experimental results for the four domes included first crack load, ultimate load, displacements at first crack load and ultimate load were presented in Table 6. The service load, energy absorption and ductility ratio were presented in Table 7. The energy absorption is calculated as the area under the load-deflection (vertical deflection) curve while Ductility ratio is defines as the ratio between the vertical deflections at ultimate load to the vertical deflections at first crack load. The first crack load and ultimate load at failure of all domes are compared in Figure 12 and Figure 13. Load-deflection curve at four measured points of all domes are presented in Figure 14, 15, 16 and 17. The service load of all the domes are found using the formula $P_s = (P_u – 1.4DL)/1.6$.

Table 6 Dome Test Results

Designation of Dome	First Crack Load(kN)	Ultimate Load (kN)	Displacement at First Crack Load (mm)				Displacement at Ultimate Load (mm)			
			HD_1	VD_2	HD_3	VD_4	HD_1	VD_2	HD_3	VD_4
FCD1	60	95	0.15	1.99	0.37	0.39	0.55	3.01	0.44	0.69
FCD2	40	65	0.21	1.70	0.29	0.64	0.66	3.92	0.30	1.17
FGPD1	45	160	0.08	1.68	0.39	0.97	0.48	4.92	1.69	5.47
FGPD2	25	140	0.20	1.03	0.09	0.20	1.47	1.15	1.29	1.08

Table 7 Service Load, Energy Absorption and Ductility Ratio of Domes

Designation of Dome	Service Load (kN)	Energy Absorption (kNmm)	Ductility Ratio
FCD1	57.79	137.5	1.76
FCD2	39	151.75	2.3
FGPD1	98.49	420.57	5.6
FGPD2	86	85.15	5.4

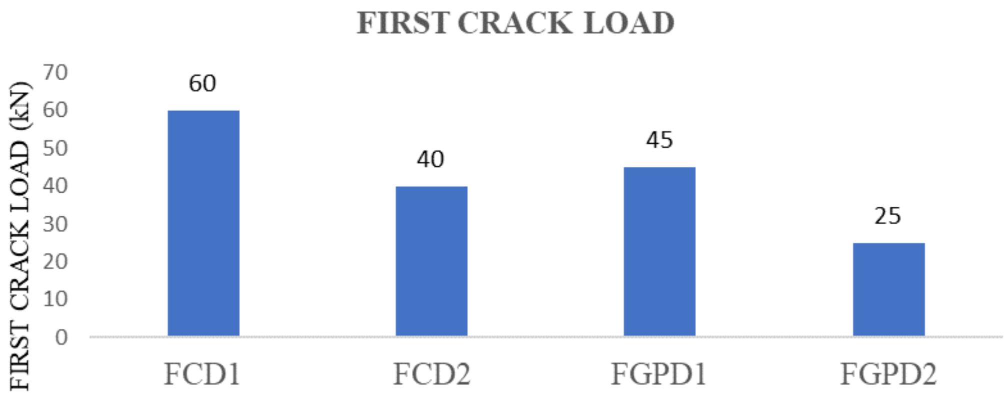


Figure 12 Comparison of First Crack Load of All Domes

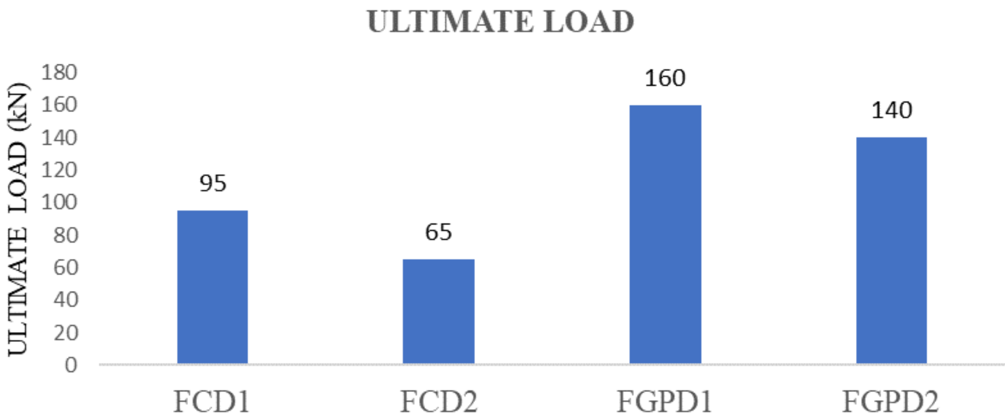


Figure 13 Comparison of Ultimate Load of All Domes

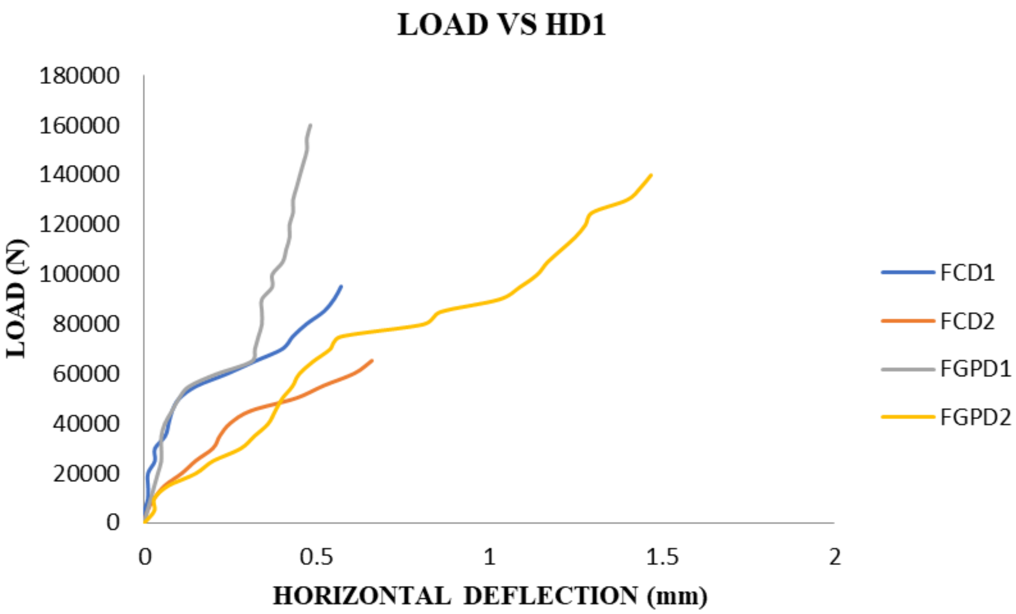


Figure 14 Comparison of Load vs Horizontal Deflection @ 150mm from base

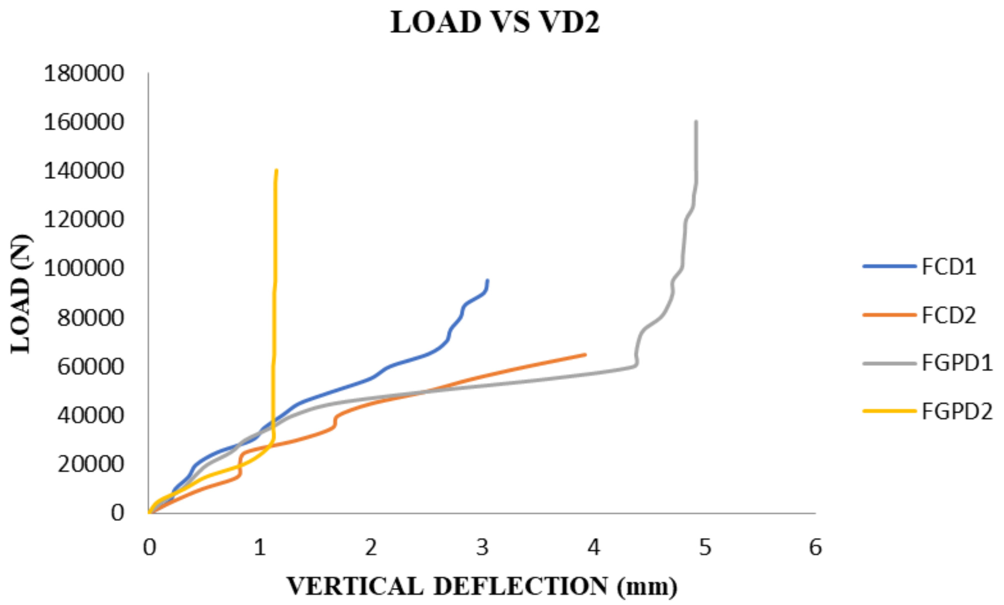


Figure 15 Comparison of Load vs Vertical Deflection @ 300mm from base

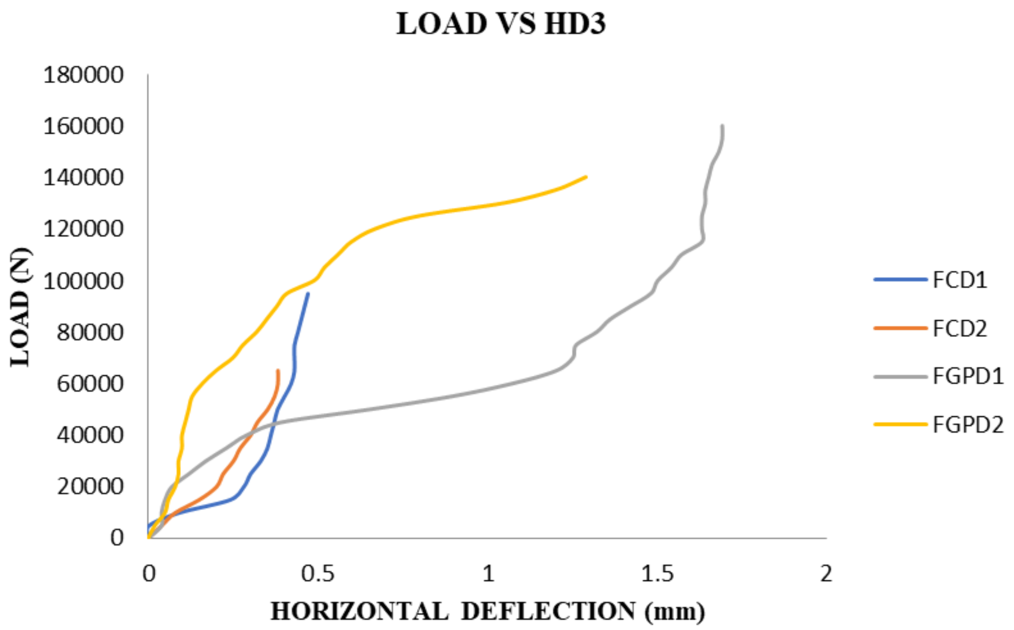


Figure 16 Comparison of Load vs Horizontal Deflection @ 250mm from base

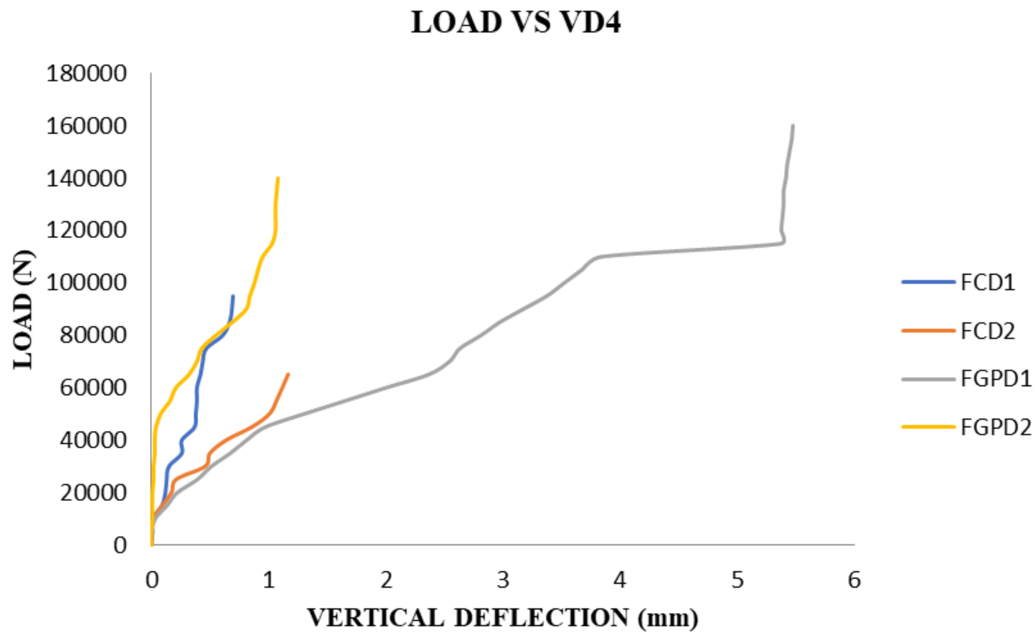


Figure 17 Comparison of Load vs Vertical Deflection @ 400mm from base

The comparison of service load, energy absorption and ductility ratio of all domes are made and shown in Figures 18, 19 and 20

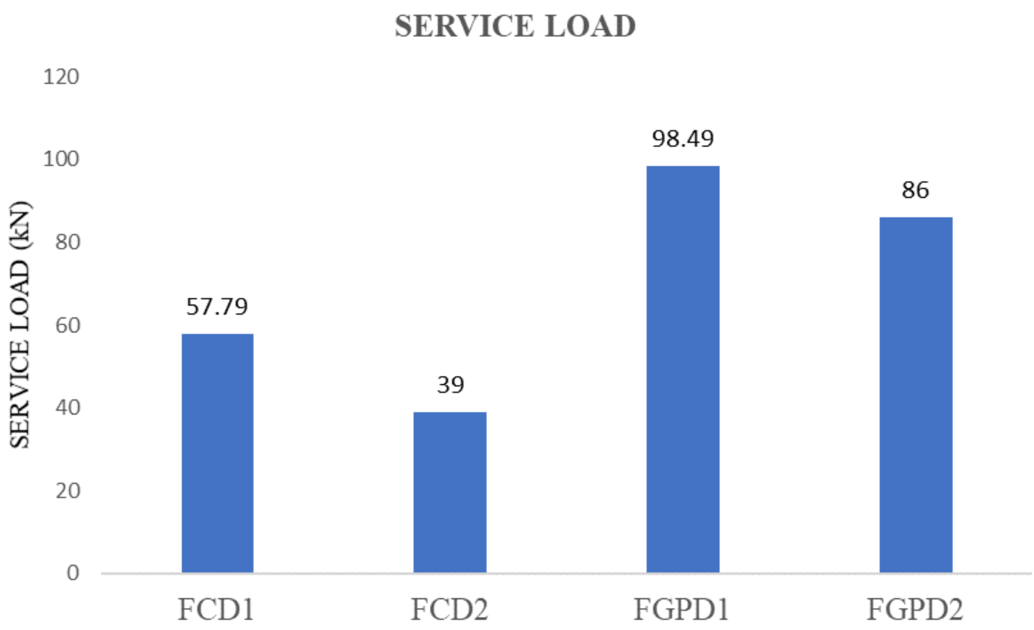


Figure 18 Comparison of Service Loads

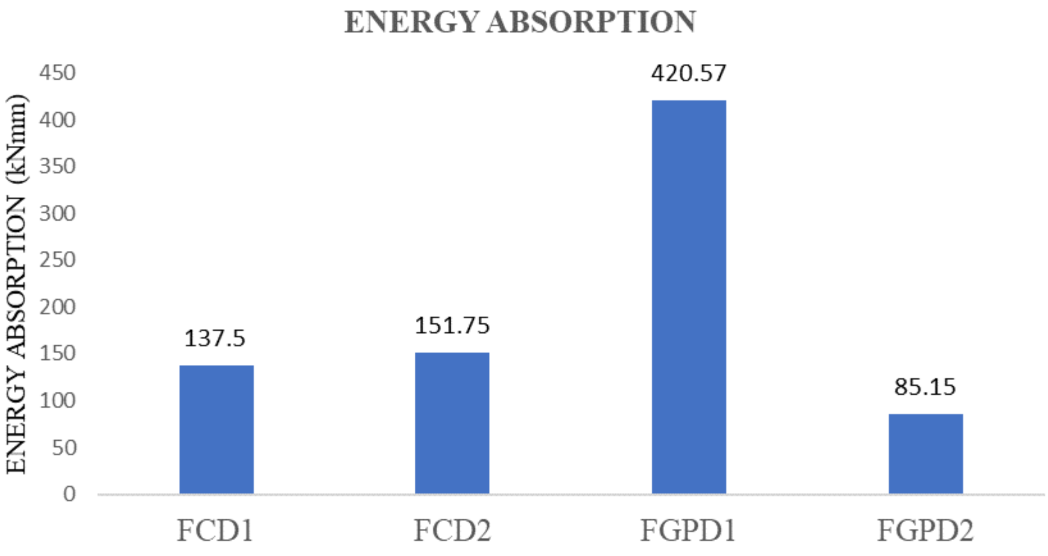


Figure 19 Comparison of energy absorption

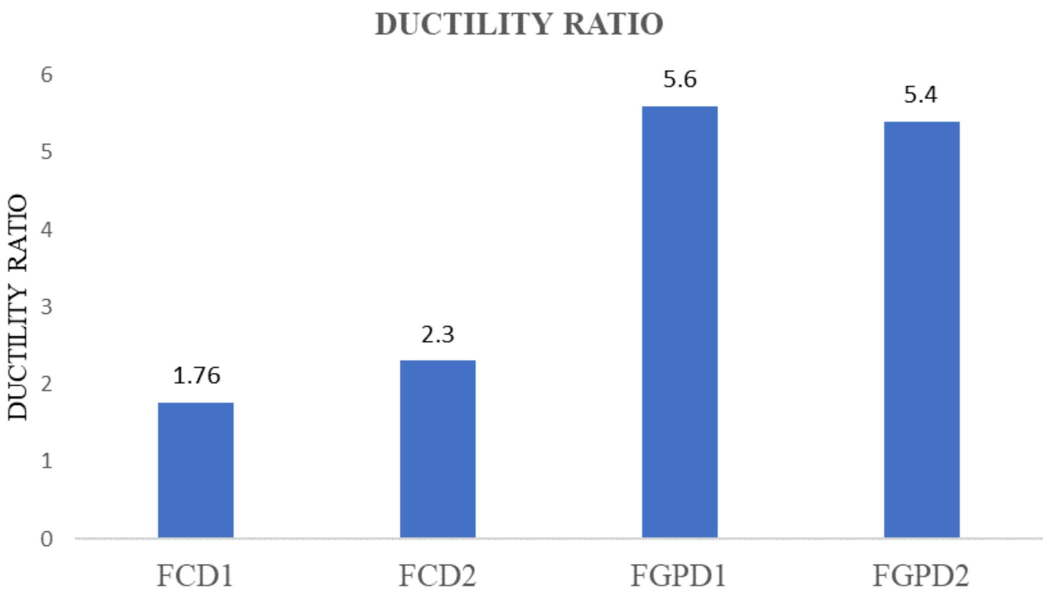


Figure 20 Comparison of ductility ratio

SUMMARY

From the experimental results it can be seen that the ferrogeopolymer dome (FGPD1) has the highest service load of 98.49 kN and ultimate load of 160 kN. Also, this dome (FGPD1) has the highest ductility ratio of 5.6 and energy absorption of 420.57 kN.mm. The ferrocement dome (FCD1) has the highest first crack load of 60 kN. On the other hand results indicated that the dome (FCD1) has the lowest ductility ratio of 1.76 when compared to all other domes. On comparing the ferrocement dome (FCD1) and the ferrogeopolymer dome (FGPD1) having similar reinforcements, the ferrogeopolymer dome (FGPD1) has 40.62% higher ultimate load than the ferrocement dome (FCD1). On comparing the ferrocement dome (FCD2) and ferrogeopolymer dome (FGPD2) having similar (50% reduced reinforcements), the ferrogeopolymer dome has the ultimate load of 53.57% higher than that of the ferrocement dome (FCD2).

CONCLUSION

The experimental program investigated the structural performance of ferrocement and ferrogeopolymer domes with varying reinforcements. Two ferrocement domes and two ferrogeopolymer domes were cast and tested up to failure. In each category of domes 100% and 50% reinforcement was used. Based on the experimental study on ferrocement and ferrogeopolymer domes, the following conclusions are drawn.

1. The ferrocement dome was cast with cement mortar 1:2.5 with w/c ratio 0.45. The circumferential and meridional reinforcement of dome is reduced to 50% and tested. Welded wire mesh and expanded metal mesh are used. The compressive strength of CM is obtained as 45 N/mm^2. The tensile (yield) strength of 6mm diameter rod, welded wire mesh and expanded metal mesh are 505.36 N/mm^2, 413 N/mm^2 and 305 N/mm^2.
2. The ferrogeopolymer dome was cast with geopolymer mortar. Instead of cement, fly ash and GGBS of equivalent quantity was used. The alkaline solution of NaOH and Na_2SiO_3 were used. The geopolymer mortar cubes were cast and cured under ambient condition for 7 days and the compressive strength was found as 46.24 N/mm^2.
3. The load carrying capacity of ferrocement dome is 95 kN while the same in 50% of its reinforcement dome is 65 kN.

4. The load carrying capacity of ferrogeopolymer dome is 160 kN while the same in 50% of its reinforcement dome is 140 kN.
5. The ferrogeopolymer dome shown 40.62% higher ultimate load when compared to the corresponding ferrocement dome.
6. The half the meridional and circumferential reinforcement domes, the ferrogeopolymer dome shown 53.57% higher ultimate load when compared to ferrocement dome.
7. The ferrocement dome of half reinforcement shown 46.1% reduction in ultimate load while the same obtained in ferrogeopolymer dome is 14.28%.
8. The energy absorption capacity is very high (420.57 kNmm) in ferrogeopolymer domes when compared to all other domes.
9. The ductility ratio is high in ferrogeopolymer domes when compared to ferrocement domes.
10. The ferrogeopolymer domes are very much feasible for structural application since they possess high load carrying capacity as well as eco-friendly one.

CHAPTER 9

DEVELOPMENT OF ROOFING SYSTEM USING FERROGEOPOLYMER CHANNELS

DIMENSIONS OF CHANNEL

Size of the specimen = 3000mm x 750mm x 290mm (including two nibs at bottom)

Size of nibs = 45mm x 45mm

Thickness = 32mm

MATERIALS USED

Fe 500 rods were used for reinforcement

8mm rods at nib

6mm rods at top

Welded wire mesh of grid size 17mm x 17mm

Expanded metal mesh of size 17mm x 10mm

Geopolymer mortar 1:3 was used

Fly ash and GGBS each 50% is used instead of cement

5 molarity of NaOH is adopted

Curing condition – Ambient curing

Fig.1 Reinforcement cage

Fig.2 Reinforcement cage on mould

Fig.3 Finished shape of ferrogeopolymer Channel

Fig.4 Ferrogeopolymer Channel After Removing from the Mould

Fig.5 Test Setup

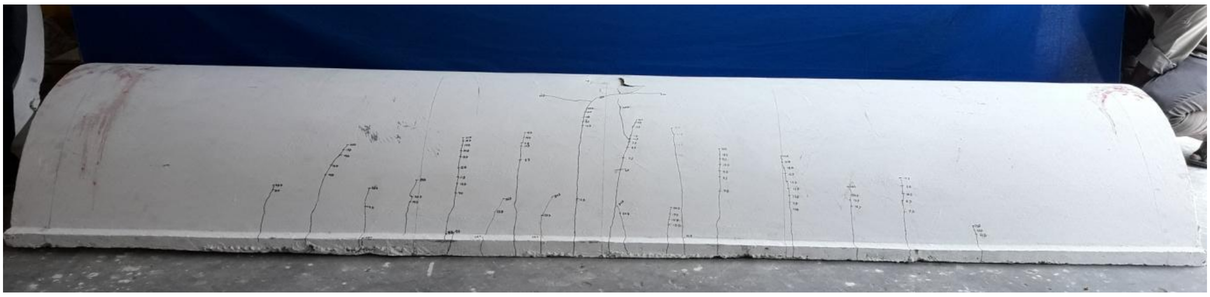


Fig.6 Crack Pattern of Ferrogeopolymer Channel

RESULTS AND DISCUSSION

GENERAL

Based on the results obtained by testing ferrocement and Ferrogeopolymer channels, the load deflection behavior, FCM Channel 1, FCM Channel 2, FGPM Channel 1 and FGPM Channel 2.The Cost Comparison for FCM Channel 1, FCM Channel 2, FGPM Channel 1 and FGPM Channel 2 are discussed in the chapter.

COMPARISON OF LOAD-DEFLECTION OF FERROCEMENT CHANNELS

The comparison of load-deflection behaviour of ferrocement channel with (FCM2) and without (FCM 1) Beam is shown in Figure 7. The test results is given in Table 1.

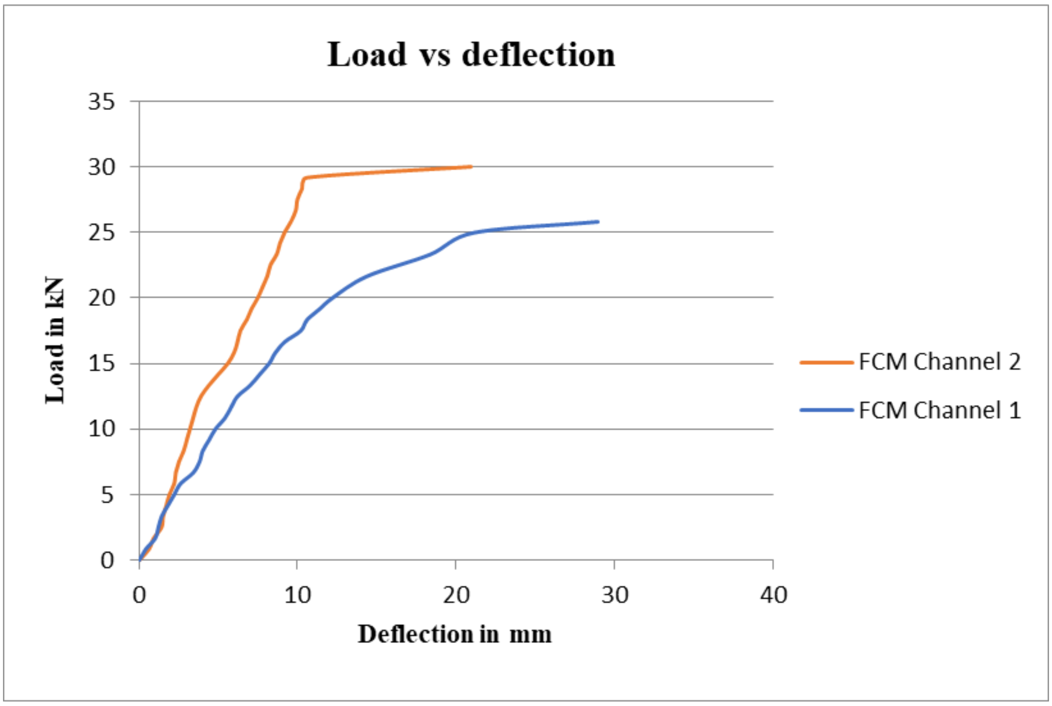


Fig. 7 Load -Deflection Curve for Ferrocement Channel (Bigger Dial gauge)

TABLE 1 Ferrocement Channel with Beam and without Beam

Sl.No.	WITHOUT BEAM [FCM 1]	WITH BEAM [FCM 2]
1	First crack load = 4.167 kN	First crack load = 7.5 kN
2	Ultimate load = 25 kN	Ultimate load = 29.16 kN
3	Central deformation for first crack load = 1.8 mm	Central deformation for first crack load = 1.5 mm
4	Failure load deformation = 29mm	Failure load deformation = 21mm

COMPARISON OF LOAD-DEFLECTION OF FERROGEOPOLYMER CHANNELS

The comparison of load-deflection behaviour of ferrogeopolymer channels with (FGPM 2) and without (FGPM 1) Beam is shown in figure 8. The test results is given in Table 2.

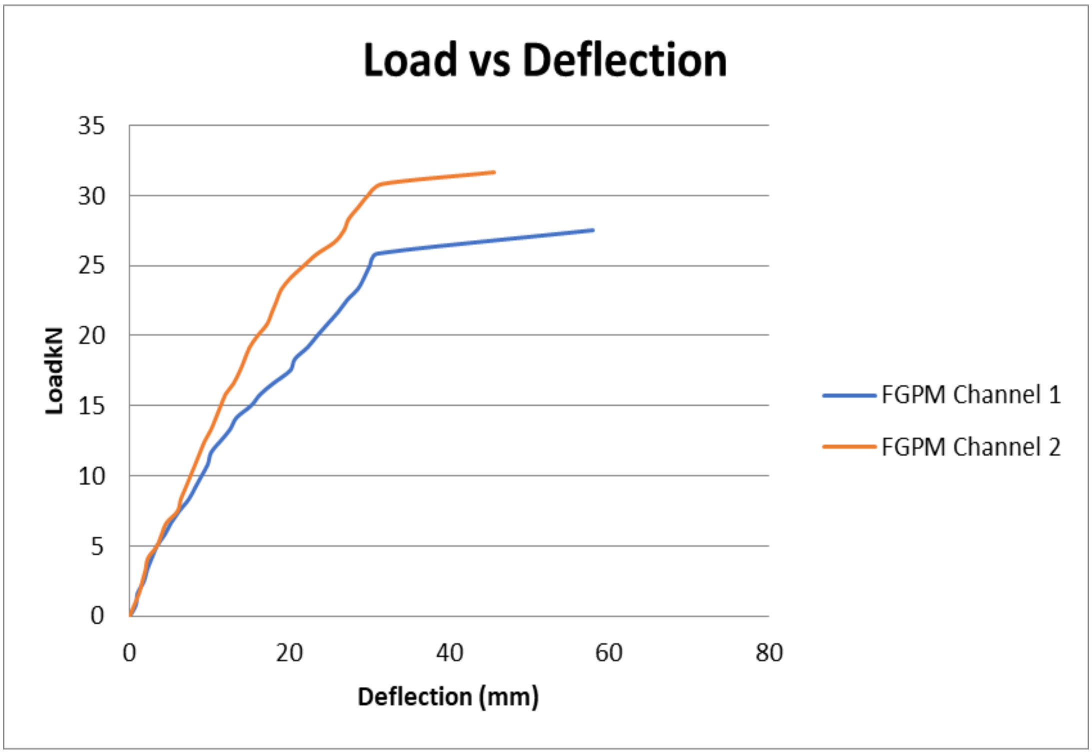


Fig.8 Load-Deflection Curve of FGPM (Channel 1&2)

Table 2 Ferrogeopolymer Channel without Beam and with Beam channels

Sl.No.	WITHOUT BEAM [FGPM 1]	WITH BEAM [FGPM2]
1	First crack load = 4.99 kN	First crack load = 7.5 kN
2	Ultimate load = 25.82 kN	Ultimate load = 30.82 kN
3	Central deformation for first crack load = 3.4 mm	Central deformation for first crack load = 6.0 mm
4	Failure load deformation = 58mm	Failure load deformation = 45.6mm

COMPARISON OF LOAD-DEFLECTION OF FERROCEMENT (FCM CHANNEL1) AND FERROGEOPOLYMER (FGPM1) CHANNELS.

The comparison of load-deflection behaviour of ferrocement channel without Beam (FCM Channel1) and Ferrogeopolymer channels without Beam (FGPM Channel1) is shown in Figure 9.

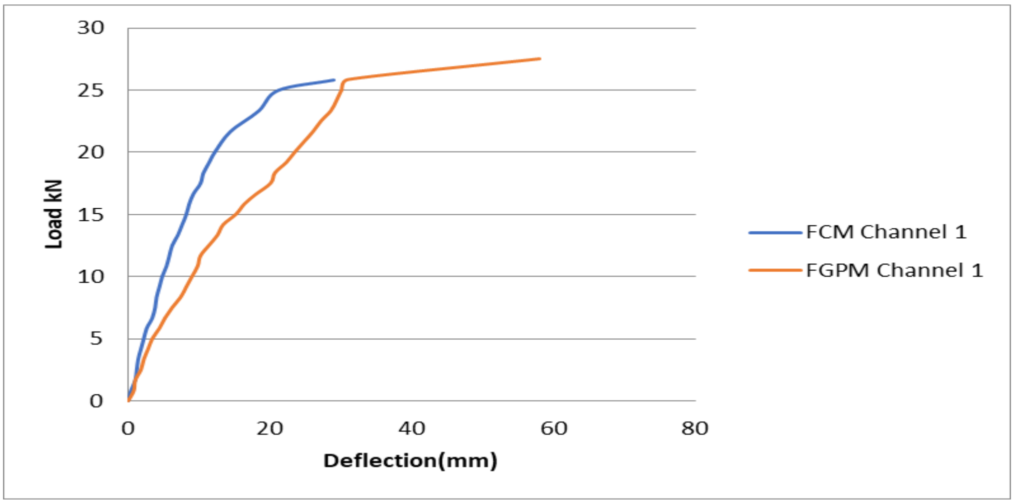


Fig.9 Load-Deflection Curve of FCM1, FGPM1

COMPARISON OF LOAD-DEFLECTION OF FERROCEMENT (FCM2) AND FERROGEOPOLYMER (FGPM2) CHANNELS

The comparison of load-deflection behaviour of Ferrocement channel with Beam (FCM Channel2) and Ferrogeopolymer channels with Beam (FGPM Channel 2) shown in. Figure 10.

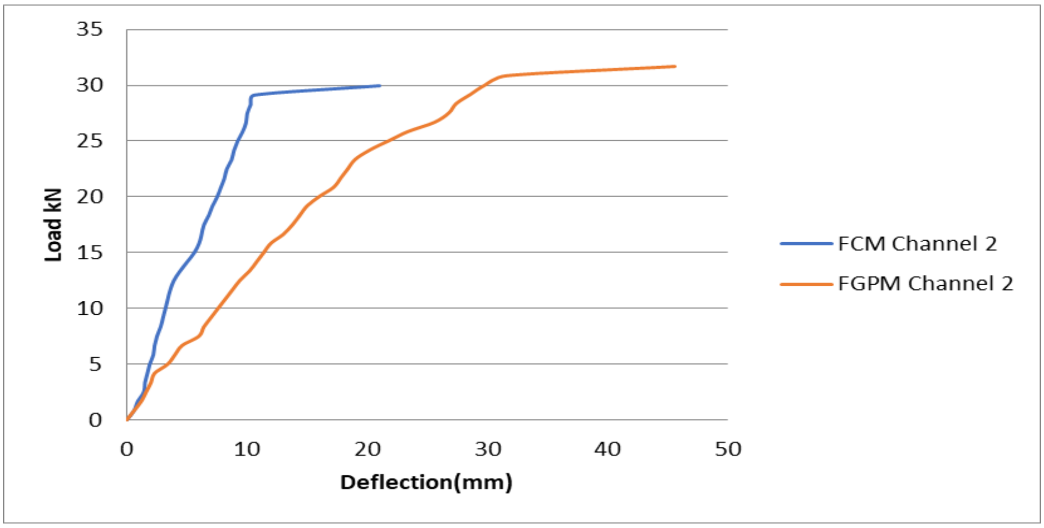


Fig.10 Load-Deflection Curve of FCM2, FGPM2

COMPARISON OF ULTIMATE LOAD AND DEFLECTION AT FAILURE OF ALL CHANNELS

The ultimate load carrying capacity of all channels is compared and shown in Figure 11.

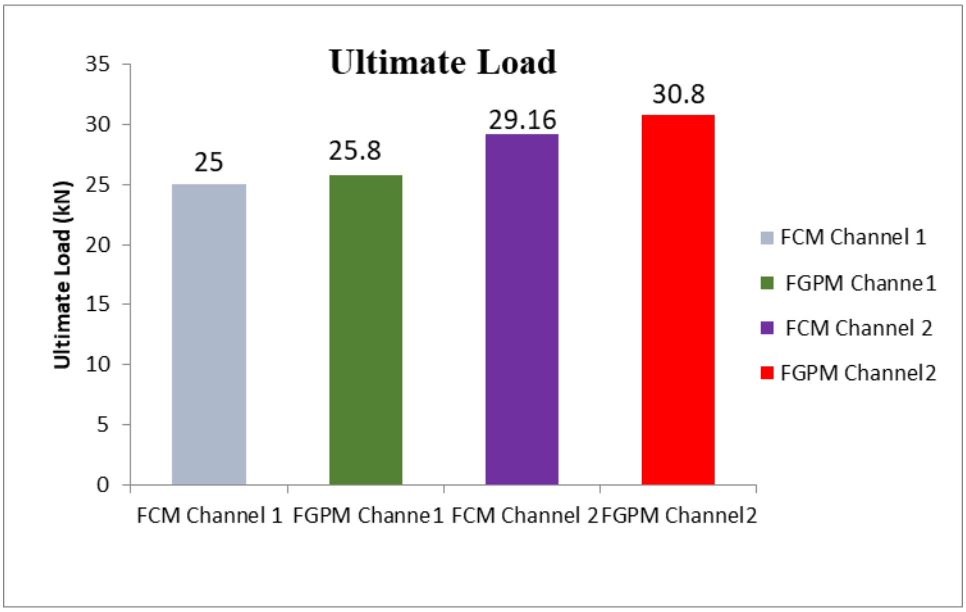


Fig.11 Comparison of Ultimate Load of all Channels

The deflection at failure of channel of all types is compared and shown in Figure 12
.

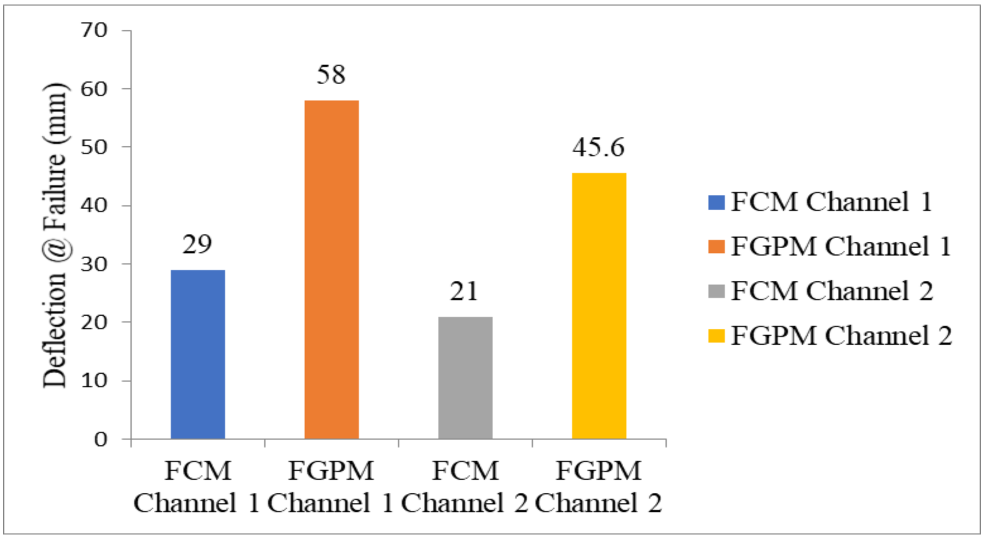


Fig. 12 Comparison of Deflection @ Failure of Channels

MOMENT CURVATURE RELATIONSHIP

From the experimental work the moment curvature relationship curve was obtained for (FCM Channel 1, FCM Channel 2, FGPM Channel 1 and FGPM Channel 2) Ferrocement and Ferrogeopolymer channel without beam compared for moment curvature relationship in Figure 13 and with beam is compared in Figure 14.

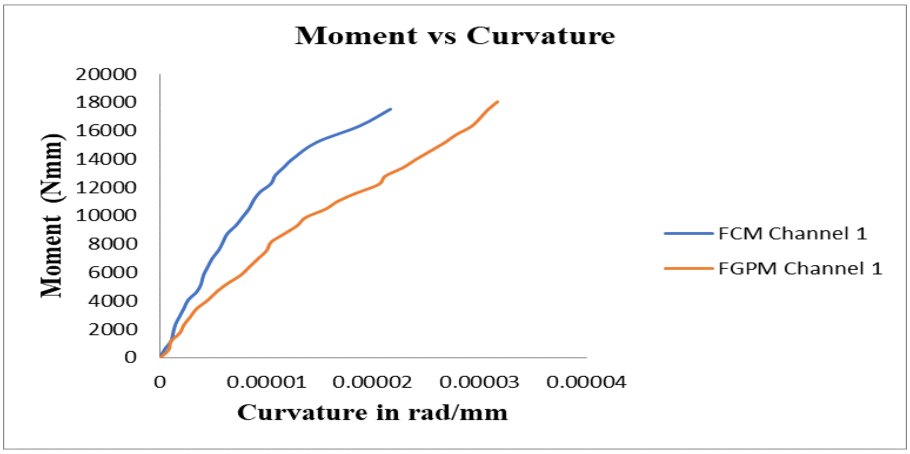


Fig. 13 Comparisons of Moment Curvature FCM, FGPM (channel 1)

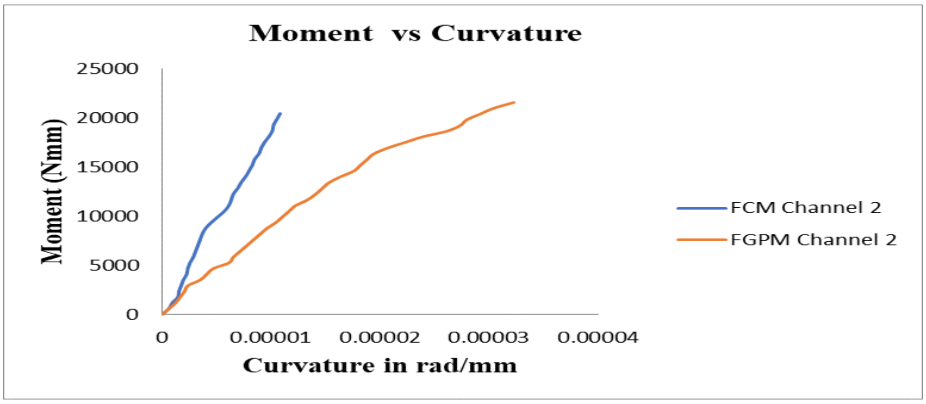


Fig. 14 Comparisons of Moment Curvature FCM, FGPM (channel 2)

COST COMPARISON

COST ANALYSIS (FCM Channel 1)

The cost of ferrocement roofing channel is worked out per item wise and given in Table 3. The cost of one channel comes Rs.2983.70 only.

Table 3 Cost Analysis for Single Ferrocement Channel (FCM Channel1)

Sl. No.	Item	Qty.	Rate	Amount (Rs)
1	Steel	4.03 Kg	40/Kg	162.00
2	Welded Mesh	40sq.ft	11/sq.ft	440.00
3	Expanded Mesh	40sq.ft	9/sq.ft	360.00
4	Cement	1.05 bag	430/bag	451.50
5	Sand	0.0735 cu.m	27/cu.ft	70.20
6	Labour (Mason)	2	450/6hr	900.00
7	Labour (Bar Bender)	2	300/4hr	600.00
			Total Rs.	**2,983.70**

COST ANALYSIS (FGPM Channel 1)

The cost of ferrogeopolymer roofing channel is worked out per item wise and given in Table 4. The cost of one channel comes Rs.3657.80 only.

Table 4 Cost Analysis for Single Ferrogeopolymer Channel (FGPM Channel1)

<table>
<tr><th>Sl. No.</th><th colspan="2">Item</th><th>Qty.</th><th>Rate</th><th>Amount (Rs)</th></tr>
<tr><td>1</td><td colspan="2">Steel</td><td>4.03 kg</td><td>40/Kg</td><td>162.00</td></tr>
<tr><td>2</td><td colspan="2">Welded Mesh</td><td>40 sq.ft</td><td>11/sq.ft</td><td>440.00</td></tr>
<tr><td>3</td><td colspan="2">Expanded Mesh</td><td>40 sq.ft</td><td>9/sq.ft</td><td>360.00</td></tr>
<tr><td>4</td><td colspan="2">Fly Ash</td><td>26.5 kg</td><td>15/kg</td><td>397.50</td></tr>
<tr><td>5</td><td colspan="2">GGBS</td><td>26.5 kg</td><td>13.80/kg</td><td>365.70</td></tr>
<tr><td rowspan="2">6</td><td rowspan="2">Alkaline Solution</td><td>Na_2SiO_3</td><td>19 kg</td><td>16/kg</td><td>304.00</td></tr>
<tr><td>NaOH</td><td>1.82 kg</td><td>40/kg</td><td>72.80</td></tr>
<tr><td>7</td><td colspan="2">Sand</td><td>0.0735 cu.m</td><td>27/cu.ft</td><td>70.20</td></tr>
<tr><td>8</td><td colspan="2">Labour (Mason)</td><td>2</td><td>450/6 hr</td><td>900.00</td></tr>
<tr><td>9</td><td colspan="2">Labour (Bar Bender)</td><td>2</td><td>300/ hr.</td><td>600</td></tr>
<tr><td></td><td colspan="2"></td><td></td><td>Total, Rs.</td><td>3,657.80</td></tr>
</table>

The ferrogeopolymer channel cost is 22.5% more than ferrocement channel.

4.8.3 COST ANALYSIS (FCM Channel 2)

The cost of ferrocement roofing channel with beam is worked out per item wise and given in . Table 5. The cost of one channel comes Rs.3431.83 only

Table 5 Cost Analysis for Single Ferrocement Channel With Beam (FCM Channel 2)

Sl. No.	Item	Qty.	Rate	Amount (Rs)
1	Steel	5.03 Kg	40/Kg	201.08
2	Welded Mesh	40 sq.ft	11/sq.ft	440.00

3	Expanded Mesh	40 sq.ft	9/sq.ft	360.00
4	Cement	1.27 bag	430/bag	546.00
5	Sand	0.0889cu.m	27/cu.ft	84.75
6	Labour (Mason)	2	450/6hr	1050.00
7	Labour (Bar Bender)	2	300/4hr	750.00
			Total, Rs.	**3,431.83**

COST ANALYSIS (FGPM Channel 2)

The cost of ferrogeopolymer roofing channel with beam is worked out per item wise and given in Table 6. The cost of one channel comes Rs.4255.63 only

Table 6 Cost analysis for single ferrogeopolymer channel With Arch Beam (FGPM Channel 2)

Sl. No.	Item		Qty.	Rate	Amount (Rs)
1	Steel		5.03 kg	40/Kg	201.08
2	Welded Mesh		40 sq.ft	11/sq.ft	440.00
3	Expanded Mesh		40 sq.ft	9/sq.ft	360.00
4	Fly Ash		32 kg	15/kg	480.00
5	GGBS		32 kg	13.80/kg	441.60
6	Alkaline Solution	Na_2SiO_3	22.59 kg	16/kg	361.44
		NaOH	2.17 kg	40/kg	86.76
7	Sand		0.0889 cu.m	27/cu.ft	84.75
8	Labour (Mason)		2	450/6 hr	1050.00
9	Labour (Bar Bender)		2	300/ 5hr.	750.00
				Total Rs.	**4255.63**

The ferrogeopolymer channel with beam is 24% more than ferrocement channel. The cost of ferrocement, ferrogeopolymer and RCC channel is worked out and compared in figure 15. The cost of ferrocement is obviously lower than RCC channel.

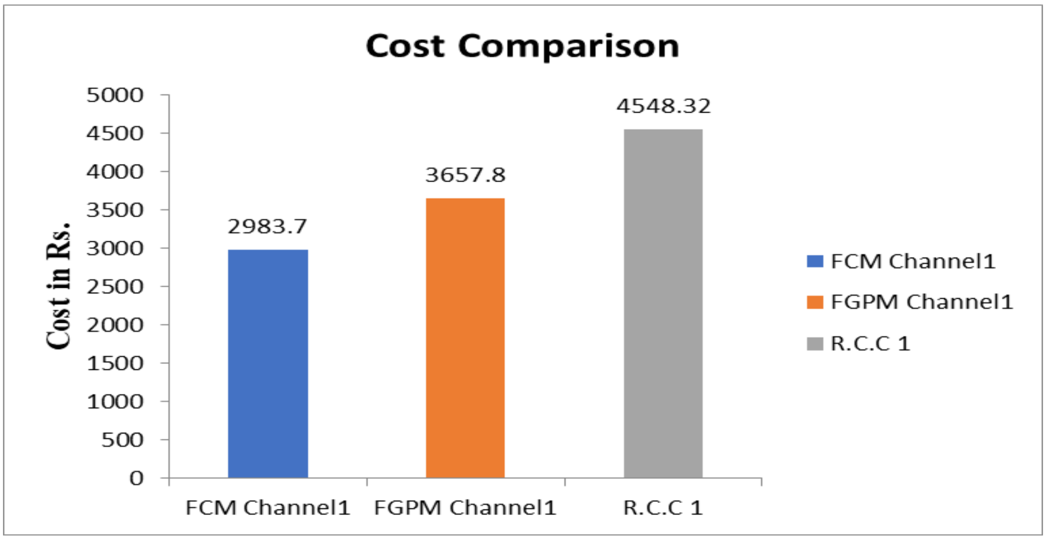


Fig. 15 Cost Comparison for Channel 1

The cost ferrocement, ferrogeopolymer and RCC channel with beam is compared in Figure 16.

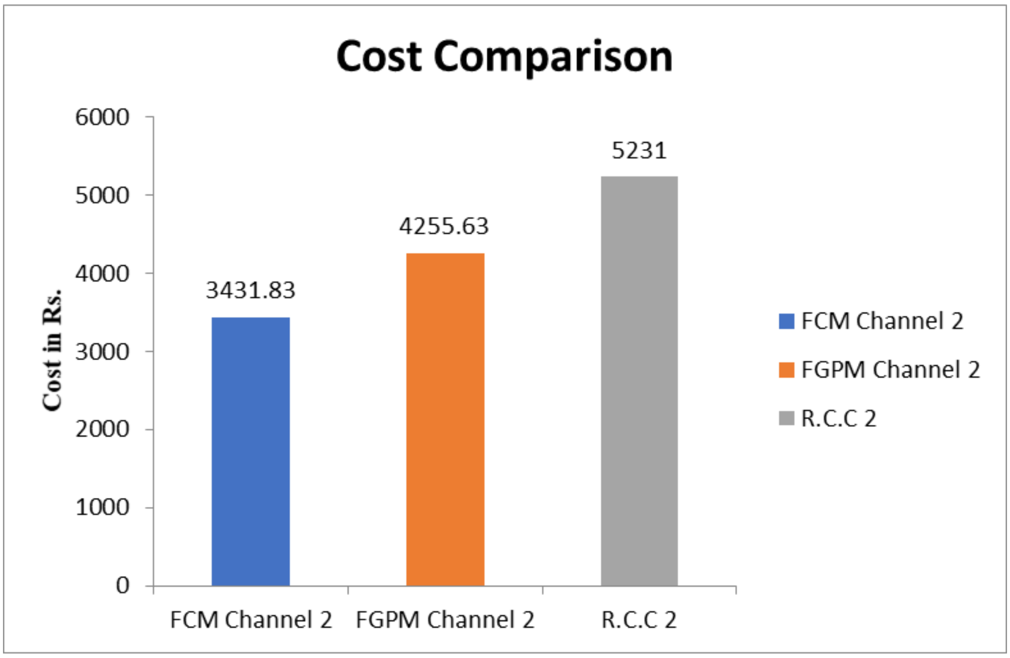


Fig.16 Cost Comparison for Channel 2

The cost of ferrocement and RCC roof channel is compared in Figure 17 and the same with beam is compared in Figure 18

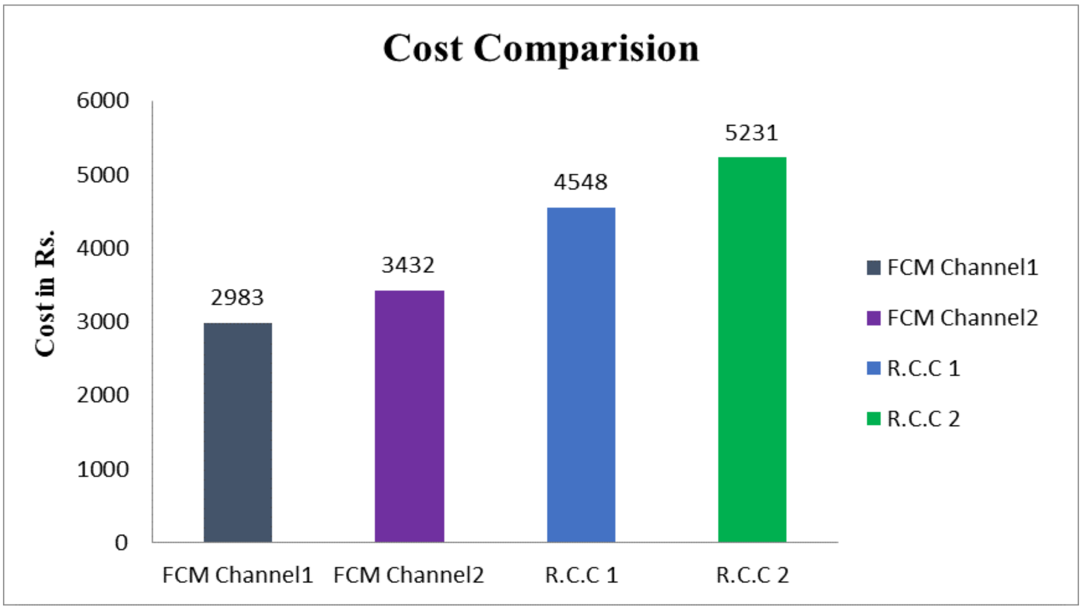


Fig. 17 Cost Comparison for FCM and RCC. (Channel 1&2)

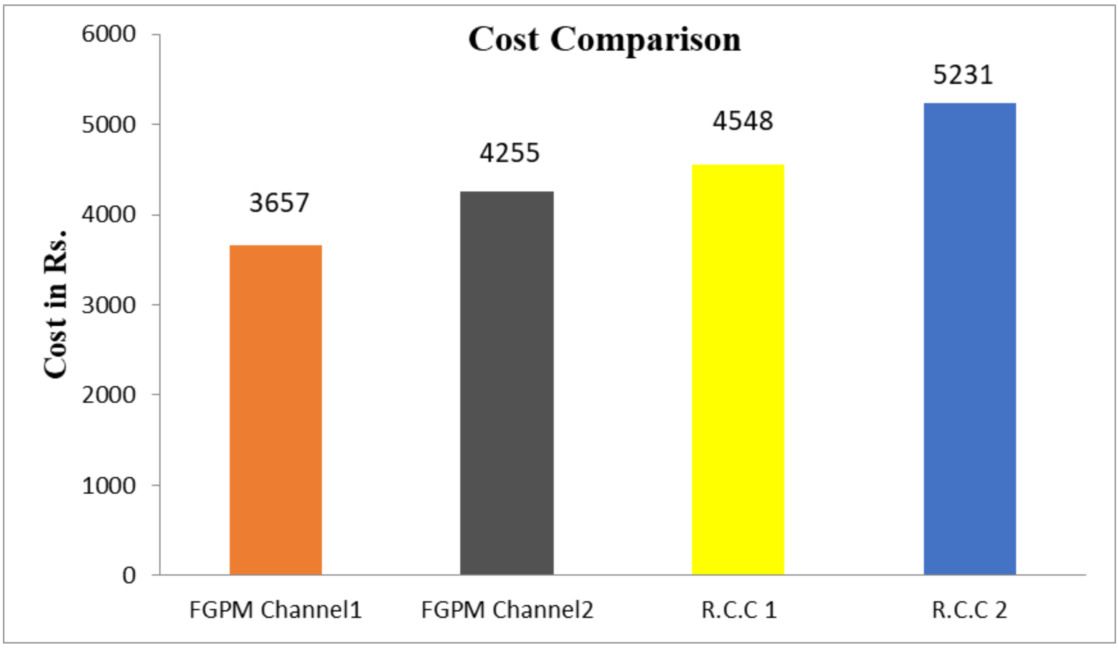


Fig.18 Cost Comparison for FGPM and RCC. (Channel 1&2)

SUMMARY

Ferrocement and Ferrogeopolymer roofing channels are cast and tested under flexure. The load deflection curve is obtained for all channels and presented. The load carrying capacity of ferrogeopolymer channel is more when compared to ferrocement channels. Also, the deflection of geopolymer channel is more when compared to ferrocement channels and it shows it is more ductile then ferrocement channel. Hence, even though the cost of ferrogeopolymer channel is higher, strength and stiffness as well as environmental point of view ferrogeopolymer roofing channel is good for civil Engineering Structural Element.

CONCLUSION

5.1 GENERAL

This chapter summaries the experimental study and investigation of material related works and cost comparative study made on existing journals the related to the thesis work. Based on the development of roofing system using Ferrogeopolymer channels obtained and following conclusions are drawn.

1. Ferrocement of cement mortar 1:3 with w/c ratio 0.45 was used to cast cement channel of size of specimen 3000mm x750 mm x 290 mm including two 40 x 45 mm

nibs at bottom. The cement mortar was tested after 28 days water curing and found as 53.17 N/mm^2.

2. The geopolymer mortar cubes of 50% fly ash and 50% GGBS with three parts of sand using alkaline solution of 0.45 .The alkaline solution is the mixture of sodium silicate and sodium hydroxide with ratio of 2.5.
3. The geopolymer mortar cubes cast and ambient cured for 7 days and tested. The compressive strength of geopolymer mortar with 5M,6M and 7M NaOH concentration after 7 days of ambient curing was found as 30.29 N/mm^2, 43.94 N/mm^2 and 49.86 N/mm^2.
4. The Ferrocement and Ferrogeopolymer roofing channel with and without beam were cast and tested under flexure.
5. The ferrocement channel with beam showed 16.6% increase in load carrying capacity as compared to ferrocement channel without beam.
6. The ferrogeopolymer channel with beam showed 19% increase in load carrying capacity as compared to ferrogeopolymer channel without beam.
7. The ferrogeopolymer channel without beam showed 3.28% increase in load carrying capacity as compared to ferrocement channel without beam.
8. The ferrogeopolymer channel with beam showed 5.69% increase in load carrying capacity as compared to ferrocement channel with beam.
9. The cost of ferrocement channel with beam is increased by 15.02% as compared to ferrocement channel without beam.
10. The cost of ferrogeopolymer channel with beam is increased by 16.35% as compared to ferrogeopolymer channel without beam.
11. The cost of ferrogeopolymer channel without beam is increased by 22.59% as compared to ferrocement channel without beam.

12. The cost of ferrogeopolymer channel with beam is increased by 24.0% as compared to ferrocement channel with beam.
13. From the results obtained from ferrocement and ferrogeopolymer channel, it is recommended that the ferrogeopolymer channels can be used in construction since it possess better performance than ferrocement channels.

    Even though the cost of ferrogeopolymer roofing channel is slightly high, from the load carrying capacity increase in deflection and ecofriendly since there is no cement, ferrogeopolymer roofing channels are recommended for structural use in modern construction.

CHAPTER 10
EXPERIMENTAL INVESTIGATION ON FERROGEOPOLYMER WATER PIPES

DIMENSIONS OF PIPE

Diameter = 360mm

Length = 1.8m

Thickness =30mm

Fe 500 steel of 6mm dia

Longitudinal bars – 4 numbers

Circular rings - 3 numbers

Welded wire mesh of grid size 17mm x 17mm

Expanded metal mesh of size 17mm x 10mm

Geopolymer mortar 1:2 was used

Fly ash and GGBS each 50% is used instead of cement

5 molarity of NaOH is adopted

Curing condition – Ambient curing

Fig.1 Reinforcement of Pipe

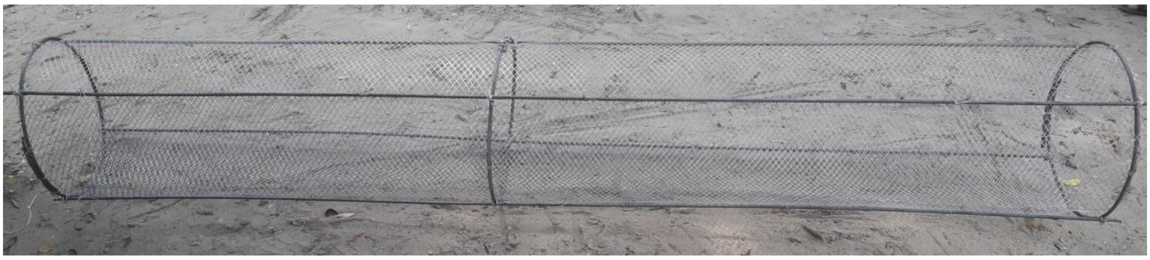


Fig.2 Expanded Mesh on Reinforcement

Fig. 3 Welded and Expanded Meshes on Reinforcement

Fig. 4 Meshes Around the Pipe Mould

Fig.5 Test Setup

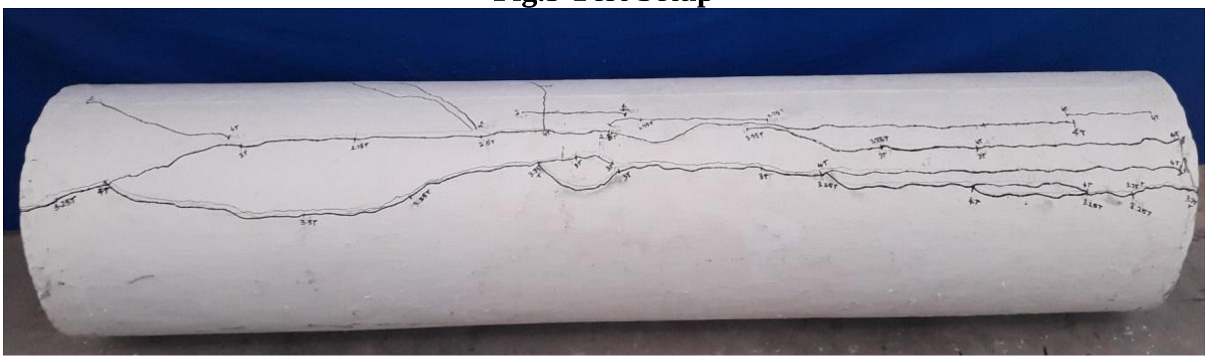


Fig.6 Crack Pattern of Ferrogeopolymer Pipe

RESULT AND DISCUSSION

The experimental results are presented and discussed. In the preliminary investigation of materials, specific gravity of different materials used in this study are found and given in Table 1. The tensile strength of 6 mm diameter rod was found and given in Table 2. Welded wire and expanded mesh were tested under tension and the results are given in Table 3. Ferrocement mortar cubes were tested under compression and the results are given in Table

4. Geopolymer mortar was made with fly ash, GGBS, sand and alkaline solution and tested for compression and the test results in Table 5 to 8.

Table 1 Specific Gravity Results

Materials	Specific Gravity
Cement	3.13
Fine aggregate	2.63
Fly ash	2.25
GGBS	2.83
Sodium Hydroxide	1.47*
Sodium Silicate	1.6*

*** Supplied by the manufacturer**

Table 2 Tensile Strength of Steel Results

Diameter of Steel (mm)	Yield Stress (N/mm^2)	Ultimate Stress (N/mm^2)	Breaking Stress (N/mm^2)
6mm diameter	462.50	627.68	528.58

Table 3 Tensile Strength of Mesh Results

Types of Mesh	Peak Load (kN)	Yield Stress (MPa)	Ultimate Stress (MPa)
Welded Mesh	1.595	465	532
Expanded Mesh	0.405	307	402

Table 4 Compressive Strength of Mortar Cubes at 28 days

Sl.No	Compressive Strength (N/mm^2)	Average Compressive Strength (N/mm^2)
1	47	48
2	48	
3	49	

5M – AMBIENT CURING (50% FLYASH : 50% GGBS)

Table 5 Compressive Strength of Geopolymer Mortar (5M NaOH) Cubes

SI.No.	Area (mm^2)	Load (kN)	Compressive Strength (N/mm^2)	Average Compressive Strength (N/mm^2)
1	70.6×70.6	127	25.47	24.87
2	70.6×70.6	126	25.28	
3	70.6×70.6	119	23.87	

6M – AMBIENT CURING (50% FLYASH : 50% GGBS)

Table 6 Compressive Strength of Geopolymer Mortar (6M NaOH) Cubes

SI.No.	Area (mm^2)	Load (kN)	Compressive Strength (N/mm^2)	Average Compressive Strength (N/mm^2)
1	70.6×70.6	156	31.29	31.96
2	70.6×70.6	163	32.70	
3	70.6×70.6	159	31.89	

7M – AMBIENT CURING (50% FLYASH : 50% GGBS)

Table 7 Compressive Strength of Geopolymer Mortar (7M NaOH) Cubes

SI.No.	Area (mm^2)	Load (kN)	Compressive Strength (N/mm^2)	Average Compressive Strength (N/mm^2)
1	70.6×70.6	168	33.71	32.62
2	70.6×70.6	156	31.29	
3	70.6×70.6	163	32.70	

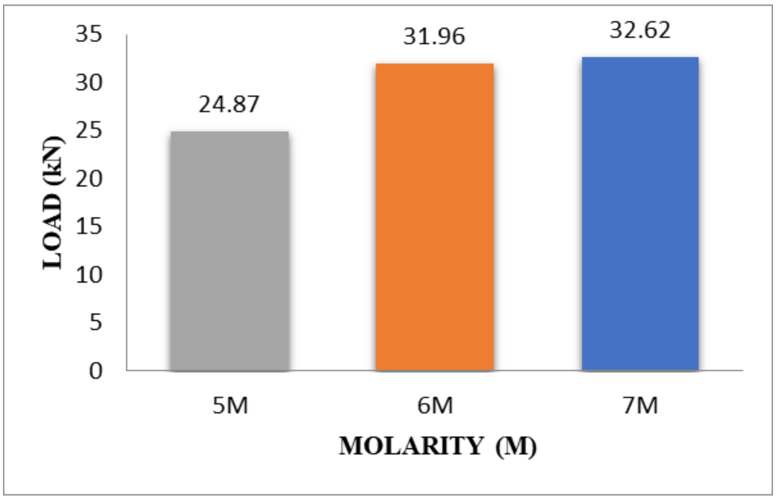


Fig.7 Compressive Strength of Geopolymer Mortar Cubes

5 M – Compressive strength of geopolymer mortar ratio is taken for the ferrogeopolymer water pipe. 2% of Super Plasticizer is added to enhance the workability of geopolymer mortar. To get higher compressive strength of geopolymer mortar 80% GGBS and 20% Fly ash was taken and cubes cast. The test results of geopolymer mortar is given in Table 8.

GEOPOLYMER MORTAR (5M - 20 % FLY ASH : 80% GGBS, 2% SP)

Table 8 Compressive Strength of Geopolymer Mortar (5M) Cubes

SI.No.	Area (mm^2)	Load (kN)	Compressive Strength (N/mm^2)	Average Compressive Strength (N/mm^2)
1	4984.36	213	42.73	45.28
2	4984.36	231	46.30	
3	4984.36	238	47.74	
4	4984.36	221	44.33	

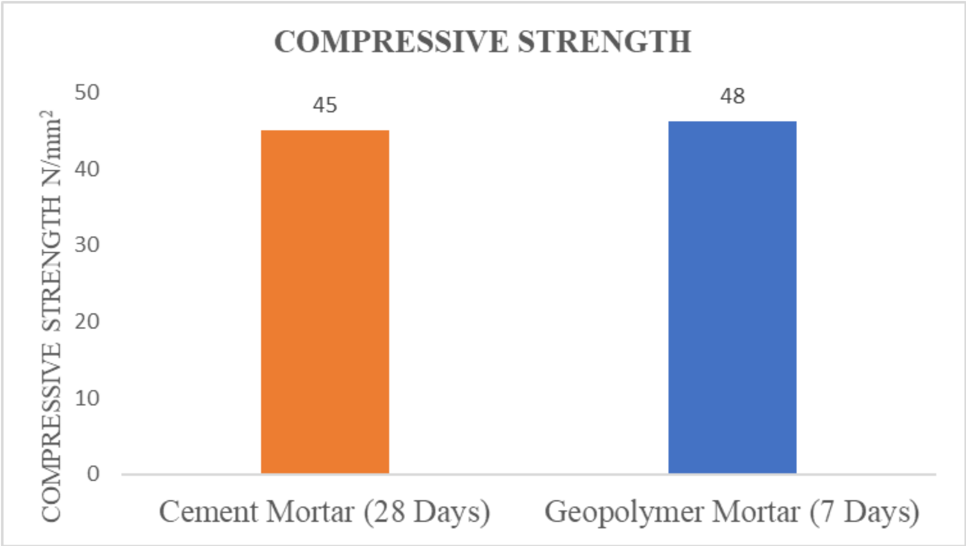


Fig.8 Comparison of Compressive Strength of Cement Mortar and Geopolymer Mortar

The result shows that the compressive strength of geopolymer mortar cubes is 2.72% higher than the compressive strength of cement mortar cubes.

The experimental results for the three pipes included first crack load, ultimate load and width of the crack were presented in Table 9. The first crack load and ultimate load at failure of all pipes are compared in Figures 9 and 10 respectively.

Table 9 Comparison Between the Different Types of Pipes

Sl.No	PIPES	FIRST CRACK LOAD (kN)	ULTIMATE LOAD (kN)	CRACK WIDTH (mm)
1	Ferrocement pipe	10	40	0.01
2	Ferrogeopolymer pipe	22.5	50	0.01
3	Commercial pipe	5	8.3	0.01

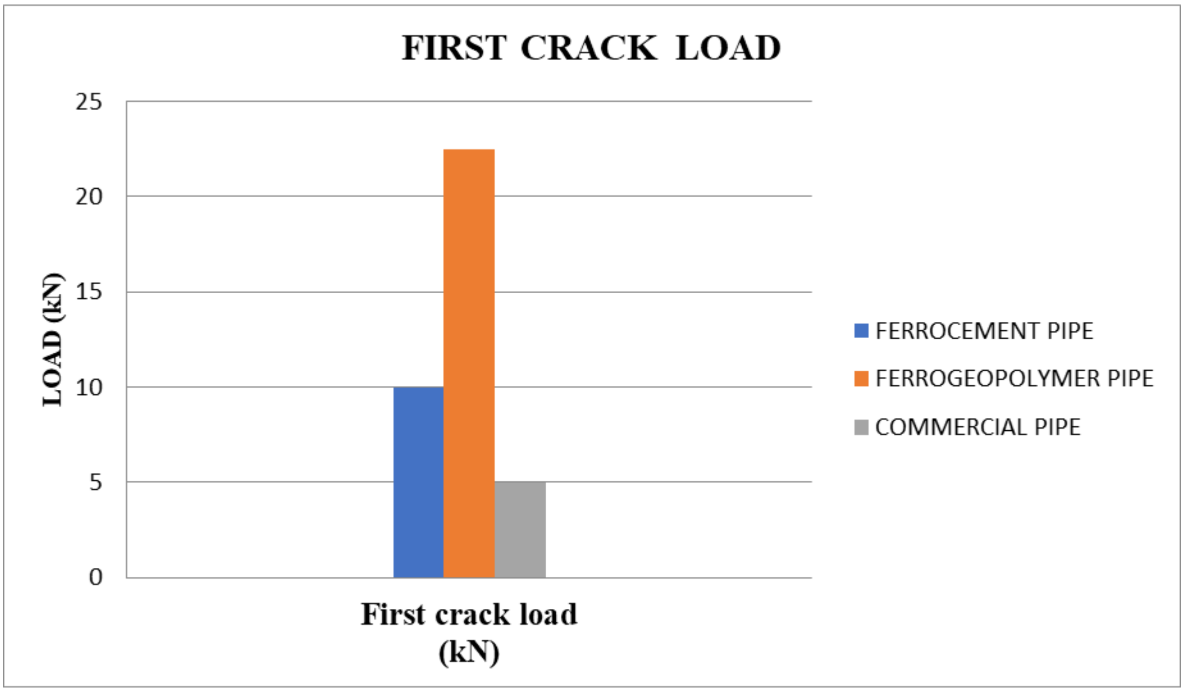


Fig.9 First Cracking load of Water Pipes

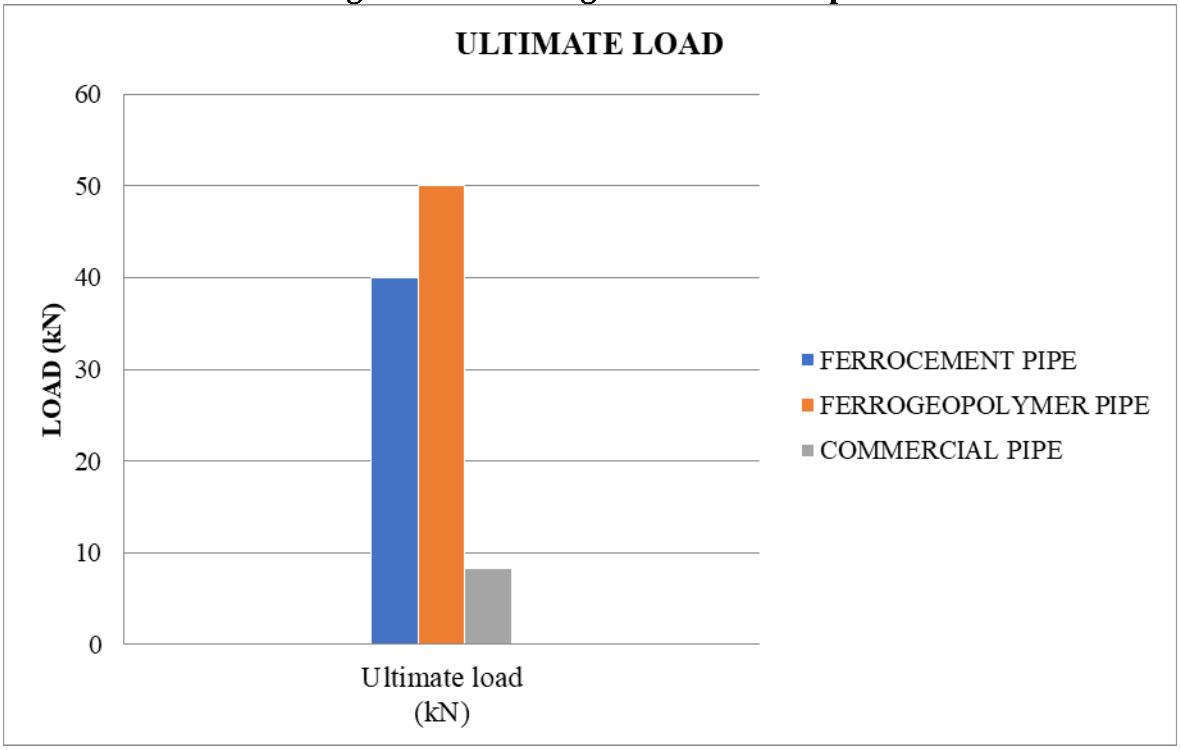


Fig.10 Ultimate Load of Water Pipes

Load – deflection curve at six measured points of all pipes presented in 4.5 to 4.9.

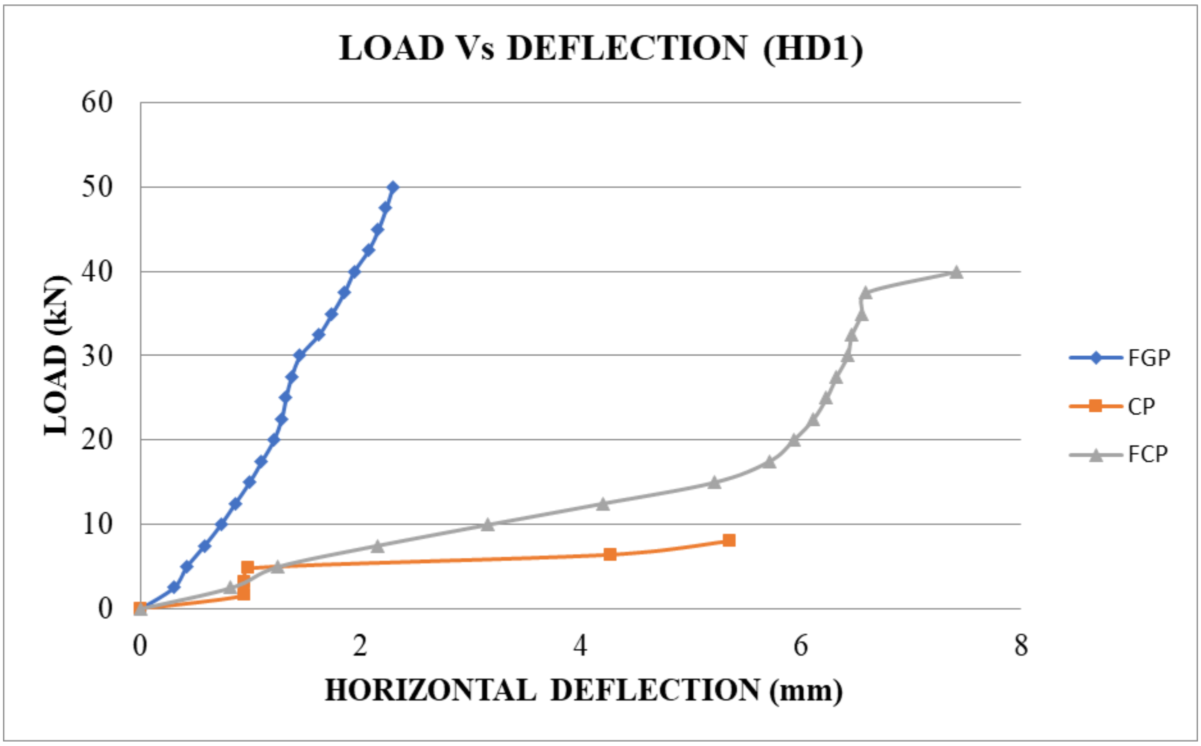


Fig.11 Load Vs Deflection curve for pipes (HD1)

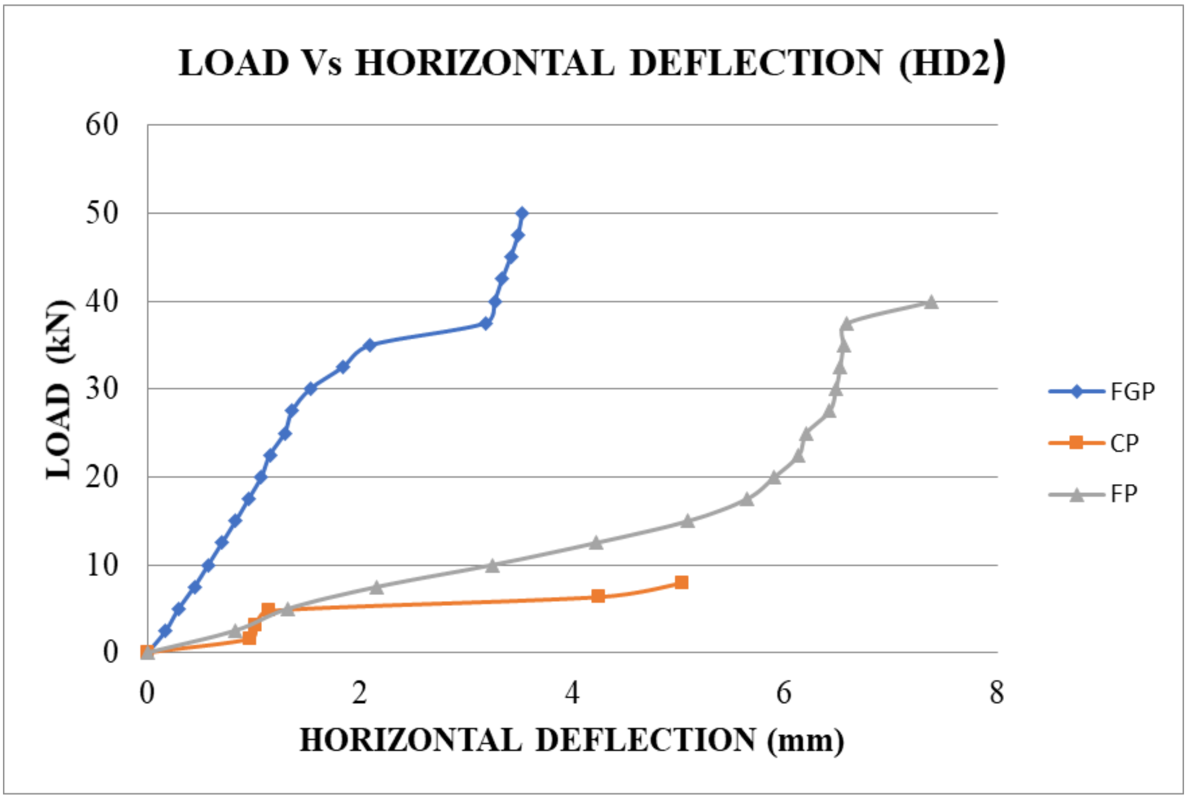


Fig.12 Load Vs Deflection Curve for Pipes (HD2)

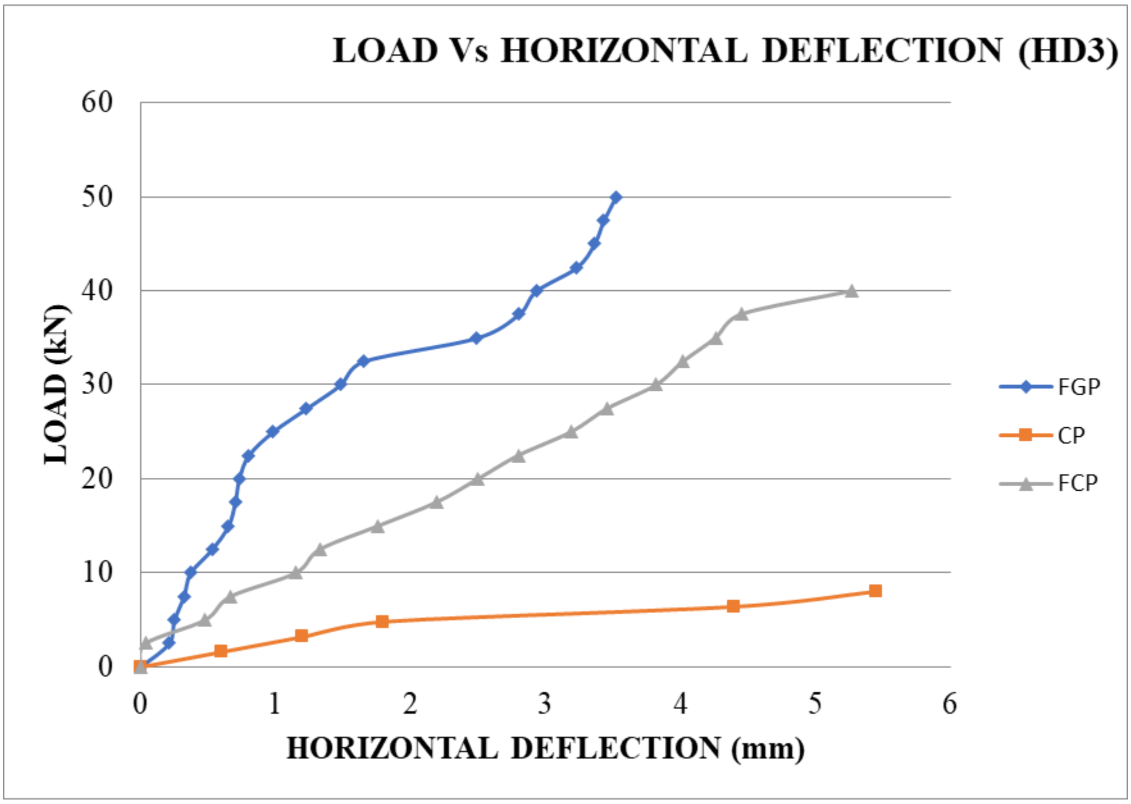


Fig.13 Load Vs Deflection Curve for Pipes (HD3)

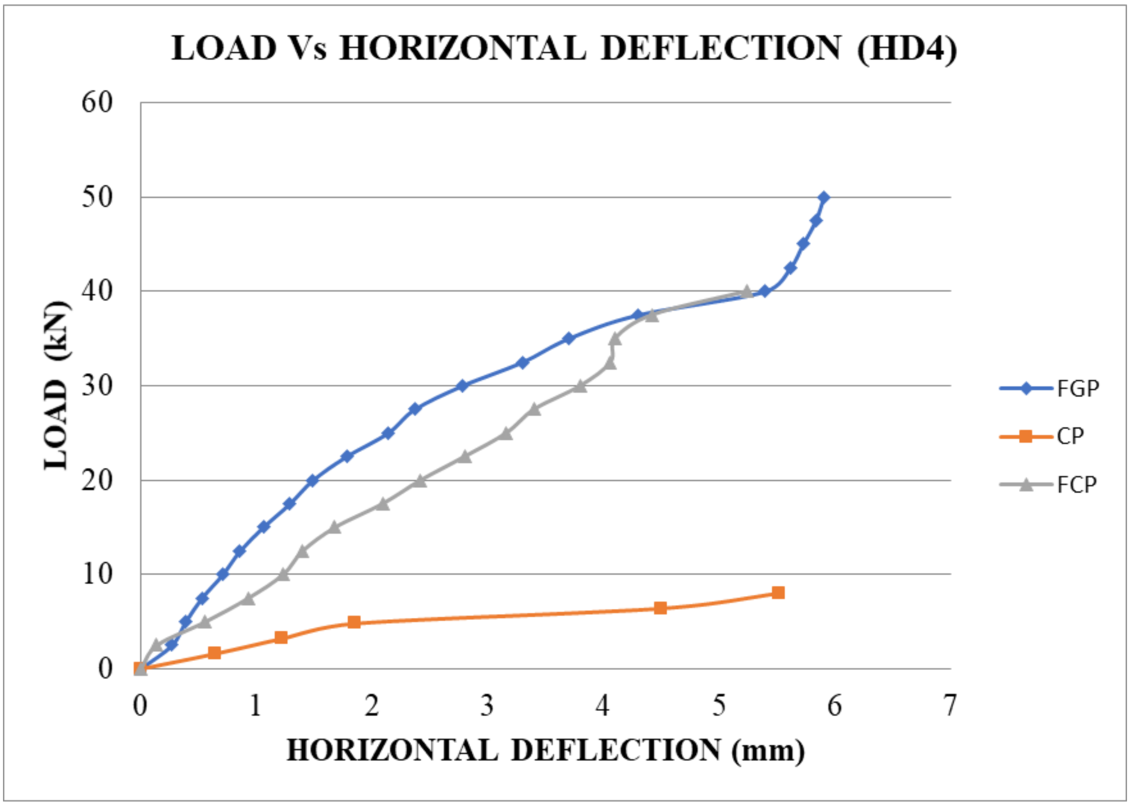


Fig.14 Load Vs Deflection Curve for Pipes (HD4)

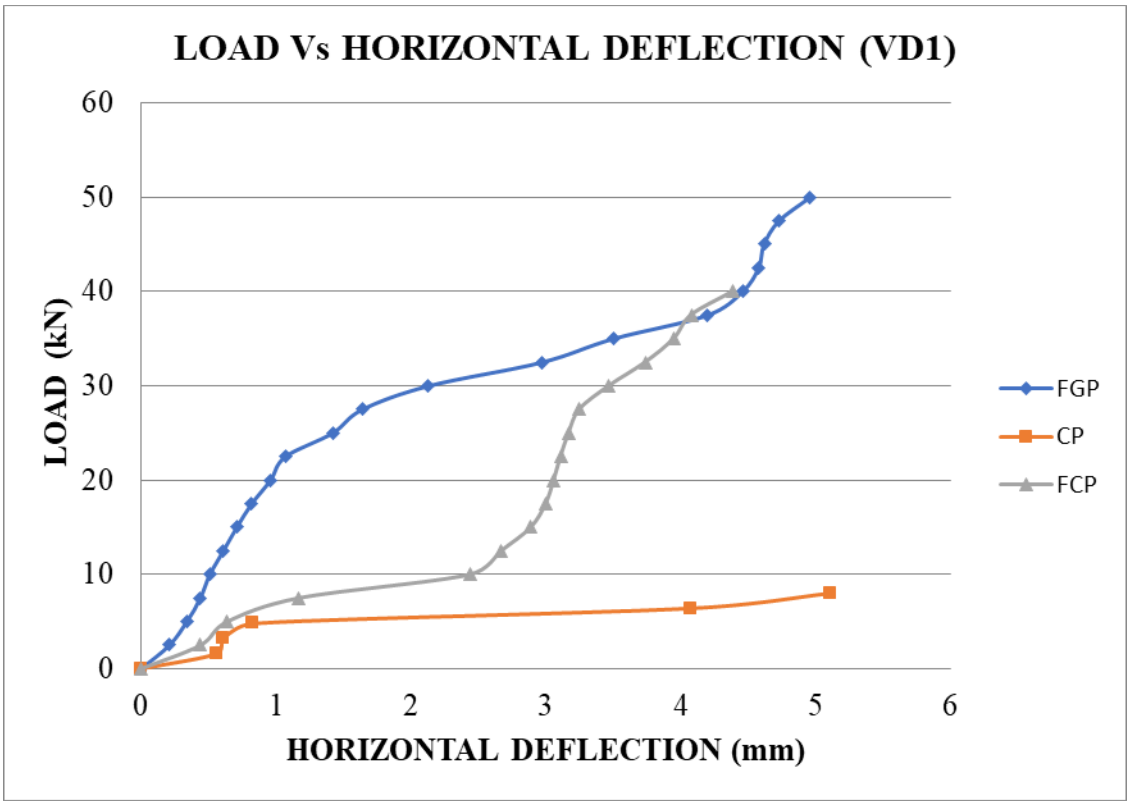


Fig.15 Load Vs Deflection Curve for Pipes (VD1)

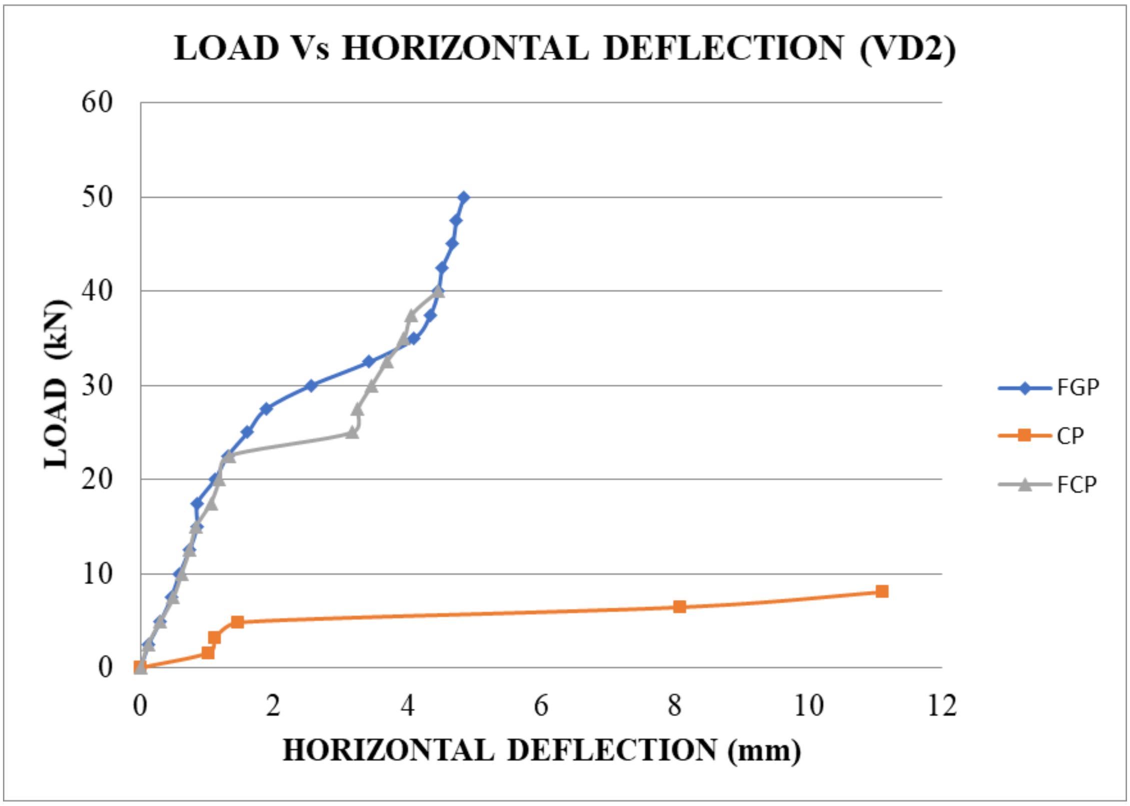


Fig.16 Load Vs Deflection Curve for Pipes (VD2)

From the experimental results, it can be seen that the ferrogeopolymer Pipe (FGP) has the high ultimate load of 50 kN when compared to 40 kN of ferrocement pipe. The ferrogeopolymer pipe (FGP) has the high first crack load of 22.5 kN when compared to the 10 kN of ferrocement pipe. On comparing, the ferrocement pipe (FCP) and the ferrogeopolymer pipe (FGP) having similar reinforcements, the ferrogeopolymer pipe (FGP) has 10 % higher ultimate load than the ferrocement pipe (FCP) and 41.7 % higher than the commercial pipe (CP).

CONCLUSION

Based on the experimental study on ferrocement and ferrogeopolymer pipes, the following conclusions are drawn.

1. Preliminary test such as specific gravity of cement, fine aggregate, fly ash, GGBS are carried out and found fit for IS code.
2. The ferrocement pipe was cast with cement mortar 1:2 with w/c ratio of 0.45 and tested by three edge bearing test. The Compressive strength of CM is obtained as 48 N/mm^2.The tensile strength of 6 mm rod, welded wire mesh and expanded metal mesh are 462.50 N/mm^2, 465 N/mm^2, 307 N/mm^2.
3. The ferrogeopolymer pipe was cast with geopolymer mortar. Instead of cement, fly ash (20%) and GGBS (80%) of quantity was used. The alkaline solution of NaOH and Na_2SiO_3 were used. The geopolymer mortar cubes were cast and cured under ambient condition for 7 days and the compressive strength was found as 45.28 N/mm^2.
4. The ferrogeopolymer Pipe (FGP) has the high ultimate load of 50 kN when compared to 40 kN of ferrocement pipe. On comparing, the ferrocement pipe (FCP) and the ferrogeopolymer pipe (FGP) having similar reinforcements, the ferrogeopolymer pipe (FGP) has 10 % higher ultimate load than the ferrocement pipe (FCP) and 41.7 % higher than the commercial pipe (CP).

5. The ferrogeopolymer pipe (FGP) has the high first cracking load of 22.5 KN. On comparing the ferrogeopolymer pipe (FGP) has 12.5% higher first cracking load than the ferrocement pipe (FCP) and 17.5% higher than the commercial pipe (CP).
6. Ferrogeopolymer pipe shown higher load carrying capacity as compared to commercially available reinforced pipe and ferrocement pipes.

References:

1. Ankit J. Patel, Harsh N. Patel, Harsh R. Patel and Hardik R. Patel (2014), Review on Use of Waste Material in Concrete, *International Journal for Technological Research in Engineering*, Volume 2, Issue 2.
2. Aradhana Mehta and Kuldeep Kumar (2016), Strength and Durability Characteristics of Fly Ash and Slag Based Geopolymer Concrete, *International Journal of Civil Engineering and Technology*, Vol.7, Issue 5, pp 305 – 314.
3. Arivalagan. S (2012), Moment Capacity, Cracking Behaviour and Ductile Properties of Reinforced Concrete Beams Using Steel Slag as Coarse Aggregate, *Global Journal of Researchers in Engineering, Civil and Structural Engineering*, Vol.12, Issue 2.
4. Balaguru, P., Stephen Kurtz and Jon Rudolph (1997), Geopolymer for Repair and Rehabilitation of Reinforced Concrete Beams, *Project Geo-Structure-Fire-Proof*, Geopolymer Institute Library, Saint-Quentin, France, pp. 1-6, www.geopolymer.org.
5. B. Vijaya Rangan (2014), Geopolymer Concrete for Environmental Protection, *The Indian Concrete Journal*, Vol.88, Issue 4.
6. Bapugouda Patil, Veerendra Kumar. M and H. Narendra (2015), Durability Studies on Sustainable Geopolymer Concrete, *International Research Journal of Engineering and Technology*, Vol.2, Issue 4.
7. Bhosale K, Swamy R. N and Lambert G. H (2012), Flexural Behaviour of Reinforced Concrete Beams made with Fly Ash Coarse Aggregates, *International Journal of Cement composites and Light Weight Concrete*, Vol.6, Issue 3, pp 189 – 200.
8. Bondar D, Lynsdale C. J, Milestone N. B. Hassani and Ramezanianpour (2010), Engineering Properties of Alkali Activated Natural Pozzolana Concrete, *2nd International Conference on Sustainable Construction Materials and Technologies*

9. C. Antony Jeyasehar, G. Saravanan, A.K. Ramakrishnan and S. Kandasamy (2013), Strength and Durability Studies on Fly Ash based Geopolymer Bricks, *Asian Journal of Civil Engineering (BHRC),* Vol.14, No. 6, pp 797-808.s

10. Chanh N. V, Sarker P, Lloyd and Rangan (2007), Shear Behaviour of Reinforced Fly Ash based Geopolymer Concrete Beams, *23rd Biennial Conference, Concrete Institute Australia.*

11. D. Annapurna, Ravande Kishore and M. Usha Sree (2016), Comparative Study o Experimental and Analytical Results of Geopolymer Concrete *International Journal of Civil Engineering and Technology* ,Vol.7, Issue 1, pp 211-219.

12. Dattatreya J K, Rajamane NP, Sabitha D, Ambily P S, Nataraja M C (2011), Flexural Behaviour of Reinforced Geopolymer Concrete Beams, *International Journal of Civil and Structural Engineering*, Vol.2, Issue 1.

13. Daniel, L.Y. Kong and Jay G. Sanjayan (2008), Damage Behaviour of Geopolymer Composites Exposed to Elevated Temperatures, *Cement & Concrete Composites*, Vol.30, August, pp. 986-991.

14. Davidovits, J. (1991), Geopolymers: Inorganic Polymeric New Materials, *Journal of Thermal Analysis,* Vol.37, pp. 1633-1656.

15. Davidovits, J. (1994a), Properties of Geopolymer Cements, *Proceedings First International Conference on Alkaline Cements and Concretes*, Ukraine, pp. 131-149.

16. Davidovits, J. (1994b), Geopolymers: Inorganic Polymric New Materials, Journal of Materials Education, Vol.16(2,3), pp. 91-138.

17. Davidovits, J. (1999), Chemistry of Geopolymeric Systems, Terminology, *Geopolymer'99 International Conference,* France.

18. Davidovits, J., Izquierdo, M., Antennuci, D., Nugteren, H., Butselaar-Orthlieb, V., Fernandez-Pereira, C. and Luna, Y. The European Research Project GEOASH: Geopolymer Cement Based on European Coal Fly Ashes, Technical Paper #22, *Geopolymer Institute Library,* pp. 1-10, www.geopolymer.org (August 2014).

19. Ganapati Naidu. P, A. S. S. N. Prasad, S. Adiseshu and P. V. V. Satyanarayana (2012), A Study on Strength Properties of Geopolymer Concrete with Addition of GGBS, *International Journal of Engineering Research and Development,* Vol.2(4).

20. Hardjito, D. and Rangan, B.V. (2005), Development and Properties of Low-Calcium Fly Ash-Based Geopolymer Concrete, *Research Report GC1, Faculty of Engineering,* Curtain University of Technology, Perth, Australia.

21. Irfan Khan, M., Khairun Azizli, Suriati Sufian, Zakaria Man, Amir Sada Khan, Hafeez Ullah and Ahmer Ali Siyal (2016), A Short Review of the Infra-Red Spectroscopic Studies of Geopolymers, *Advanced Materials Research,* Vol. 1133, pp. 231-235.
22. Ismail K. N, Kamarudin Hussain andMohd Sobri Idris(2007), Physical, Chemical & Mineralogical Properties of Fly Ash, *Journal of Nuclear and Related Technology*, Vol.4, pp 47-51.
23. John L. Provis, Angel Palomo and Caijun Shi (2015), Advances in Understanding Alkali-Activated Materials, *Cement and Concrete Research*, Vol.78, June, pp. 110-125.
24. Joseph Davidovits (1994a), Global Warming Impact on the Cement and Aggregates Industries, *World Resource Review,* Vol.6, No.2, pp. 263-278.
25. Joseph Davidovits (1994b), Recent Progress in Concrete for Nuclear Waste and Uranium Waste Containment, *Concrete International,* Vol.16, No.12, pp. 53-58.
26. Joseph Davidovits (2002a), 30 Years of Sucesses and Failures in Geopolymer Applications, Market Trends and Potential Breakthrough, *Geopolymer 2002 Conference*, Melbourne, Australia, October , pp. 1-16.
27. Joseph Davidovits (2002b), Environmentally Driven Geopolymer Cement Applications, *Geopolymer 2002 Conference,* Melbourne, Australia, October, pp. 1-9.
28. Joseph Davidovits (2013), Geopolymer Cement a Review, *Geopolymer Science and Techniques*, *Technical paper #21,* Geopolymer Institute Library, www.geopolymer.org. pp. 1-11.
29. Joseph Davidovits (2015), False Values on CO_2 Emission for Geopolymer Cement/Concrete Published in Scientific Papers, Technical Paper #24, *Geopolymer Institute Library*, www.geopolymer.org. pp. 1-9.
30. K. Vijay, R. Kumutha and B. G. Vishnuram (2010), Effect of Types of Curing on Strength of Geopolymer Concrete, *International Journal of Physical Sciences*, Vol.5(9), pp 1419 – 1423.
31. Kamel Arbi (2016), Durability of Geopolymer Concrete, SQAPE Geopolymer Technology, Delft University of Technology, CITG, Materials & Environment Microlab.
32. Kamal Neupane, Des Chalmers and Paul Kidd (2018), High-Strength Geopolymer Concrete Properties, Advantages and challenges, Advances in Materials, *http://www.sciencepublishing group.com/j/am.*

33. Kannapiran. K, Sujatha. T and Nagan. S (2013), Resistance of Reinforced Geopolymer Concrete Beams to Acid and Chloride Migration, *Asian Journal of Civil Engineering*, 14, pp 225 – 238.
34. Khoa Tan Nguyen, Tuan Anh Le, Kihak Lee (2016), Experimental Study on Flexural Strength of Reinforced Geopolymer Concrete Beams, *World Academy of Science, Engineering and Technology*, Vol.10, No.4.
35. Lazarescu, A.V., Szilagyi, H. and Baera Loani, A. (2017), The Effect of Alkaline Activator Ratio on the Compressive Strength of Fly Ash-Based Geopolymer Paste, *IOP Series: Materials Science and Engineering*, Vol.209, pp. 1-6 (01204).
36. Lyon, E. Richard., Balaguru, P.N., Andrew Foden, Usman Sorathia, Joseph Davidovits, Michel Davidovits (1997), Fire Resistance Aluminosilicate Composite, *Fire amd Materials,* Vol.21, pp. 67-73.
37. Prakash, R. Vora and Urmil V. Dave (2013) Parametric Studies on Compressive Strength of Geopolymer Concrete, *Procedia Engineering – Chemical. Civil and Mechanical Engineering Tracks of 3rd Nirma University International Conference on Engineering (NUiCONE-2012),* Vol.51, pp. 201-219.
38. Shetty, M.S., Concrete Technology – Theory and Practice, Seventh Revision Edition, S. Chand & Company Pvt. Ltd., Ram Nagar, New Delhi, 2013.
39. Siddique, R. (2008), Metakaolin, *Waste Materials and by-products in Concrete*, pp. 41-92, Springer-Verlag Berlin Heidelberg.
40. Sreevidya V, Anuradha R, Dinakar. D and Venkatasubramani. R (2012), Acid Resistance of Geopolymer Mortar under Ambient Curing and Heat Curing, *International Journal of Engineering Science and Technology*.

(c) Has the progress been according to original plan of work and towards achieving the objective

Yes

(d) Please indicates the difficulties, if any experienced in implementing the project

Nil

(e) If the project has not been completed, please indicates the approximate time by which it is likely to be completed. A summary of the work done for the period (Annual basis) may please be sent to the commission on a separate sheet.

Not Applicable

(f) If the project has been completed, please enclose a summary of the findings of the study. Two bound copies of the final report of work done may be sent to the commission.

Yes

(g) Any other information which would help in evolution of work done on the project. At the completion of project, the first report should indicate the output, such as (i) Manpower trained (ii) Ph.D. awarded (iii) Publications of results (iv) other impact, if any

i) Man Power Trained

The investigator, post-graduate structural students, research scholars are educated and trained about the geopolymer technique and the methods of casting structural elements using geopolymer concrete under ambient temperature.

ii) Ph.D. Awarded

Sl. No.	Name of the Student	Title of the Thesis /Area of Research
1	B. Parthiban	Study on Mechanical and Durability Properties of Recycled Waste Glass Aggregates in Cement and Geopolymer Concrete
2	S. Annamalai	Behaviour of Ambient Cured Reinforced Geopolymer Concrete Beams under Compression Cyclic Loading
3	N. Suganya	Study on Geopolymer Concrete using Scrap Steel as Coarse Aggregate
4	R. Anu	Behaviour of RC Frames Infilled with Geopolymer Bricks
5	Dhavamani Doss S	Behaviour Of Reinforced Geopolymer Concrete Frames With And Without Infill Subjected To Cyclic Lateral Loading

iii) Publications of the Results

PAPERS PUBLISHED IN BOOK CHAPTER

1. Thirugnanasambandam S., Antony Jeyasehar C. (2019) **Ambient Cured Geopolymer Concrete Products.** In: Das B., Neithalath N. (eds) Sustainable Construction and Building Materials. **Lecture Notes in Civil Engineering**, vol 25. Springer, Singapore.

PAPERS PUBLISHED IN PEER REVIEWED JOURNALS

1. Dhavamani Doss S and S. Thirugnanasambandam (2018), **Geopolymer Concrete – An Alternative to Cement Concrete: A Review,** ***International Journal of Emerging Technology and Advanced Engineering,*** ISSN 2250-2459, Vol. 8, Issue 6, June, pp. 124-131.
2. R. Anu and S. Thirugnanasambandam (2018), **Geopolymer Bricks,** ***International Journal of Emerging Technology and Advanced Engineering***, ISSN 2250-2459, Vol. 8, Issue 6, June, pp. 132-136.
3. Suganya N and Thirugnanasambandam. S (2019), **Geopolymer Concrete using scrap Steel Slag as Coarse Aggregate,** ***International Journal for Research in Applied Science & Engineering Technology (IJRASET),*** ISSN 2321-9653, Vol. 7, Issue 1, pp. 781-785.
4. Suganya N and Thirugnanasambandam. S (2019), **Mechanical Proerties of ordinary, standard and High strength concrete using scrap Steel Slag as Coarse Aggregate,** ***International Journal of Innovative Technology and Exploring Engineering (IJITEE)***, ISSN 2278-3075, Vol. 8, Issue 5, March, pp. 585-589.
5. Suganya N and Thirugnanasambandam. S (2018), **Steel Slag as Coarse Aggregate in Concrete,** ***International Journal of Emerging Technology and Advanced Engineering***, ISSN 2250-2459, Vol. 8, Issue 6, June, pp. 137-141.
6. Suganya. N and Thirugnanasambandam. S (2019), **Flexural Behaviour of Geopolymer RC Beam with Scrap Steel Slag Coarse Aggregate,** ***International Journal of Geopolymer RC Beam with Scrap Steel Slag Coarse Aggregate***, ISSN 2277-3878, Vol. 8, Issue 4, November, pp. 10872-10875.
7. Suganya. N and Thirugnanasambandam. S (2020), **Durability of Geopolymer Concrete with Scrap Steel Slag as Coarse Aggregate,** ***International Journal of Engineering and Advanced Technology (IJEAT)***, ISSN 2249-8958, Vol. 9, Issue 3, February, pp. 2415-2417.
8. Suganya. N and Thirugnanasambandam. S (2019), **Experimental Investigation on Low Calcium Fly Ash Based Geopolymer Concrete Using Steel Slag as Coarse Aggregate**, *Journal of Emerging Technologies and Innovative Research,* ISSN 2349-5162, Vol. 6, Issue 2, February, pp. 364-369.
9. Raghulkumar. R and Thirugnanasambandam. S (2019), **Study on Conventional and Geopolymer Bricks,** ***Journal of Emerging Technologies and Innovative Research***, ISSN 2349-5162, Vol. 6, Issue 2, February, pp. 370-375.

10. Dhinesh. R and Thirugnanasambandam. S (2019), **Development of Ambient Cured Geopolymer Concrete,** ***Journal of Emerging Technologies and Innovative Research***, ISSN 2349-5162, Vol. 6, Issue 2, February, pp. 376-381.
11. Dhavamani Doss S and Thirugnanasambandam. S (2019), **Performance of Ferrogeopolymer Slab Pannels,** ***Journal of Emerging Technologies and Innovative Research***, ISSN 2349-5162, Vol. 6, Issue 4, April, pp. 631-635.

(h) **Other Impact:**

The geopolymer technique is an innovative method to make innovative concrete using industrial waste materials such as fly ash and Ground Granulated Blast Furnace Slag (GGBS). Geopolymer concrete is a 100% cementless concrete. Geopolymer concrete is an alternative to conventional concrete. The use of geopolymer concrete has great positive impact on the environment by reducing the carbon foot print. The is mainly due to the reduction of usage of cement in the construction industry. The finding from this project will be more helpful to make eco-friendly concrete. The utilisation of industrial waste material for making geopolymer concrete will leads to reduction in environmental pollution by their safe disposal.

Signature of the Principal Investigator	**Signature of the Registrar (i/C)**

Lecture Notes in Civil Engineering

Bibhuti Bhusan Das
Narayanan Neithalath *Editors*

Sustainable Construction and Building Materials

Select Proceedings of ICSCBM 2018

Springer

Editors
Bibhuti Bhusan Das
Civil Engineering Department
National Institute of Technology
Karnataka, Surathkal
Mangalore, Karnataka, India

Narayanan Neithalath
School of Sustainable Engineering
and the Built Environment
Ira A. Fulton Schools of Engineering
Arizona State University
Tempe, AZ, USA

ISSN 2366-2557 ISSN 2366-2565 (electronic)
Lecture Notes in Civil Engineering
ISBN 978-981-13-3316-3 ISBN 978-981-13-3317-0 (eBook)
https://doi.org/10.1007/978-981-13-3317-0

Library of Congress Control Number: 2018961224

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

Ambient Cured Geopolymer Concrete Products

S. Thirugnanasambandam and C. Antony Jeyasehar

Abstract The most commonly used building material in the construction industry is concrete. Portland cement is an important ingredient to manufacture concrete. Due to the rapid growth of urbanisation, the need of cement is inevitable. The manufacturing of Portland cement releases approximately an equal amount of carbon dioxide into the atmosphere. In this regard, it is mandatory to find out a solution to avoid the usage of cement in the construction industry. It is proved that the geopolymer technology is an alternative method to create a binder instead of cement. In this study, geopolymer concrete is made with fly ash, ground granulated blast furnace slag, alkaline solution to bind the river sand, and granite coarse aggregate. The geopolymer concrete specimens are cured in ambient temperature. Geopolymer concrete beams, railway sleepers are cast and tested for flexure. The test results are compared with conventional cement concrete specimens and it is found that the geopolymer specimens are performing better than cement concrete specimens. The ferrocement roofing channels and domes are cast with cement mortar and geopolymer mortar. Both of the specimens are tested and found that the ferrogeopolymer elements are showing better results than conventional ferrocement elements.

Keywords Geopolymer · Beams · Sleepers · Roofing channels
Domes

1 Introduction

Concrete is widely used as one of the important construction materials. The various ingredients of concrete are cement, fine aggregate, coarse aggregate, and water. Although the strength and durability of concrete are mainly based on cement, the production of cement is one of the main causes of global warming due to the emission of carbon dioxide (CO_2). In this aspect, the great scientist, Joseph Davidovits invented

S. Thirugnanasambandam (✉) · C. Antony Jeyasehar
Annamalai University, Chidambaram, India
e-mail: agstsai@gmail.com

B. B. Das and N. Neithalath (eds.), *Sustainable Construction and Building Materials*, Lecture Notes in Civil Engineering 25,
https://doi.org/10.1007/978-981-13-3317-0_73

a new binding component instead of cement called geopolymer. Geopolymers are chains of minerals containing silica and alumina in association with an alkaline solution [1, 2]. The by-products obtained from the thermal power station and steel industries are fly ash and Ground Granulated Blast Furnace Slag (GGBS), respectively, that contain rich amount of silica and alumina. An alkaline solution is a mixture of sodium silicate and sodium hydroxide. A hardened binder is obtained by mixing minerals such as fly ash, GGBS, and alkaline solution [3]. Due to this chemical reaction, a polymerization process takes place which produces a chain of molecules. The entire polymerization process is taking place in presence of heat [4]. It is known that the hydration process takes place when cement is mixed with water which results in binding of aggregates together to form concrete. Generally, a complete hydration process of cement concrete requires a curing period of 28 days to obtain its target strength. Hence, a continuous supply of water is essential for getting the complete strength of cement concrete.

Unlike in the hydration process of cement concrete, polymerization of geopolymer concrete takes place under heat/stream curing at 60 °C for 24 h. During the polymerization process of geopolymer concrete, water is expelled which is in contrast to the hydration process which consumes water. Heat curing of geopolymer concrete can be done in two ways. One is by maintaining 60 °C temperature in heat/steam curing chamber and another one is curing under sunlight. It is experimentally found that sunlight curing is possible only when GGBS is added with fly ash. The sunlight curing otherwise called ambient curing can be used in cast in situ concrete elements.

2 Geopolymer Concrete (GPC)

The ingredients for the production of geopolymer concrete are fly ash, GGBS, sand, coarse aggregate, and alkaline solution as shown in Fig. 1. The fly ash used in this study is low calcium fly ash (F type) obtained from Mettur Thermal Power Station. The alkaline solution is prepared by mixing sodium silicate and sodium hydroxide pellets with water as shown in Fig. 2. The strength of concrete depends upon the concentration of sodium hydroxide in terms of molarity which ranges from 8 to 14.

Fig. 1 Ingredients of geopolymer concrete

Fig. 2 Preparation of the alkaline activator solution

Fig. 3 Mixing of geopolymer concrete

Like conventional mixing, geopolymer concrete ingredients are also mixed thoroughly in a pan mixer as shown in Fig. 3. Also, the workability of geopolymer concrete is similar to that of cement concrete and the measurement of slump of geopolymer concrete is shown in Fig. 4.

Fig. 4 Slump test on GPC

Fig. 5 Casting of GPC cubes

The GPC cubes are cast (Fig. 5) and cured in ambient temperature for 24 h as shown in Fig. 6.

The daytime temperature varies between 30 and 35 °C and night time temperature varies between 25 and 30 °C. By using various mix proportions of GPC, the required target strengths can be achieved.

Fig. 6 Curing of GPC cubes in ambient temperature

3 Geopolymer Concrete Beams

- Mix design for conventional cement concrete grade of M 20 is carried out as per IS 10262:2009 and obtained as the ratio of 1:1.58:3.02 with w/c ratio 0.5. The concrete specimens are cured under water for 28 days. The compressive strength of conventional concrete is obtained as 29.56 N/mm^2.
- The GPC is made with the same mix ratio of conventional concrete with 100% replacement of cement by 50% each of fly ash and GGBS. The ratio of fly ash and GGBS to the alkaline solution is 0.5. The ratio of sodium silicate to sodium hydroxide is kept as 2.5. The concentrations of sodium hydroxide solution are kept as 8 mole. The GPC specimens are kept cured in ambient condition for seven days. The 7th-day compressive strength of GPC is 29.76 N/mm^2.
- The conventional cement concrete and geopolymer concrete beams are cast with two numbers of 12 mm diameter bars at the bottom and two bars of 10 mm diameter bars at the top as shown in Fig. 7.
- The beams of size 125 × 250 × 3100 mm are cast (Fig. 8) in steel moulds.
- The conventional cement concrete beam is cured in water for 28 days. The GPC beam is cured in ambient temperature for 24 h (Fig. 9).

Fig. 7 Reinforcement grills for beams

Fig. 8 Casting of geopolymer concrete beams

Fig. 9 Ambient curing of geopolymer concrete beam

- The beams are tested under two-point bending as shown in Fig. 10. The ultimate load carrying capacity of geopolymer concrete beam with steel rebars is 44.6 kN and the same in the conventional concrete beam is 41.8 kN. Hence GPC beam takes 6.7% more load when compared to a conventional beam.
- The crack pattern obtained in conventional cement concrete and GPC Beams are shown in Figs. 11 and 12.
- The comparison of load-deflection curves is shown in Fig. 13. The test result of beams is shown in Table 1.

The steel-reinforced GPC beams showed higher yield deflection when compared to corresponding control beams. The geopolymer concrete beams made with steel reinforcement showed an increase in ultimate deflection when compared to corresponding control concrete beams.

Fig. 10 Testing of geopolymer concrete beam

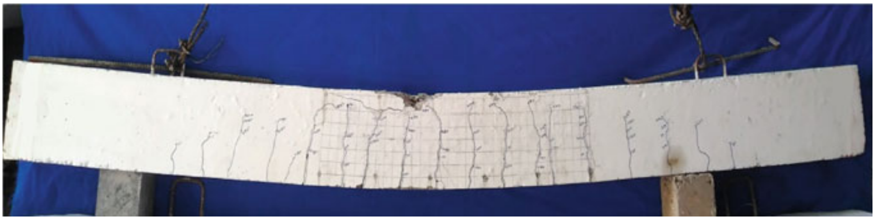


Fig. 11 Crack pattern of conventional cement concrete beam

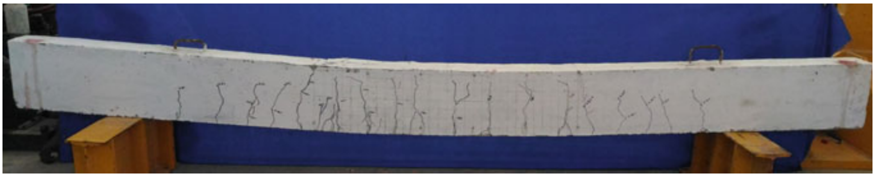


Fig. 12 Crack pattern of geopolymer concrete beam

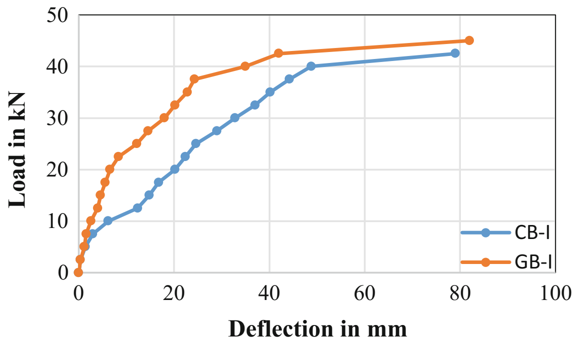


Fig. 13 Comparison of load–deflection behaviour of conventional cement concrete and GPC beams with steel reinforcements

Table 1 Test results of concrete and GPC beams

S. No.	Beam designation	Load at different stages (kN)			Deflection (mm)		
		First crack	Yield	Ultimate	First crack	Yield	Ultimate
1	CBI	10.2	24.8	41.8	6.6	22.2	78.6
3	GBI	11.6	26.7	44.6	9.8	24.3	82.8

4 Railway Sleepers

Due to the abundant requirement of railway sleepers, GPC is also tried to produce them using conventional and GPC of grade M60. A steel mould is fabricated to cast railway sleepers. The conventional sleeper is made with a concrete mix of 1:1.41:1.82 with water cement ratio of 0.3. The compressive strength of conventional concrete 28 days is 71.8 N/mm^2. The geopolymer concrete is made with the same ratio of conventional concrete with 100% replacement of cement by the cementitious material of GGBS (80%) and fly ash (20%). In GPC, the alkaline solution is made with sodium hydroxide and sodium silicate. The GPC specimens are cured under ambient temperature for 1 day. The compressive strength of GPC is obtained as 74.6 N/mm^2. Both conventional and GPC sleepers are prestressed with 18 numbers of 6 mm diameter high tensioned tendons having a yield stress of 2922 N/mm^2.

4.1 *Pre-tensioning and Casting of GPC Sleepers*

The following are the steps for the production of GPC railway sleepers:

(i) Barrel and Wedge system is used to anchor the prestressed tendons as shown in Fig. 14.
(ii) Prestressing of the tendons is done by applying tension using jack as shown in Fig. 15.
(iii) Conventional concrete and geopolymer concrete sleepers are cast. The casting of GPC sleeper is shown in Fig. 16. The de-tensioning of pre-stressed tendons is carried out as shown in Fig. 17.
(iv) GPC sleepers are kept in ambient temperature for 24 h as shown in Fig. 18.

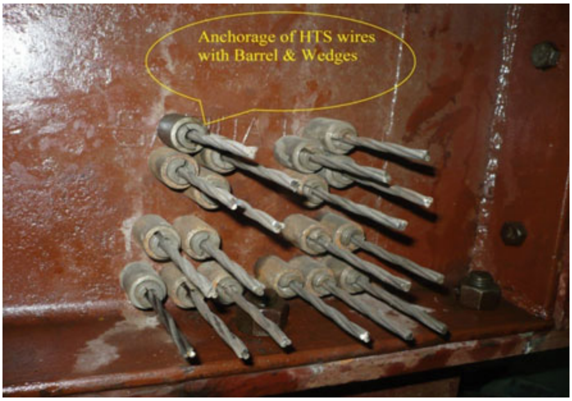


Fig. 14 Anchorage of tendons with barrel and wedges

Fig. 15 Pretensioning of tendons

Fig. 16 Casting of GPC sleeper

Fig. 17 De-tensioning of tendons

The railway sleepers are tested as per the procedure given in T-39 Standard Specification adopted by Indian Railways [5]. The bending test setup is shown in Fig. 19. The experimental test results of cement concrete and geopolymer concrete railway sleepers are given in Table 2. The M60 grade prestressed geopolymer concrete sleeper obtained an ultimate load of 318 kN when compared to that of 291 kN in prestressed cement concrete sleeper. The load carrying capacity of GPC sleeper is increased by 10%. At ultimate load level, 34% increase in deflection was observed in GPC sleeper compared to conventional cement concrete sleeper. The crack distribution and crack width are found increased in GPC sleeper with respect to conventional cement concrete sleeper.

Ambient curing temperature (40 °C) is found adequate for curing of GPC sleepers. From the studies carried out on geopolymer concrete, it is concluded that the geopolymer sleepers show an encouraging result in a strength point of view.

Fig. 18 Ambient curing of GPC sleeper

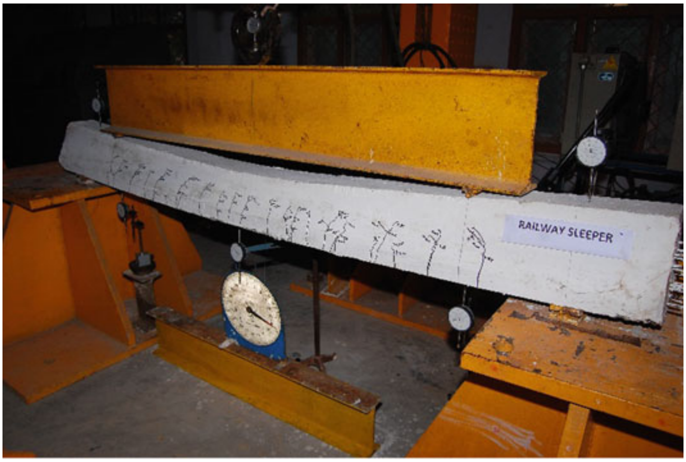


Fig. 19 Test setup of GPC sleeper

Table 2 Experimental results of railway sleepers

Cement concrete sleeper				Geopolymer concrete sleeper			
First crack load in kN	Yield load in kN	Ultimate stage		First crack load in kN	Yield load in kN	Ultimate stage	
		Load in kN	Deflection in mm			Load in kN	Deflection in mm
88.5	118	291	31.5	94.6	178	318	48.6

5 Ferrogeopolymer Channel

A ferrocement roof channel is a longitudinal element of a curved section, (often semi-cylindrical). It is precast using moulds, easy to construct, consumes less cement and steel than a conventional RCC roof and is also cheaper. During the installation process, the roof channel is lifted into place and can immediately be joined together in order to provide a shelter, a roof or a floor slab. The construction procedure of ferrocement and ferrogeopolymer roofing channel is as follows:

- Ferrocement of cement mortar ratio of 1:3 with w/c ratio of 0.45 is used to cast ferrocement channel of size 3000 mm × 750 mm × 290 mm including two 40 × 45 mm nibs at bottom. The thickness of the channel was 30 mm. The cement mortar is tested after 28 days water curing and found as 43.17 N/mm^2.
- The geopolymer mortar is made of 50% fly ash and 50% GGBS with three parts of sand using alkaline solution. The ratio of fly ash and GGBS to the alkaline solution is kept as 0.45. The ratio of sodium silicate to sodium hydroxide is kept as 2.5. The geopolymer mortar cubes are cast and ambient cured for 7 days and tested. The compressive strength of geopolymer mortar using six molarity concentrations of sodium hydroxide is found as 43.94 N/mm^2.
- Ferrocement and Ferrogeopolymer roofing channel are cast and tested. The reinforcement grill is prepared with 8 and 6 mm steel rods with weld mesh and diamond mesh as shown in Fig. 20. The geopolymer mortar is applied over the mesh as shown in Fig. 21. The ferrocement channel is cured under water for 28 days and ferrogeopolymer channel is cured at ambient temperature for 7 days.
- These channels are tested with a central point load as shown in Fig. 22. The test result is given in Table 3.

The ferrogeopolymer channel showed 9.3% increase in load carrying capacity as compared to ferrocement channel. From the results obtained from ferrocement and ferrogeopolymer channels, it is recommended that the ferrogeopolymer channels can be used in construction since it possesses better performance than ferrocement channels.

Fig. 20 Reinforcement grill

Fig. 21 Geopolymer mortar

Fig. 22 Test setup of ferrogeopolymer channel

Table 3 Test results of channels

S. No.	Ferrocement channel	Ferrogeopolymer channel
1	First crack load = 4.167 kN	First crack load = 4.99 kN
2	Ultimate load = 25.5 kN	Ultimate load = 27.50 kN
3	Deflection at first crack load = 1.8 mm	Deformation at first crack load = 3.4 mm
4	Ultimate deflection = 29 mm	Ultimate deflection = 58 mm

6 Ferrogeopolymer Domes

The domes of diameter 1000 mm and height of 500 mm with 50 mm thick are made with ferrocement and ferrogeopolymer mortar with identical reinforcement. The ferrocement dome is cast with cement mortar 1:2.5 with w/c ratio 0.45. The circumferential and meridional reinforcement of dome are 5 numbers of 6 mm diameter bars and 6 numbers of 6 mm diameter bars, respectively. Welded wire mesh and expanded metal mesh are used. The compressive strength of cement mortar is obtained as 46.5 N/mm^2. The tensile (yield) strength of 6 mm diameter rod, welded wire mesh and expanded metal mesh are 498.5/mm^2, 416.2/mm^{2,} and 303.8 N/mm^2. The ferrogeopolymer dome is cast with geopolymer mortar. Instead of cement, fly ash and GGBS of equivalent quantity is used. The geopolymer mortar cubes are cast and cured under ambient condition for 7 days and the compressive strength is found as 47.4 N/mm^2.

The reinforcement cage of the dome is made using 6 mm diameter bars tied at ring and meridian. After the making of reinforcement cage, the Expanded Metal Mesh is kept at the inner side of it and the welded Wire Mesh are kept at the outer surface of the reinforcement as shown in Fig. 23. Cement mortar is applied over the mesh along the outer surface as shown in Fig. 24. After the hardening of the outer surface, mortar is applied at the inner surface of the dome. After the hardening of

Fig. 23 Dome reinforcement

Fig. 24 Outer and inner surface of dome

ferrocement mortar applied at both inner and outer surface of the dome, it is cured using wet gunny bags for 28 days. The ferrogeopolymer mortar dome is cast and cured at ambient temperature for seven days. The testing setup and crack pattern of tested ferrogeopolymer domes are shown in Figs. 25 and 26, respectively.

The experimental results of both the domes showing first crack load, ultimate load, displacements at first crack load and ultimate load are presented in Table 4. The service load, energy absorption, and ductility ratio are presented in Table 5. The energy absorption is calculated as the area under the load-deflection (vertical deflection) curve while the ductility ratio defines the ratio between the vertical deflections at ultimate load to the vertical deflections at first crack load.

From the experimental results, it can be seen that the ferrogeopolymer dome has the highest service load of 101.20 kN. Also, this dome has the highest ductility ratio of 6.20 and energy absorption of 446.72 kN mm. The ferrocement dome has the

Fig. 25 Testing of dome

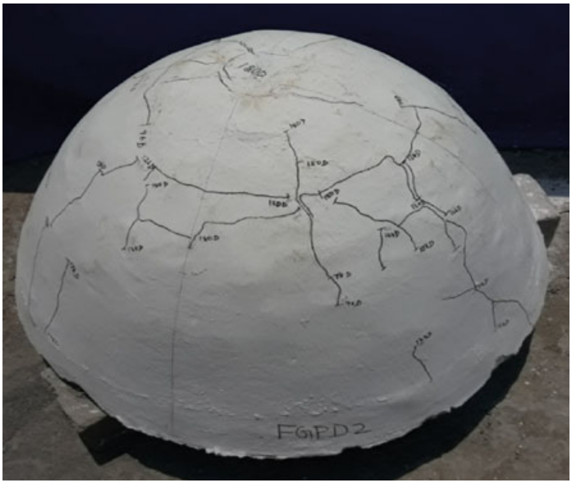


Fig. 26 Crack pattern

lowest ductility ratio of 1.82 when compared to ferrogeopolymer domes. On comparing the ferrocement dome and the ferrogeopolymer dome having similar reinforcements, the ferrogeopolymer dome has 72.16% higher ultimate load than the ferrocement dome. The ferrogeopolymer domes are very much feasible for structural application since they possess high load carrying capacity as well as eco-friendly one.

Table 4 Test results of domes

Designation of dome	First crack load (kN)	Ultimate load (kN)	Displacement at first crack load (mm)				Displacement at ultimate load (mm)			
			HD_1	VD_2	HD_3	VD_4	HD_1	VD_2	HD_3	VD_4
FCD	58	97	0.14	2.01	0.41	0.42	0.52	3.20	0.51	0.72
FGPD	61	167	0.16	2.18	0.48	0.95	0.61	5.20	1.76	5.33

FCD—Ferrocement dome; FGPD—Ferrogeopolymer dome
HD_1—Dial gauge placed horizontally at 150 mm from base
VD_2—Dial gauge placed vertically at 300 mm from base
HD_3—Dial gauge placed horizontally at 250 mm from base
VD_4—Dial gauge placed vertically at 400 mm from base

Table 5 Service load, energy absorption and ductility ratio of domes

Designation of dome	Service load (kN)	Energy Absorption (kN mm)	Ductility ratio
FCD	65.40	162.52	1.82
FGPD	101.20	446.72	6.20

7 Conclusions

Based on experimental studies, the following conclusions are drawn.

i. GPC can be manufactured without cement for different grades of concrete.
ii. Ambient curing of GPC is very much suitable in tropical countries like India.
iii. CO_2 emission can be eliminated drastically by producing GPC without cement.
iv. Ambient cured GPC can be used in both precast and cast in situ elements.
v. High strength GPC can be utilised to make prestressed concrete elements.

Acknowledgements The authors wish to acknowledge the financial support provided by the University Grants Commission, New Delhi by sanctioning a research project, (MRP–MAJOR-CIVIL—2013-36977) entitled "Development of geopolymer concrete and testing of elements" to Annamalai University.

References

1. Davidovits, J. (1991). Geopolymers: Inorganic geopolymeric new materials. *Journal of Thermal Analysis, 37,* 1633–1656.
2. Davidovits, J. (1994). High—Alkali cements for 21st century concretes in concrete technology, past, present and future. In P. Kumar Metha (Ed.), *Proceedings of V. Mohan Malhotra Symoposium* (pp. 383–397). ACI SP-144.

3. Hardjito, D., & Rangan, B. V. (2005). *Development and properties of Low calcium fly ash-based geoploymer concrete research report*. Perth: GCI Faculty of Engineering Curtin University of Technology.
4. Malhotra, V. M. (2002). High-performance high-volume fly concrete. *Concrete International 24*(7), 30–34.
5. Standard Specification for Pre-tensioned Prestressed Concrete Sleepers for Broad Gauge and Metre Gauge, Serial No. T – 39. (2016). Research Designs and Standards Organisation, Lucknow.

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 8, Issue 6, June 2018)

Geopolymer Concrete - An Alternative to Cement Concrete: A Review

Dhavamani Doss S[1], S. Thirugnanasambandam[2].

[1]*Research Scholar, Department of Civil and Structural Engineering, Annamalai University, Annamalaingar, Tamilnadu, India - 608002*

[2]*Associate Professor, Department of Civil and Structural Engineering, Annamalai University, Annamalaingar, Tamilnadu, India - 608002*

***Abstract*— Concrete is an essential building material, in the construction field as it forms the core of the entire construction industries throughout the world. The raw material usedfor making the concrete is generally compri se s of cement, fine aggregate and coarse aggregates. Due to the vast increase in the growth of construction field day by day there is a huge demand for concrete. This leads to high utilisationof concrete raw materials. Because of the continued high utilization of these materials; there is a danger of scarcity for these materials and enhance the pollution rate in the atmosphere. If this continuedthen, it will affect the ecosyste m and the surrounding environment. Today numerous number of research works were undergoing to find an alternative solution to the conventional concrete. Many researchers conducted research to decrease the high rate of pollution, scarcity of natural limestone and high energy loss. Since the production of cement requires, burning of limestone at very high temperature the availability of limestone is becoming extinct and also to produce cement, a very high temperature and a lot of resources were utilised to create high energy. With all these problems another huge pain for the pollution controlling board is carbon dioxide emission during the production of cement. One molecule of cement produces one molecule of carbon dioxide which contribute more than 7% of emission of carbon dioxide throughout the world. So, there is a need for finding an alternative material for cement in concrete. In 1978 Prof. Dr. Joseph Davidovits and J.L. Sawyer came up with a solution by an alternative material for ceme nt and Prof. Dr. Joseph Davidovits named it as "Geopolymer". After that many researchers made their studies in geopolymer and find out its suitability of replacing cement in concrete. Their studies prevail that using geopolymer in concrete may leads to development of green concrete since the geopolymer concrete is made up of using by-products of earth materials. A widely used material in geopolymer concrete is fly ash, a by-product from burnt coal in the thermal power plant. Further the research shows that using geopolymer concrete may reduce the emission of carbon dioxide and save the high energy loss. This paper deals with the review of studiesconducted to find the suitability of geopolymer concrete as a replacement for conventional cement concrete.**

***Keywords*— Alkaline Solution, Byproduct, Carbon dioxide, Cement, Concrete, Fly ash, Geopolymer.**

I. INTRODUCTION

In the field of constructions, there is a requirement for new materials owing to the demand of raw materials used for making concrete. Cement is a basic important constituent for creation of concrete. At present the infrastructure development around the world is vastly increasing and it leads the way for high consumption of cement since cement is used as binding material in concrete. The strength of the concrete is mainly reliant upon the cement, so the production of cement also growing day by day. As there is an increase in the manufacturing of cement, it leads to emanation of carbon dioxide into the atmosphere. CO_2 is the main contributor of pollution among the greenhouse gases [1]. Global warming is an important problem that alarming the whole world about the danger building up today. So, we are in the position to find a new material as a replacement for cement concrete without creating pollution to the atmosphere. Such a concrete may be possible by using geopolymer which is called as geopolymer concrete. Geopolymer concrete is a concrete which is made up of using fly ash as replacement for cement. By using geopolymer concrete, the discharge of carbon dioxide may be comparatively reduced. Reduction of cement production also reduce the limestone usage and high energy. This is possible because the material used as a substitute for cement is obtained as a by-product when burning the coal in the thermal power plants. In India there is a huge content of fly ash, dumped around the areas where the thermal power plants are located. These massive amounts of fly ash are a headache for the industry people for disposing them

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 8, Issue 6, June 2018)

safely. Consuming these waste by-products for the creation of concrete will stretch solutions for the problems occurs in the cement production. The geopolymer concrete technology displays significantly the potential for the convention in concrete industry as a substitute binder for ordinary Portland cement [4] [6]. The geopolymer concrete is also expressively reduces the emanation of CO_2 to the atmosphere by the cement producers [5] [6]. The usage of a reduced amount of cement may play a vivacious role in diminishing the global warming.

II. Cement and Global Warming

Cement is a foremost constituent in the production of concrete. Due to the intensification in the urbanisation, the prerequisite of concrete is also exceedingly increasing today and expected to upsurge in future too. Ordinary Portland Cement, consequential from the calcination of calcium carbonate and silica ($5CaCo_3 + 2SiO_2 \rightarrow (3CaO, SiO_2) (2CaO,SiO_2) + 5CO_2$) produce 0.55 tonnes chemical CO_2 and 0.40 tonnes of CO_2 (used for combustion of fuel for burning involved in cement production). Generally, an amount of one tone of CO_2 is emanated during the manufacturing of one tone of cement [1]. On the other hand, the climate change due to global warming, is one of the greatest environmental issues that has become a major concern today. The global warming is caused by the emanation of greenhouse fumes to the atmosphere by human actions. Among the greenhouse fumes, CO2 contributes about 65% of global warming [2]. Figure 1 denotes the process involved in cement and concrete production.

The significance of finding an alternative source for OPC is primarily because of its involvement in emanation of greenhouse gases and the exploitation of high energy for its production after steel and aluminium among the building materials used in construction [7]. Figure 2 illustrates the process of CO_2 emission during OPC production. One of the key hindrances of conventional cements usage in nuclear and uranium waste containment are it holds a high amount of bounded water, and there is a possibility of existence of strong radiolytic deprivation of this water into hydrogen gas. They do not have the property binding for safe underground clearance, namely the absence of any steam explosion and hydrogen release, resulting from radiations and heat generated by the confined radioactive waste [8]. Dewatering of Portland cement based radioactive waste forms is a slow and difficult process which often leads to consequent cracking of the waste-form [8]. The downsides of the cement concrete could be overcome by replacing it with geopolymer concrete.

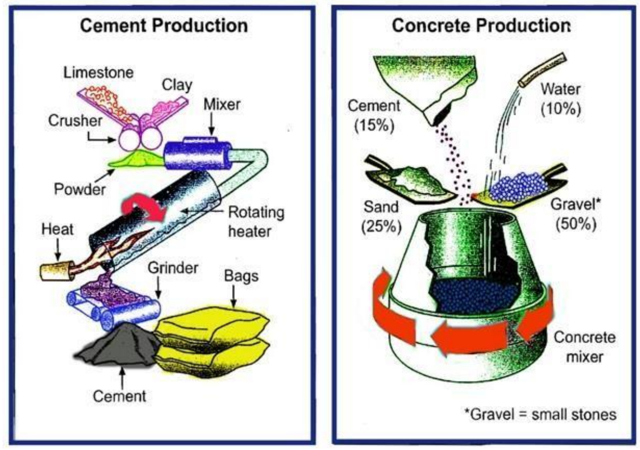


Fig. 1 Stages and Equipment used in the Cement and Concrete production process *([37])*

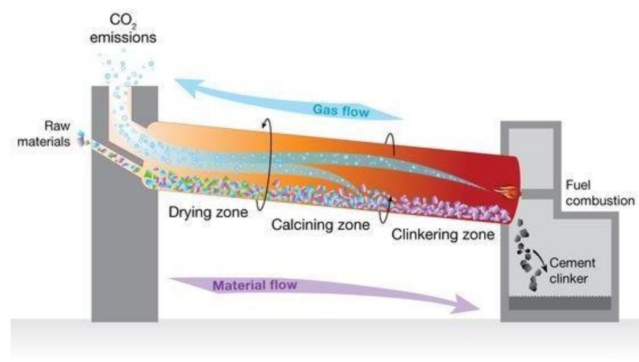


Fig. 2 Pictorial representation of emanation of CO_2 during the process of cement production *([37])*

III. The Impact and Necessity of Geopolymer Concrete on Global Warming

Geopolymer concrete a boon to the concrete industry by its nature of assuredness over cement concrete in terms of global warming. If still we are continuing the production of concrete using OPC without knowing its dangerousness effects on our planet, in near future there will be a chance of new employment called *Concrete Sentry*. *"The year is 4085. On a broad, sage- studded plain in what had been the western United States of America, 256 monoliths stake out a 32 square- mile rectangle. Inside are dozens of artificial hills, each ringed by more towering monuments. Pictographs and Old Era writings etched into these huge stone slabs warn of danger and demand that people not dig into the mounds. The monoliths and their messages date* *from the time, two millennia ago, when human were still obtaining energy from splitting atoms and developing weapons by processing plutonium. Local resident shuns the area believing it to be cursed, but outsiders consider the enormous memorial one the wonders of the Old Era; hovercrafts bring eager tourists daily. The monuments' builders wished these stones to "speak" for at least another 8,000 years, while the lethal and mutagenic substances they warn of slowly exhaust themselves. (Excerpt from an article written in Omni Magazine, by Carole Douglis, titled Stone Sentry, 1983)" [8*].

Once the leftover is entombed for perpetuity, how do we caution our future generations of its possible threat? Markings rust, documents crumble, buildings fail, languages change, places are forgotten. Life and climate 10,000 ages into the future may be drastically diverse from what we recognise today. The issue of Global Warming and its connection with the concrete industry [1], shows how wild fluctuations might ensue within a period frame as tiny as double century. It is a tough call to communicate with our successors who are going to come after some centuries. They will not have knowledge and ideas that we have today and there is a lot of possibilities for them to discharge the fatal substance into the surroundings knowingly or unknowingly [8]. An important statistic of geopolymer technology is that it consumes very low energy, low cost and increases 5 – 10 times the amount of geopolymer cementitious product with the same venture invested in the industries following Ordinary Portland Cement technology [1], [10].

Geopolymer concrete are also withstand higher temperature (1250ºC) and non-ignitable compared to conventional concrete which are ignitable at higher temperatures [9]. The geopolymer concrete is basically forms from the alkali-activated materials, possessing low permeable property compared to cement concrete [11]. They also cost effective associated to OPC subsequently the capital costs of a plant manufacturing alkali-activated materials will accordingly lower than that of a plant manufacturing Portland cement [12]. Geopolymer concrete usage in construction may play a vigorous role in controlling the global warming. The figure 3 and 4 shows the process of binding mechanism and conceptual model for geopolymerisation of geopolymer concrete. Due to its high resistance to fire it may also be used in the field of fire resistant wood panels, Insulated panels and walls, decorative stone artifacts, foamed (expanded) geopolymer panels for thermal insulation, low-tech building materials, energy low ceramic tiles, refractory items, Thermal shock refractory, aluminum foundry application, geopolymer cement and concrete, fire resistant and fire proof composite for infrastructures repair and strengthening, fireproof high-tech applications, aircraft interior, automobile, high-tech resin systems [26]. Figures 3 and 4 denote polymerisation of geopolymer.

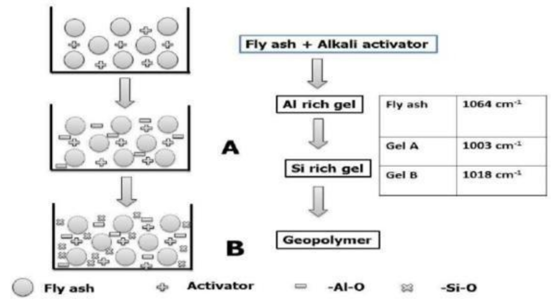


Fig. 3 Pictorial Representation of Geopolymerisation mechanism *(ResearchGate [38])*

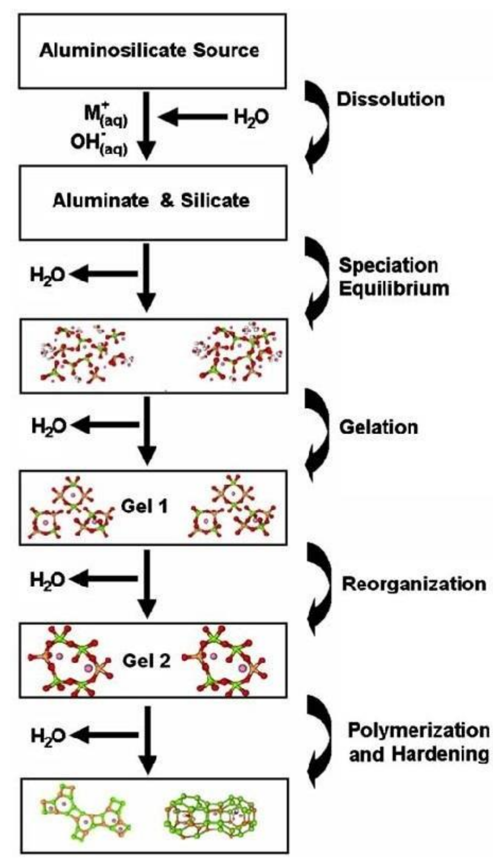


Fig. 4 Conceptual model for geopolymerisation ofgeopolymer concrete *(ResearchGate [39])*

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 8, Issue 6, June 2018)

IV. GEOPOLYMERS

The term geopolymer can be understood easily by splitting the term into two words, geo + polymer. Creating a cementitious material using materials / by-products obtained from earth materials and binding process is taken care by the polymerisation reactions. The term "*Geopolymer*" was coined by Davidovits since the reaction takes place is "*Polymerisation process*" [12], [13]. The main constituents of geopolymers are the source materials and the alkaline liquids. The source materials should rich in silicon and Aluminium such as kaolinite, clays, fly ash, silica fume, slag, rice husk ash, red mud, etc. The alkaline solution mostly used in geopolymers are soluble alkali metals such as sodium silicate(Na_2SiO_3) or potassium silicate (K_2SiO_3) and sodium hydroxide (NaOH) or potassiumhydroxide (KOH) [14].

At ambient temperature the hardening of geopolymer cements happens with good strength in compression in the range of 20 MPa in a period of four hours only and about 70 – 100 MPa after 28 days [15]. The hazardous wastes are locked inside the geopolymeric matrix and they act as a binder to convert semi solid wastes into adhesive solids. The exceptional assets of geopolymer cements such as resistance to sulphate, corrosion resistance, high early strength, low shrinkage, resistance to freeze and thaw benefits them for long term inhibition in surface disposal facilities and also they do not create any alkali – aggregate reaction [15].

Geopolymers are member of the cluster of inorganic polymers. The chemical composition of the geopolymer material is like natural zeolitic materials, but the microstructure is amorphous. The polymerization process involves a substantially fast chemical reaction under alkaline condition on Si-Al minerals, that results in a three-dimensional polymeric chain - a ring structure consisting of Si-O-Al bonds [16]. Figures 5 to 7 show the preparation of alkaline solution, materials used in geopolymer concrete and polymerization reaction of geopolymer concrete respectively.

Fig. 5 Preparation of Alkaline Activator Solution *[27]*

Fig. 6 Materials used for making ofgeopolymer concrete *[27]*

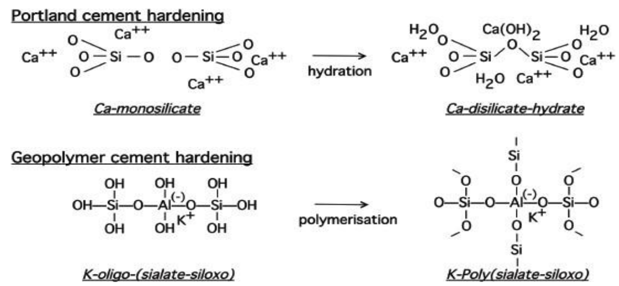


Fig. 7 Polymerisation reaction of geopolymerconcrete *[27]*

V. MATERIALSUSED FOR PRODUCTIONOF GEOPOLYMER CONCRETE

Among the all other materials such as kaolinite, clays, silica fume, slag, rice husk ash, red mud, etc. fly ash is mostly used for making geopolymer concrete [14]. There are two types of fly ash available all over the world namely low- calcium (ASTM Class F) fly ash and high calcium (ASTM Class C) fly ash. For manufacturing of geopolymer concrete low-calcium (ASTM Class F) fly ash is widely used all over the world. In most of the countries the availability of low-calcium (ASTM Class F) fly ash is enormous. The low calcium fly ash is obtained as by-product of burning anthracite or bituminous coal in power plants [14]. The low calcium fly ash was effectively manufactured with 80 % of silicon and aluminium oxides by mass and the Silicon to Aluminium ratio of 2 [14]. The studied reveals that the fly ashes are very small in size, lesser than 50 μm by accompanying particle size distribution test [3,14,17-25]. The filler materials used in cement concrete are suitable for making geopolymer concrete [3,14,17-22]. The alkaline activator solution is an amalgamation of sodium hydroxide (97 – 98 % purity, pellet form) and sodium silicate solution. The strength of the geopolymer concrete is mainly depends upon the concentration of the alkaline solution. The suitable molarity of geopolymer concrete ranges from 8 M to 16 M but 8 M is adequate for attaining the required strength of geopolymer concrete [14]. Generally, the setting time of geopolymer concrete is high so ground granulated blast furnace slag is added to accelerate the setting time and improve the curing effects of geopolymer concrete.

A. Casting Procedure for Geopolymer Concrete:

The alkaline solution should be prepared before 24 hours of casting. The pellet form sodium hydroxide is mixed with water and then it is mixed with sodium silicate solution and stirred well for obtaining better alkaline solutions. Then the fly ash, GGBS and sand is added and allowed to mix in pan mixer for 2 minutes for uniform distribution of fly ash and GGBS next coarse aggregate are added in the pan mixer and allow the mixer to mix the materials up to 2 minutes and then the prepared alkaline activator solution is added and mixed for 2 minutes. Finally, the geopolymer concrete will be ready for casting. the geopolymer concrete can be cast in required sized or shaped moulds to get different specimens [28]. The addition of GGBS will leads to ambient curing of geopolymer concrete. Higher concentration of NaOH results in high compressive strength and addition of 4 % of superplasticizer may improve workability but degrade the compressive strength [14, 27]. Figures 7 and 8 indicates the casting of geopolymer concrete [27].

B. Curing Procedures for Geopolymer Concrete:

The ordinary cement concrete hardens due to hydration process in the occurrence of water. The Geopolymer concrete revealed that cannot attain any strength by water curing since it hardens due to polymerization process in presence of temperature. The Geopolymer concrete will harden at steam curing or hot air curing and the minimum curing period shall be 24 hours. After casting the specimens, they are kept in rest period in room temperature for 2 days. The term 'Rest Period' was created to designate the time taken from the completion of casting of assessment specimen to the start of curing at a higher temperature. The geopolymer concrete specimens are demoulded and then placed in steam curing chamber for 24 hours at a temperature of 60^{o} C. The geopolymer concrete specimens are then allowed to cool in room temperature for 24 hours [27-28].

If the geopolymer concrete is cured in ambient conditions, the strength will not progress up to its full capacity. To improve the strength development under ambient conditions, materials like silica fume and slag should be added up to 30 to 40 percent. In that case, the geopolymer concrete is not fully based on fly ash and the cost will be more than that of concrete with ordinary Portland cement [27-28]. But comparing with steam curing or hot air curing, geopolymer concrete with slag will be energy efficient and cost efficient in terms of using steam curing chamber or hot air oven chamber, as they require high energy to create steam which is completely not needed when slag is added with the geopolymer concrete. Slag is also a by-product obtained during the production of steel[29].

VI. APPLICATIONS OF GEOPOLYMERS

On the view of Davidovits [30] the geopolymer has a wide range of applications around the world. The features like early strength, fire resistance [32], acid resistance makes geopolymer concrete as a versatile material for constructions. some of the applications of geopolymers are fire resistance wood panels, insulated panels and walls, decorative stone artifacts, foamed (expanded) geopolymer panels for thermal insulation, low-tech building materials, energy low ceramic tiles, refractory items, thermal shock refractory, aluminium foundry application, geopolymer cement and concrete, fire resistant and fire proof composite for infrastructures repair and strengthening, fireproof high-tech applications, aircraft interior, automobile, high-tech resin systems[26]. Its application based on the ratio of silica to alumina atomic ratio [14,27] is given in the Table 1. It also used as a material for repair the reinforced concrete beams [31]. Geopolymer can be a good alternative material for the construction and other industries.

Table 1 Application of Geopolymer base on Silica – Alumina Atomic Ratio *([14,27])*

Si:Al Ratio	Applications
1	- Can be used to make bricks. - Can be used for producing ceramics. - Can be used as fire protection where there is a frequent chances of fire accidents.
2	- Low CO2 cements and concretes. - Radioactive and toxic waste encapsulation.
3	- Fire protection fibre glass composite. - Foundry equipments – Heat resistant composites, 200° C to 1000° C. - Tooling for aeronautics titanium process.
>3	- Sealants for industry, 200° C to 600° C. - Tooling for aeronautics SPF Aluminium.
20 – 35	- Fire resistant and heat resistant fibre composites

Some other application of geopolymer are, it can be used in ferro-geopolymer elements, hallow geopolymer concrete blocks, GFRP reinforced geopolymer concrete beams, pre-tensioned geopolymer sleepers. Figures 8 to 11 represent the typical ferro-geopolymer dome structures [33]. A typical research work was found in the application of geopolymer in pre-tensioned railway sleepers (GPCRS) and it is represented in the Figures 12 to 14 [27,35].

IJETAE
EXPLORING RESEARCH AND INNOVATIONS

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 8, Issue 6, June 2018)

Fig. 8 Outer surface of Dome

Fig.9 Inner Surface of Dome

Fig. 10 Test Setup of Dome

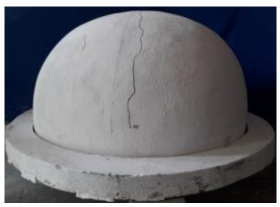


Fig.11 Crack Pattern of Dome

Fig. 12 Pre-tensioned setup GPCRS

Fig. 13 Pre-tensioned GPCRS

Fig. 14 Testing of GPC Railway Sleepers

Correspondingly, some other significant work was done in ferro-geopolymer water pipes (FGPWP) and ferro-geopolymer channel for roofing systems (FGPRS). Figures 15 to 17 show the ferro-geopolymer water pipe casting, test setup and crack pattern [34]. Figures 18 and 19 denote the test setup and crack pattern of ferro-geopolymer channels for roofing system respectively [40].

Fig. 15 Casting of Ferro-geopolymer Water Pipes

Fig. 16 Test setup of FGPWP

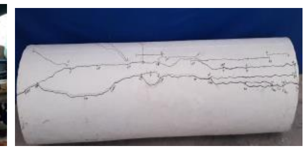


Fig. 17 Test setup of FGPWP

Fig. 18 Test Setup of FGPRS

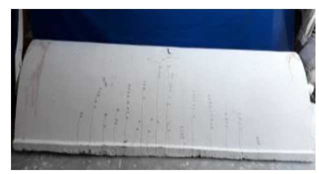


Fig. 19 Crack pattern of FGPRS

Like this, the application of geopolymer is vast and an extensive research work were conducted and also in progress in the Department of Civil and Structural Engineering, Annamalai University.

VII. CONCLUSIONS

- The use of geopolymer concrete in the construction field will be a suitable alternative for Ordinary Portland Cement concrete and other elements produced using Ordinary Portland Cement.
- The researches in the field of geopolymer concrete fascinated by many researchers, resulting in the arrival of innovative applications of geopolymer concrete in concrete industries.
- It is clearly understood by the investigation conducted on geopolymer concrete exhibit is good performance in strength and durable aspects.

- Through this study, it is concluded that the geopolymer concrete can be used as an appropriate alternative to the cement concrete.

Acknowledgement

We, the authors sincerely acknowledge the support and encouragement provided by the University Grants Commission, New Delhi by sanctioning a research project, (MRP- MAJOR- CIVIL-2013-36977) entitled 'Development of geopolymer concrete and testing of elements' to Annamalai University.

References

[1] Joseph Davidovits., 1994. Global Warming Impact on the Cement and Aggregates Industries. published in World Resource Review, Vol. 6, No.2, pp. 263-278, 1994.
[2] McCaffrey, R. (2002). Climate Change and the Cement Industry. Global Cement and Lime Magazine (Environmental Special Issue), 15-19.
[3] Wallah, S. E., and Rangan, B. V. 2006. Low-Calcium Fly Ash-Based Geopolymer Concrete: Long-Term Properties, Research Report GC 2 Faculty of Engineering Curtin University of Technology Perth, Australia.
[4] Duxson. P., Provis, J. L., Lukey, G. C., and Van Deventer, J. S. J. 2007. "The roleof Inorganicpolymer technology in thedevelopment of green concrete", cement and concrete research, 37 (12), 1590 – 1597.
[5] Gartner, E. 2004. Industrially interesting Approaches to Low – CO2 Cements. Cement and Concrete research, 34(9), 1489 – 1498.
[6] Krishnan, L., et al. 2014. Geopolymer Concrete an Eco -Friendly Construction Material. International Journal of Research in Engineering and Technology, Vol. 3 special issue.
[7] Kawade, U. R., Salunkhe, P. A., Kurhade, S. D. 2014. Fly Ash based Geopolymer Concrete. International Journal of Innovative Research in Science, Engineering and Technology, Vol. 3, Special Issue 4, (April 2014).
[8] Joseph Davidovits., 1994. Recent Progress in Concretefor Nuclear Waste and Uranium Waste Containment. Concrete International, Vol. (16), pp. 53 – 58 (1994).
[9] Joseph Davidovits., 1994. GEOPOLYMERS: Man-Made Rock Geosynthesis and the Resulting Development of Very Early Strength Cement. J. Materials Education, Vol. 16 (2&3), pp 91 - 139 (September 1994).
[10] Joseph Davidovits., 2015. False Value on CO_2 Emission for Geopolymer Cement / Concrete published in Scientific Papers, Technical Paper #24, Geopolymer Institute Library, www.geopolymer.org.
[11] Bernal, Susan. A. and Provis, John. L. 2014. Durability of Alkali-Activated Materials: Progress and Perspectives. Journal of the American Ceramic Society, Vol.97, No. 4.
[12] Davidovits, J. 1994. High-Alkali Cements for 21st Century Concretes. In Concrete Technology, Past, Present and Future. Proceedings of V. Mohan Malhotra Symposium, Editor: P. Kumar Metha, ACI SP- 144, 1994, pp.383-397.
[13] Davidovits, J. 1988. Soft Mineralogy and Geopolymers. Proceedings of the of Geopolymer 88 International Conference, the Université de Technologie, Compiègne, France
[14] Vijaya Rangan, B. 2014. Geopolymer Concrete for Environmental Protection. The Indian Concrete Journal, Vol. 88, Issue 4, pp. 41 - 48, 50 – 59.
[15] Joseph Davidovits., 1994. Properties of Geopolymer Concrete. Proceedings First International Conferenceon Alkaline Cements and Concrete, Scientific Research Institute on Binders and Materials, Kiev State Technical University, Kiev, Ukrine, pp. 131-149.
[16] Davidovits, J. (1994) " High – Alkali cements for 21st century concretes in concrete technology, past, present and future". IN proceedings of V.Mohan Malhotra Symoposium. Editor: P. Kumar Metha, ACI SP -144.pp383-397.
[17] Gourley, J. T. 2003. Geopolymers; Opportunities for Environmentally Friendly Construction Materials. Paper presented at the Materials 2003 Conference: Adaptive Materials fora Modern Society, Sydney.
[18] Gourley, J. T., and Johnson, G. B. 2005. Developments in Geopolymer Precast Concrete. Paper presented at the International Workshop on Geopolymers and Geopolymer Concrete, Perth, Australia.
[19] Hardjito, D. and Rangan, B. V., Development and Properties of Low- Calcium Fly Ash-based Geopolymer Concrete. Research Report GC1, Faculty of Engineering, Curtin University of Technology, Perth, 2005 available at espace@curtin or www.geopolymer.org
[20] Sumajouw, M.D.J. and Rangan, B.V. , Low-Calcium Fly Ash-Based Geopolymer Concrete: Reinforced Beams and Columns. Research Report GC3, Faculty of Engineering, Curtin University of Technology, Perth, 2006, available at espace@curtin or www.geopolymer.org.
[21] Rangan, B.V. 2008. Low-Calcium Fly Ash-based Geopolymer Concrete. Chapter 26 in Concrete Construction Engineering Handbook, Editor-in Chief: E.G. Nawy, Second Edition, CRC Press, New York,.
[22] Rangan, B.V. 2009. " Engineering Properties of Geopolymer Concrete", Chapter 11 in Geopolymers: Structures, Processing, Properties, and Applications, Editors: J.Provis and J. van Deventer, Woodhead Publishing Limited, London.
[23] Fernández-Jiménez A. M., Palomo A., and López-Hombrados C. Engineering Properties of Alkali-activated Fly Ash Concrete. ACI Materials Journal, 103(2), 2006, pp. 106-112.
[24] Sofi M., Van Deventer J. S. J., Mendis P. A., and Lukey G. C. 2007. Engineering Properties of Inorganic Polymer Concretes (IPCs), Cement and Concrete Research, 37(2),, pp.251-257.
[25] Siddiqui, K.S. 2007. Strength and Durability of Low-Calcium Fly Ash- based Geopolymer Concrete. Final Year Honours Dissertation, The University of Western Australia, Perth.
[26] Prof. Dr. Joseph Davidovits. 2002. 30 Years of Successes and Failures in Geopolymer Applications. Market Trends and Potential Breakthroughs. Geopolymer 2002 Conference, October 28-29, 2002, Melbourne, Australia.
[27] Dr. Antony Jeyasehar, C., Dr. Salahuddin, M., Dr. Thirugnanasambandam, S. 2013. Development of fly ash based geopolymer concrete precast elements. Research project submitted to Ministry of Environment and Forests, New Delhi.
[28] Kumaravel, S., Thirugnanasambandam, S. 2013. Flexural Behaviour of Reinforced Low Calcium Fly Ash based Geopolymer Concrete Beam. Global Journals of Researches in Engineering: Civil and Structural Engineering. Vol. 13, Issue 8, Version 1.0.
[29] Rafat Siddique., Rachid Bennacer. 2012. Use of Iron and Steel Industry By-products (GGBS) in Cement Pasteand Mortor. Elsevier, Resources, Conservation and Recycling 69 (2012) 29-34.
[30] Davidovits, J., 1994. High-Alkali Cements for 21st Century Concretes. In Concrete Technology, Past, Present and Future",

International Journal of Emerging Technology and Advanced Engineering

Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 8, Issue 6, June 2018)

Proceedings of V. Mohan Malhotra Symposium, Editor: P. Kumar Metha, ACI SP- 144, 1994, pp.383-397.

[31] Balaguru, P. N., Stephen Kurtz., Jon Rudolph. 1997. Geopolymerfor Repair and Rehabilitation of Reinforced Concrete Beams. A project on GEO-STRUCTURE, Fire – Proof External Repair and Structural Retrofit for aging infrastructure, aging building, earthquake and hurricane proneareas at Rutgers the State University of New Jersey, Piscataway, NJ 08855-0909, USA.

[32] Lyon, E. Richard., Balaguru, P. N., Andrew Foden., Usman Sorathia., Joseph Davidovits., Michel Davidivits. 1997. Fire Resistant Aluminosilicate Composities. Fire and Materials, Vol. 21, 67 – 73 (1997), USA.

[33] Priyadharshini, S. 2017. Experimental Investigations on Ferrogeopolymer Domes. Thesis Submitted to Department of Civil and Structural Engineering, Annamalai University, Annamalainagar, Tamilnadu, India - 608002.

[34] Suvetha, G., S. 2017. Experimental Investigations on Ferrogeopolymerwaterpipes. Thesis Submitted to Department of Civil and Structural Engineering, Annamalai University, Annamalainagar, Tamilnadu, India - 608002.

[35] Selvakumar, S. 2016. Study on Flexural Behaviour of Pretensioned Geopolymer Sleepers. Thesis Submitted to Department of Civil and Structural Engineering, Annamalai University, Annamalainagar, Tamilnadu, India - 608002.

[36] Web source. Available at https://www.ieltsbuddy.com/diagram-task-1-cement-making-process.html.

[37] Web source. Available at http://slideplayer.com/slide/3979026/.

[38] Web source. Available at ResearchGate. https://www.researchgate.net/figure/An-illustration-of-the-geopolymerization-mechanism-and-subsequent-variation-in- FTIR-9_fig1_288856881

[39] Web source. Available at ResearchGate. https://www.researchgate.net/figure/Conceptual-model-for-Alkaline-Activation-Processes_fig1_303160905

[40] Sushil Kumar Singh. 2017. Development of Roofing System using Ferrogeopolymerchannels. Thesis Submitted to Department of Civil and Structural Engineering, Annamalai University, Annamalainagar, Tamilnadu, India - 608002.

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal,Volume 8, Issue 6, June 2018)

Geopolymer Bricks

R. Anu[1], S. Thirugnanasambandam[2]

[1]Research Scholar, Department of Civil & Structural Engineering, Annamalai University, Annamalai Nagar
[2]Associate Professor, Department of Civil & Structural Engineering, Annamalai University, Annamalai Nagar

Abstract— **Geopolymer Brick is an alternative for the burnt clay bricks. Geopolymer bricks are made by using the industrial wastes such as Ground Granulated Blast Furnace Slag (GGBS), fly ash with sand. The Class F fly ash collected from Mettur Thermal Power Station has been used. The fly ash and GGBS react with alkali activator solution of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3). The size of geopolymer brick is 225 x 110 x 75mm. The fly ash based geopolymer bricks were cured under the hot air oven curing at 60^0C for 24 hours. The fly ash and GGBS based geopolymer bricks were cured under ambient temperature. The compressive strength, water absorption and acid resistance tests were carried out. The strength of geopolymer bricks were compared with locally available conventional bricks.**

Keywords— **Geopolymer Bricks; Fly ash; GGBS; Sodium Silicate; Sodium Hydroxide.**

I. INTRODUCTION

Geopolymer technology was developed by DAVIDOVITS in 1980 by silicon and aluminium or from by-products materials of fly ash. Geopolymer technology reduces the CO_2 emissions. The ratio of silicon and aluminium is 2 to 3.5. The chemical composition of the geopolymer material is similar to natural zeolitic materials, but the microstructure is amorphous. Higher concentration of sodium hydroxide solution results in higher compressive strength of geopolymer products. The Class F fly ash is produced from the combustion of anthracite or bituminous coal.

II. LITERATURE STUDY

Ashish Kumar Parashar and Rinku Parashar [1] investigated the bricks made with various materials to clay bricks. They added rice husk, wood ash, fly ash, cement to cast bricks. By casting of bricks with different raw materials, the compressive strength of brick increases again while increasing the percentage of wood ash from 8 to 16 percent. Gopinandandey and Joyanta Pal [2] studied the use of brick aggregate in standard concrete and its performance in elevated temperature. The standard concrete can be made with crushed brick aggregate which are also having very good heat resistance up to a temperature of 60^0C. Brick aggregate concrete was made by partial replacement of natural stone aggregate by brick aggregate of 12 to 20 percent. Mamta Rajgor and Jayeshkumar Pitroda [3] studied the utilization of stone sludge waste in manufacturing fly ash in which bricks. Marble and granite industries stone sludge waste used for casting bricks in which fly ash was replaced by stone waste. Mohammad Shahid Arshad and Paward P.Y [4] studied the reuse of natural waste material for making light weight bricks. Bricks prepared from natural waste material which comprises of orange peels (10 to 40% weight) and coconut waste (10 to 60% weight) and paper mill waste (22.36%). These wastes are used to reduce the quantity of clay as there is a greater shortage of clay in many parts of the world. The result shows the comparison of compressive strength of bricks, when it is prepared by orange peels (low) and coconut (high) waste. Rinku Kumar and Naveen Hooda [5] studied an experimental study on properties of fly ash bricks. The bricks produced were about 29% lighter than clay bricks and was found to be compact, homogeneous and free from any defects like holes, lumps, etc as compared to normal bricks.

III. MATERIALS USED

The geopolymer brick was prepared using fly ash, GGBS, fine aggregate, sodium silicate and sodium hydroxide.

A. Fly Ash

Fly ash is a waste product obtained from Thermal Power Plant Industries and is produced during the operation of coal-fired. Based on two types of fly ash called as Class F and Class C. Class F fly ash is called as low calcium fly ash which has less than 10% of calcium oxide (CaO) with $SiO_2 + Al_2 O_3 + Fe_2 O_3 > 70\%$ produced from the combustion of anthracite or bituminous. Class C fly ash is called as high calcium fly ash which has more than 10%

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 8, Special Issue 3, March 2018)

calcium oxide [CaO] with $SiO_2 + Al_2O_3 + Fe_2O_3 > 50\%$ produced from the combustion of lignite or sub-bituminous coal. In India, produced mostly Class F (low calcium) type of fly ash and generates more than 150 million tons/year. The specific gravity of fly ash is 2.36. The calcium oxide content is 0.95% in Class C type fly ash which was used in this study.

B. Ground Granulated Blast Furnace Slag [GGBS]

GGBS is a waste product produced when iron is melt in blast furnace in 1400-1600^{0}C temperature. Floating impurities containing lime, silica, alumina from blast furnace used to produce a glassy, granular product that is then dried and ground into a fine powder. The specific gravity of GGBS is 2.9.

C. Sodium Hydroxide [NaOH]

The sodium hydroxide is available in pellets form, also called as caustic soda. Sodium hydroxide is used as a common base in chemical laboratories.

D. Sodium Silicate [Na_2SiO_3]

The sodium silicate is available in liquid form, also called as water glass or liquid glass. There silicates are supplied to the detergent company and textile industry as bonding agent.

E. Activator Solution

Generally, alkaline liquids are prepared by mixing the sodium silicate and sodium hydroxide solution at the room temperature. When the solution mixed together, the both solution start to react (i.e., polymerization take place) it liberates large amount of heat, so it is recommended to leave it for about 24 hours thus alkaline liquid is get ready as binding agent. Concentration of sodium hydroxide 4M, 5M, 6M, 7M and 8M were used. NaOH pellets is diluted and mixed with sodium silicate. Sodium silicate and sodium hydroxide are taken in the ratio of 2.5. The ratio of fly ash and sand is 1:3 with ratio of activator solution to fly ash ratio is taken as 0.45.

F. Fine Aggregate

Fine aggregate has the following properties. Specific gravity : 2.60. Fineness modulus : 2.43. Conforming to Zone-II as per IS: 383-1970.

IV. GEOPOLYMER MORTAR

The laboratory program conducted in this investigation focused on five basic mixes based on the molarities of NaOH such as 4M, 5M, 6M, 7M and 8M of NaOH. The ratio of fly ash and sand was kept constant on 1:3. The materials required for geopolymer mortar is shown in Fig. 1.

FIG. 1 MIXING OF RAW MATERIALS IN PAN MIXTURE

The raw materials of geopolymer mortar were mixed in the laboratory pan mixture. Premixed alkaline activated solution is then added gradually in the mixture. Mixing is continued for further 4 to 6 minutes depending on the consistency of the mixture. Mortar moulds of size 50cm^2 cross sectional area were filled with geopolymer mortar in three layers and compacted. The moulds are then kept in room temperature for 24 hours as shown in Fig. 2. To know the effect of concentration of NaOH on strength of mortar, 4 to 8 Molarity of NaOH were used in this study. The geopolymer mortar cubes with varying NaOH concentration are shown in Fig. 3.

FIG. 2 GEOPOLYMER MORTAR CUBES IN MOULD

Curing temperature is an important factor for the strength point of geopolymer mortar. The main polymerization process or the chemical reaction of geopolymer mortar takes place with the temperature imposed to it during the curing. It may attain almost its 70% strength within the first 3 to 4 hours of hot curing. The rate of increase of strength is rapid in the initial 24 hours of curing beyond that the gain of strength was moderate. The electric oven (Fig.4) was used to cure fly ash based geopolymer mortar cubes at 60^{0}C for 24 hours.

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 8, Special Issue 3, March 2018)

(a) 8M

(b) 7M

(c) 6M

(d) 5M

(e) 4M

FIG. 3 GEOPOLYMER MORTAR CUBES

FIG. 4 GEOPOLYMER MORTAR AT OVEN CURING

.

The hot cured geopolymer mortar cubes were tested in compressive testing machine and results are shown in Table 1. The comparison of compressive strength of various NaOH concentrations is shown in Fig. 5.

TABLE 1
COMPRESSIVE STRENGTH OF GEOPOLYMER MORTAR CUBES

Sl. No	Concentration of NaOH	Average Compressive Strength on Geopolymer Mortar Cube (MPa)
1	8M	11.93
2	7M	10.53
3	6M	9.13
4	5M	4.60
5	4M	2.87

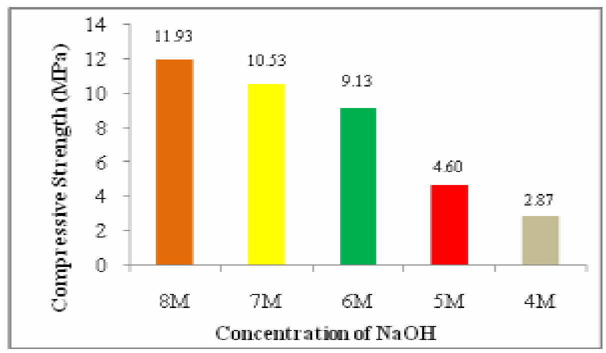


FIG. 5 COMPARISON OF COMPRESSIVE STRENGTH ON GEOPOLYMER MORTAR CUBE

V. GEOPOLYMER BRICKS

The normal strength of bricks available in the market is 5 MPa which is greater the minimum strength required as per (IS: 1077 : 2007) code as 3.5 N/mm^2. From the results of different molarities of geopolymer mortar cubes, 6M was chosen for the casting of geopolymer bricks. Before casting geopolymer bricks, again mortar cubes cast with fly ash and GGBS as source material. The addition of GGBS is to cure the specimen in ambient temperature. Geopolymer mortar was prepared source material by (50% fly ash + 50% GGBS) with sand is 1:3 ratio. The alkaline solution was prepared as per specification mentioned above. The purpose of addition of GGBS is for finding two curing method of specimen. These specimens were tried with hot air oven curing at 60°C as well as at roof top in ambient condition for 24 hours. The compressive strength of geopolymer mortar with 6M NaOH is given in Table 2. The compressive strength of geopolymer mortar cubes obtained as 18.08 MPa in hot curing and 16.60 MPa in ambient temperature curing.

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 8, Special Issue 3, March 2018)

TABLE 2
GEOPOLYMER MORTAR CUBES (6M NaOH)

Sl. No.	FA : GGBS	Curing	Average Compressive Strength of Geopolymer Mortar Cubes (MPa)
1	50 : 50	Oven	18.08
2	50 : 50	Ambient	16.60

. The geopolymer bricks were cast in standard size mould of 225 x 110 x 75 mm. The source material (50% fly ash + 50% GGBS) with sand is 1:3 ratio was used to cast geopolymer brick. 6M NaOH was used to prepare alkaline solution. The casting of geopolymer bricks in mould is shown in Fig. 6. Fig. 7 shows the curing of geopolymer brick at roof top in ambient condition of 24 hours. For compression purpose similar bricks are cured in hot air oven at 60°C for 24 hours.

FIG. 6 GEOPOLYMER BRICKS IN MOULD

FIG. 7 CURING OF GEOPOLYMER BRICKS AT ROOF TOP

A. Compressive Strength on Geopolymer Bricks

The geopolymer bricks were tested at the same side of casting as shown in Fig. 8. The compressive strength of geopolymer bricks cured at 60°C and ambient condition is shown in Table 3.

TABLE 3
STRENGTH OF GEOPOLYMER BRICKS

Sl. No.	NaOH	FA : GGBS	Curing	Average Compressive Strength (MPa)
1	6M	50 : 50	Oven	16.50
2	6M	50 : 50	Ambient	14.80

FIG. 8 COMPRESSION TEST ON GEOPOLYMER BRICKS

VI. WATER ABSORPTION TEST

The geopolymer bricks and conventional clay bricks were immersed in water for 24 hours (Fig. 9). Then, bricks were taken now and wiped by cloth. The percentage of water absorption of bricks are calculated and shown in Table 4.

(a) GEOPOLYMER BRICKS

(b) CONVENTIONAL CLAY BRICKS

FIG. 9 WATER ABSORPTION TEST

TABLE 4
STRENGTH OF GEOPOLYMER BRICKS

SI. No	Types of Bricks	Average Percentage of Water Absorption (%)
1	Geopolymer Brick	4.06
2	Clay Brick	15.29

As per IS code the minimum percentage of water absorption of bricks is 20%. The geopolymer brick is absorbed 4.06% of water and clay brick absorbed 15.29% of water.

VII. DURABILITY TEST ON BRICKS

A. *Acid Resistance Test*

Acid resistance test was conducted with 1% of H_2SO_4 and 3% of HCL. The geopolymer bricks and conventional clay bricks were immersed in acid solution for 28 days (Fig. 10).

(a) Geopolymer Brick in H_2SO_4 (b) Conventional Brick in H_2SO_4

(c) Geopolymer Brick in HCL (d) Conventional Brick in HCL

FIG. 10 ACID RESISTANCE TEST

Then, the specimens were taken out from the acid solution and the surfaces of the bricks were cleaned. The weight and the compressive strength of the specimens were found. The results of acid resistance test are given in Table 5.

TABLE 5
ACID RESISTANCE TEST RESULT

Sl. No.	Types of Brick	Loss of Weight (%)		Loss of Compressive Strength (%)	
		H_2SO_4 (1%)	HCL (3%)	H_2SO_4 (1%)	HCL (3%)
1	Conventional	2.40	4.42	23.61	24.05
2	Geopolymer	2.26	1.02	18.96	5.07

VIII. CONCLUSIONS

Based on the experimental study carried on geopolymer bricks and conventional clay bricks, the following conclusions are derived.

1. The compressive strength of 8M, 7M, 6M, 5M and 4M NaOH concentration geopolymer mortar cubes obtained as 11.93, 10.53, 9.13, 4.60 and 2.87 MPa respectively.
2. The 6M NaOH geopolymer mortar cubes with 50% FA + 50% GGBS cast and cured in oven and ambient curing. The compressive strength of oven cured geopolymer mortar is 18.08 MPa and ambient cured geopolymer mortar shows compressive strength of 16.6 MPa.
3. The compressive strength of geopolymer bricks cured in ambient condition and 60°C in oven are 16.50 and 14.80 MPa.
4. The percentage of water absorption of 6M NaOH geopolymer bricks made with 50% FA + 50% GGBS obtained as 4.06% only which is very low when compared to all other bricks.
5. The percentage of weight loss observed after 28 days immersed in 1% concentration of Sulphuric acid (H_2SO_4) in conventional and geopolymer bricks is 2.40% and 2.26% respectively.
6. The reduction in strength observed in acid resistance test on conventional and geopolymer bricks is 23.61 % and 18.96 % respectively.
7. The percentage of weight loss observed after 28 days immersed in 3% concentration of Hydrochloric acid (HCL) in conventional and geopolymer bricks is 4.42 % and 1.02 % respectively.
8. The reduction in strength observed in acid resistance test on conventional and geopolymer bricks is 24.05 % and 5.07 % respectively.
9. Hence, the ambient cured geopolymer bricks are found suitable for construction purposes since it is satisfying all the requirements.

ACKNOWLEDGEMENT

We, the authors sincerely acknowledge the support and encouragement provided by the University Grands Commission, New Delhi by sanctioning a research project, (MRP- MAJOR- CIVIL-2013-36977) entitled 'Development of geopolymer concrete and testing of elements' to Annamalai University.

References

[1] Ashish Kumar Parashar and Rinku Parashar (2012). Comparative Study of Compressive Strength of Bricks made with various Materials to Clay Bricks. *International Journal of Scientific and Research Publications,* Vol 2, pp 1-4.

[2] Gopinandan Dey and Joyanta Pal (2013). Use of Aggregate in standard Concrete and Its Performance in elevated Temperature. *International Journal of Engineering and Technology,* Vol 5, pp 523-526.

[3] Mamta Rajgor and Jayeshkumar Pitroda (2013). Stone Sludge: Economical solution for manufacturing of Bricks. *International Journal of Innovative Technology and Exploring Engineering,* Vol 2, pp 16-20.

[4] Mohammad Shahid Arshad and P.Y Pawade (2014). Reuse of Natural Waste Material for making Light Weight Bricks. International Journal of Scientific and Technology Research, Vol 3, pp 49-53.

[5] Rinku Kumar and Naveen Hooda (2014). An Experimental Study on properties on Fly Ash Bricks. *International Journal of Research in Aeronautical and Mechanical Engineering,* Vol 2, pp 56-67.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 6.887
Volume 7 Issue I, Jan 2019- Available at www.ijraset.com

Geopolymer Concrete Using Scrap Steel Slag as Coarse Aggregate

Suganya. N[1], Thirugnanasambandam. S[2]
[1, 2]Department of Civil and Structural Engineerin, Annamalai University, Tamil Nadu, India

Abstract: ***This study is to evaluate the performance of scrap steel slag as coarse aggregate in low calcium fly ash based geopolymer concrete. Geopolymer concrete is an innovative material which is 100% cement-less. This experimental work was carried out to make it more sustainable by replacing the natural gravel coarse aggregate in geopolymer concrete by scrap steel slag, an industrial waste. Laboratory investigation was carried out and the conclusion is made based on mechanical – Compressive, Tensile, Flexural strength and Durability – Acid resistance, Sulphate resistance properties of concrete. It is found that steel slag performs similar to that of natural gravel coarse aggregate in concrete.***
Keywords: Low calcium fly ash, Geopolymer, Scrap steel slag, Mechanical properties, Durability properties.

I. INTRODUCTION

Geopolymer concrete replaces cement binder in conventional concrete by alkali activated pozolanic material rich in silica and alumina. This innovative invention to replace cement in concrete is gaining importance in recent decades and is being put to field applications recently.

Replacement for cement is attentive because of the fact that concrete production involves release of huge amount of CO_2 into the atmosphere contributing largely to global warming.

Next to that, coarse aggregate which forms 60-70% of concrete leads to natural resource depletion, since natural gravel is used as coarse aggregate in conventional concrete. 8-12 million tons of natural aggregates are involved in concrete making annually. Globally, the amount of industrial waste products generated annually increases at a faster rate. In India around 960 MT of solid wastes are being generated every year out of mining and industrial activities.

To preserve this fast depleting natural resource, many research works are going on to replace the coarse aggregate in concrete. Scrap steel slag is selected in this study because the physical and chemical properties of steel slag are similar to that of natural gravel *(Suganya.N and Thirugnanasambandam. S)*[7].

Thus, this experimental study is carried out replacing the natural coarse aggregate in cement-less geopolymer concrete by scrap steel slag, an industrial waste.

II. LITERATURE REVIEW

1) *Sultan Tarawneh et al (2014)*[1] studied the effects of using steel slag aggregate on mechanical properties of concrete and reports that steel slag acts as accelerator at early age and 7 days strength of steel slag concrete is higher and at 28 days, the effect is reduced.
2) *Mohammed Nadeem, Arun Pofale (2012)*[2] investigated use of different types of steel slag as coarse in concrete and reports that steel slag absorbs lesser water than brick aggregate. Also the compressive strength of steel slag coarse aggregate concrete is similar to or better than that of conventional aggregate concrete. Heavy weight steel slag yield better compressive strength.
3) *N A Lloyd and B V Rangan (2010)*[3] presents a detailed report on making of geopolymer concrete, its short term and long term properties and suggests that geopolymer is well suitable for precast elements.
4) *B. Vijaya Rangan (2008)*[4] developed low calcium fly ash based geopolymer concrete and reports its material properties, mix design, fresh and hardened properties of concrete. Reports that geopolymer concrete is more durable and undergoes very low creep and shrinkage.
5) *Vinothini.P, Kumaravel. S and Girija. P(2015)*[5] studied the ambient curing of fly ash based geopolymer concrete with addition of GGBS. Reports that GGBS in geopolymer accelerates its setting time and aids curing at ambient temperature.
6) *Pradip Nath et al (2015)*[6] reports that fly ash based geopolymer shall be made under ambient curing by adding small percentage of GGBS, OPC or CH. Low to moderate strength concrete shall be achieved by this method.

ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 6.887
Volume 7 Issue I, Jan 2019- Available at www.ijraset.com

III.MATERIALS

A. Fly Ash

Class F type – low calcium fly ash conforming to ASTM C 618 obtained from lignite burning thermal power station was collected in dry state and used for making concrete. Specific gravity of fly ash was 2.39. Chemical composition of fly ash used is listed in table 1.

TABLE I

CHEMICAL COMPOSITION OF FLY ASH

S.No.	Component	Weight %
1	Si	66.63
2	Al	28.67
3	K	2.26
4	Mg	1.56
5	Ca	0.92

B. GGBS

Ground granulated blast furnace slag conforming to IS 12089-1987 with specific gravity 2.8 was used for the study. Chemical composition of GGBS used is listed in Table II

TABLE III

CHEMICAL COMPOSITION OF GGBS

S.No.	Component	Weight %
1	Si	42.2
2	Al	16.87
3	K	1.69
4	Mg	5.09
5	Ca	34.15

C. Gravel Coarse Aggregate

Crush gravel agregate conforming to IS 383 – 2016 of maximum size 20 mm was used for the study. Physical properties of coarse aggregate is listed in Table III.

TABLE IIIII

PHYSICAL PROPERTIES OF GRAVEL AGGREGATE

S.No.	Parameter	Value
1	Bulk density	1380 kg/m^3
2	Specific gravity	2.66
3	Water absorption	1%
4	Fineness Modulus	6.23

D. Steel Slag Aggregate

Scrap steel slag obtained from steel re-rolling mill was crushed down using mechanical jaw type crusher and graded to a maximum size of 20 mm. Physical properties of steel slag are listed in Table IV.

TABLE IVV

PHYSICAL PROPERTIES OF STEEL SLAG AGGREGATE

S.No.	Parameter	Value
1	Bulk density	1260 kg/m^3
2	Specific gravity	2.18
3	Water absorption	1.5%
4	Fineness Modulus	6

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 6.887
Volume 7 Issue I, Jan 2019- Available at www.ijraset.com

E. Sand

River sand of maximum size 4.75 mm conforming to Zone II of IS 383-1970 was used as fine aggregate. Physical properties of sand are listed in Table V.

TABLE V
PHYSICAL PROPERTIES OF SAND

S.No.	Parameter	Value
1	Bulk density	1420kg/m^3
2	Specific gravity	2.6
3	Water absorption	0.5%
4	Fineness Modulus	2.7

F. Alkaline Solution

Alkaline solution used in activating the pozolanic binder is combination of sodium hydroxide and sodium silicate. Sodium hydroxide was obtained in pellet form and dissolved in distilled water to form 8M sodium hydroxide solution. (8x40=320g of sodium hydroxide pellets dissolved to form 1 litre solution. 40 – molecular weigth of sodium hydroxide, M-mole). Sodium silicate was obtained in solution form. Chemicals were obtained in extra pure form.

G. Superplasticizer

Naphthalene based superplasticizer Conplast SP430 with specific gravity 1.24 was used in the study.

IV. MIX DESIGN

M20 grade of concrete was taken for the purpose of this study. Geopolymer mix proportion was obtained on the basis of trial in the laboratory with binder to solution ratio of 0.45 and sodium silicate to sodium hydroxide ratio of 2.5. Mix proportion of ingredients is listed in Table VI.

TABLE VI
MIX DESIGN

S.No.	Ingredient	M I (kg/m^3)	M II(kg/m^3)
1	Fly Ash	218	218
2	GGBS	93	93
3	Activator solution	140	140
4	Sodium hydroxide	40	40
5	Sodium silicate	100	100
6	Fine aggregate	727	727
7	Coarse aggregate	1267 (Gravel)	1038 (Steel slag)
8	SP	6.22	6.22

V. EXPERIMENTAL WORK

A. Mixing

Conventional procedure was followed in mixing concrete. Sodium hydroxide solution was prepared a day before making concrete. Just before start of concrete mixing, sodium hydroxide and silicate solutions were mixed together. First all the dry ingredients were mixed well and then the solution was added to get a homogeneous mix. Sp was added at the last to gain required workability.

B. Casting

Standard concrete specimens – cube 150mm x 150mm x 150mm, cylinder 150mm dia and 300mm length, prism 100mm x 100mm x 500mm were cast. After 24 hours, the specimens were demoulded.

C. Curing

Ambient curing of concrete specimens was carried out. The specimens were left to laboratory temperature (32^0C ± 2^0C) for a period of 28 days and was put to testing.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 6.887
Volume 7 Issue I, Jan 2019- Available at www.ijraset.com

D. Testing

Cubes were put to compressive strength (Fig.1) and cylinders were put to tensile strength (Fig.2) test under ACTM. Plain beams were studied for flexural strength under two point loading in flexure testing machine (Fig.3). Failure pattern in specimens are shown in Fig. 4, 5 and 6. Cubical specimens were subjected to acid attack with 1% H_2SO_4 and sulphate attack with 5% sodium sulphate for 30 days and checked for reduction in compressive strength. Standard procedures were followed.


Fig.1 Compression Test


Fig. 2 Tensile Test


Fig. 3 Flexure Test


Fig.4 Cube Crack Pattern


Fig. 5 Cylinder Crack Pattern


Fig. 6 Prism Crack Pattern

VI. RESULTS & DISCUSSION

Table VI reports mechanical strength at 28 days and Table VII reports durability values.

TABLE VI
MECHANICAL PROPERTIES

S.No.	Test Conducted	M I (MPa)	M II (MPa)
1	Compressive Strength	26.22	25.11
2	Tensile Strength	2.83	2.36
3	Flexural Strength	4.68	4.03

TABLE VII
DURABILITY PROPERTIES

S. No	Parameter	Result after 30 days immersion in 1% Sulphuric acid		Result after 30 days immersion in 5% Sodium sulphate	
		M I	M II	M I	M II
1	Compressive Strength (Mpa)	25.18	25	26.1	24.96
2	% reduction in strength	0.8	1	0.5	0.6

From the test results it is found that steel slag performs similar to that of conventional gravel aggregate. Though not significant a, a slight drop in strength values were found for steel slag aggregate. It was understood because of the reason that steel slag is relatively porous than gravel aggregate. Mechanical performance of the concrete is good and shows excellent durability properties.

VII. CONCLUSION

From this experimental study, it is concluded that scrap steel slag can be used as coarse aggregate in geopolymer concrete. The strength behaviour is similar to that of conventional gravel concrete. Further long term research work is recommended to put scrap steel slag as coarse aggregate in structural applications.

VIII. ACKNOWLEDGMENT

The support and encouragement provided by the University Grants Commission, New Delhi by sanctioning a research project, (MRP- MAJOR- CIVIL-2013-36977) entitled 'Development of geopolymer concrete and testing of elements' to Annamalai University is sincerely acknowledged.

REFERENCES

[1] Sultan Tarawneh, Emhaidy Gharaibeh and Falah M. Saraireh (2014) , Effect Of Using Steel Slag Aggregate On Mechanical Properties Of Concrete, American Journal of Applied Sciences 11 (5): 700- 706.

[2] Mohammed Nadeem, Arun Pofale (2012),Experimental Investigation Of Using Slag As An Alternative To Normal Aggregates (Coarse And Fine) In Concrete ,International Journal Of Civil And Structural Engineering, Volume 3, No 1.

[3] N A Lloyd and B V Rangan (2010) , Geopolymer Concrete with Fly Ash, Second Interrnational Conference on Sustainable Construction materials and technologies, June 28- 30, 2010, Universita Politecnica delle Marche, Ancona, Italy. ISBN 978-1-4507-1490-7.

[4] B. Vijaya Rangan (2008), Studies on Fly Ash based Geopolymer Concrete, Article June 2008, ResearchGate DOI 10.1201/9781420007657.ch26.
Chinnaraju1, Ramkumar(2013), Study On Concrete Using Steel Slag As Coarse Aggregate Replacement And Eco sand As Fine Aggregate Replacement , International Journal of Research in Engineering & Advanced Technology, Volume 1, Issue 3.

[5] Vinothini.P, Kumaravel. S and Girija. P(2015), Effect of Ambient Curing in Geopolymer Concrete, International Journal of Applied Engineering Research, ISSN 0973-4562 Vol.10 No.51(2015).

[6] Pradip Nath, Prabir Kumar Sarker and Vijaya B Rangan (2015), Early age properties of low- calcium fly ash geopolymer concrete suitable for ambient curing, The 5th International Conference of Euro Asia Civil Engineering Forum (EACEF-5) Surabaya, Indonesia, 15-18 September 2015.

[7] Suganya.N and Thirugnanasambandam (2017), Steel Slag as Coarse Aggregate in Concrete, International Journal of Emerging Technology and Advanced Engineering, ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 7

Mechanical Properties of Ordinary, Standard and High Strength Concrete Using Scrap Steel Slag as Coarse Aggregate.

Suganya. N, Thirugnanasambandam. S

Abstract*: *This experimental work reports on the mechanical strength properties of three grades of concrete – Ordinary (M20), Standard (M40) and High strength (M60) concrete using scrap steel slag as coarse aggregate. No conventional gravel was used in making of concrete. Scrap steel slag is analyzed for its suitability to be used as coarse aggregate in concrete by evaluating its physical, chemical and durability performance. Detailed report on the material characterization of scrap steel slag is presented. The concrete was tested for its compressive strength, flexural strength and tensile strength at 28 days. Experimental work reports that scrap steel slag excels in mechanical performance in all there grades of concrete, except for that, the crushing value of scrap steel slag is higher than that of IS code's specification for wearing surfaces. Hence it is observed that the scrap steel slag is suitable to be used as coarse aggregate in concrete other than wearing surfaces.

Index Terms*: *Coarse aggregate, Scrap steel slag, Mechanical properties, 100% no natural gravel.

I. INTRODUCTION

Million tones of natural aggregates are involved in making of concrete annually since coarse aggregates form 70% of total volume of concrete. This contributes to the faster resource depletion. Also, the industrial waste production is expanding significantly. Out of the various solid wastes from industries, scrap steel slag was selected for the purpose of this study because it well suits the requirements of IS 383-2016 to be used as coarse aggregate in concrete. Rough estimates put that India generates around 10 million tones of scrap steel every year. Effective recycling opportunities of the scrap steel exist with assured availability of its slag in significant amount. This research work promotes the utilization of scrap steel slag in concrete so as to find a way making concrete more sustainable and resource friendly.

A. Objective

The main objective of this study is to make three grades of concrete – M20, M40 and M60 with 100% scrap steel slag as coarse aggregate and study its mechanical properties.

II. LITERATURE REVIEW

R. Padmapriya et al [1] reports that steel slag performs well with increased strength values upto a replacement level of 40% by conventional gravel because of the shape, size and surface texture of steel slag which shows greater adhesion with the cement matrix. Beyond this replacement level performance of concrete drops due to the inherent porosity of steel slag . Recommends that steel slag aggregate concrete is more suitable for applications in areas not exposed to marine conditions.

Tarek U. Mohammed et al [2] reports that the absorption capacity of steel slag aggregate is lower than that of brick aggregates and shows relatively better workability. The work reports the relationship between compressive strength, tensile strength and modulus of elasticity of concrete with different slag aggregates.

Shekhar Saxena et al [3] replaced natural coarse aggregate with steel slag in ratios of 15%, 25%, 50%, 75% and 100%and used waste water in making concrete and found that 50% replacement of basalt aggregate with steel slag gave higher compressive strength, flexural strength and modulus of elasticity of concrete by 33%, 9.8% and 22% at age of 28 days respectively. SEM analysis, UPV test and RCPT indicates dense microstructure of concrete with enhanced durability.

Karolina. R and A L A Putra [4] reports that the high quality concrete made with steel slag coarse aggregate has higher compressive strength than conventional high quality concrete at 28 days. But the tensile strength of steel slag concrete was lesser than conventional concrete at 28 days. Fracture modulus and flexure moment of high quality steel slag concrete is greater than that of high quality conventional concrete

Gozde Inan Sezer and Mert Gulderen [5] reports that steel slag can be used as coarse aggregate or fine aggregate in concrete. But it cannot be used as both coarse and fine aggregate. Flexural strength of steel slag concrete is higher than that of its tensile strength. Steel slag performs well as coarse aggregate than that of fine aggregate based when evaluated for its water penetration depth and freeze thaw resistance.

Deepa. B and Felix Kala. T [6] replaced conventional granite coarse aggregate by steel slag aggregate in concrete and found that upto 80% replacement level, the concrete show enhanced compressive strength.

Revised Manuscript Received on March 10, 2019.

Suganya. N, Research Scholar, Department of Civil & Structural Engg., Annamali University, Tamil Nadu, India.

Thirugnanasambandam. S, Associate Professor, Department of Civil & Structural Engg., Annamali University, Tamil Nadu, India.

*Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication*

Beyond that though decrease in strength was found, minimum required strength was achieved.
Ravikumar H et al [7] studied M20, M30, M40 and M50 grades of concrete with steel slag coarse aggregate and reports that the compressive strength of all grades of concrete improved by 4 to 7% upto a replacement level of 60% of natural aggregate by steel slag. Bleeding and seggregateion was found in 100% steel slag concrete but the density of steel slag concrete was 7% higher than conventional aggregate concrete.

III. MATERIALS USED

A. Cement

Ordinary Portland cement of grade 43, conforming to IS 8112-2013 was used. Physical properties of cement used are reported in Table 1. Method of tests were referred with IS 4031-1988 Part 2,3,5,8 and IS1727 – 1967.

Table 1 Properties of Cement

Parameter	Result	Requirement as per IS 8112-2013
Fineness, m^2/kg	300	Min 225
Soundness (By Le Chatelier method), mm	1	Max 10
Setting time a) Initial, min b) Final, min	 35 420	 30 600
Specific gravity	3.15	-
Standard Consistency	32%	-

B. Scrap steel slag

Steel slag was collected from a local scrap steel rerolling mill. They were collected in irregular shapes and then crushed using mechanical jaw type crusher, graded to required size, Figure 1. Various tests were conducted to check the properties of scrap steel slag, its durability and chemical composition. The results are listed below.

Figure 1 Graded Scrap Steel Slag

1. Physical appearance and Surface texture

The steel slag was dark grey in colour with rough surface texture. Voids were visible on the surface. Surface was well angular with sharp points around.

2. Physical properties

The specific gravity of scrap steel slag was lesser than that of the conventional gravel aggregate. Absorption capacity, flakiness and elongation indices with other mechanical strength values are all reported in Table 2. It is observed that the crushing value of scrap steel slag is higher than that recommended by IS code to be used as coarse aggregate for application in wearing surfaces. Methods of testing was referred with IS 2386 Part 1,3 and 4.

Table 2 Physical Properties of Scrap Steel Slag

Parameter	Result	Requirement as per IS 383-2016
Specific gravity	2.18	-
Water absorption	1.5%	-
Flakiness index	6.2	Combination shall not exceed 40%
Elongation index	24.8	
Abrassion (Loss Angles)	32%	Max 50%
Crushing Value	50%	30% for wearing surfaces
Impact Value	38%	Max 45%

3. Soundness

When put to 5 cycles in Sodium Sulphate solution, scrap steel slag suffered a reduction of 1.2% by weight. When observed with Magnesium Sulphate, 1.4% reduction in weight was observed.

4. p^H

Scrap steel slag was ground powder and then mixed with distilled water to get a paste. Handheld p^H meter was then used to find the p^H of the material. The p^H of the scrap steel slag used in this study was found to be 7.9.

5. **Alkali Aggregate Reactivity**

Alkalinity of 1N NaOH solution was observed to get reduced by 110 millimoles /lit and the dissolved silica was 21.64 millimoles/lit on reaction with scrap steel slag.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

6. Chemical Composition

The major constituent of scrap steel slag is Calcium oxide. It constitutes 48% of the total oxides. SiO_2 was found available 18%, Al_2O_3 7%, FeO 10%, MnO 15% and traces of oxides of K, Ti, Cr, Mg, Cl are found. Free Calcium in the form of CaO was found 2%.

C. Sand

River sand of maximum size 4.75mm conforming to Zone II of IS 383-1970 was sourced from a local supplier and used as fine aggregate in this study. The properties of sand used in this study are listed in Table 3.

Table 3 Properties of Sand

Parameter	Value
Bulk density	1420 kg/m^3
Specific gravity	2.6
Water absorption	0.5%
Fineness Modulus	2.7

D. GGBS

GGBS with specific gravity 2.8, conforming to IS 12089-1987 with chemical composition as listed in Table 4 was used in this study.

Table4 Chemical Composition of GGBS

Element	Si	Al	K	Mg	Ca
Weight %	42.2	16.87	1.69	5.24	33.36

E. Superplasticizer

Sulphonated naphthalene formaldehyde – a naphthalene based super plasticizer Conplast SP430 @ 2% dosage was used in this research work.

IV. MIX PROPORTIONING

Three grades of concrete – M20, M40 and M60 was selected for the purpose of this study as an attempt to check the mechanical properties of all three strength categories of concrete – Ordinary, Standard and High strength concrete. Mix proportioning of ingredients of concrete was based on IS 10262 – 1982 and is presented in Table 5.

Table 5 Mix Proportioning of Ingredients

	Cement	GGBS	Sand	Scrap steel slag	W/C Ratio
	Kg/m^3	Kg/m^3	Kg/m^3	Kg/m^3	
M20	311	-	727	1038	0.45
M40	311	133	815	870	0.36
M60	374	161	870	721	0.29

V. EXPERIMENTAL WORK

Cubical specimens (150x150x150mm), Cylindrical specimens (150mm dia and 300mm length), Prism specimens (100x100x500mm) were cast for each grades of concrete based on the mix proportion presented in Table 5 and the specimens were put to Compressive strength, Splitting tensile strength and Flexural strength respectively at 28 days.

Conventional method of casting and testing of concrete was carried out. Workability was achieved by using required dosage of SP which was fixed based on trial. Figure 2,3,4 and 5 indicate specimens cast for testing, compression test, tensile test and flexural test respectively.

Figure 2 Specimens Cast for Testing

Figure 3 Compression Test

Figure 4 Tensile Test

Published By:
Blue Eyes Intelligence Engineering & Sciences Publication

Figure 5 Flexural Test

VI. RESULTS AND DISCUSSION

A. Physical properties of scrap steel slag

Specific gravity of scrap steel slag is 2.18 which is less than that of the conventional gravel aggregate, which would be around 2.7. The absorption capacity of the steel slag aggregate was not found to affect the properties of concrete. Shape indices were well conformed to the code. Abrasion and impact value of the scrap steel slag meets the code's requirement to be used as coarse aggregate in concrete. Crushing strength of slag aggregate was found 50% which makes the aggregate not suitable to be used in wearing surfaces. Hence this scrap steel slag is not recommended for applications involving wearing surfaces.

B. Chemical properties of scrap steel slag

Scrap steel slag coarse aggregate has no harmful alkali aggregate reaction . Also they passed soundness test when subjected to sodium sulphate and magnesium sulphate solution with minimum reduction in weight – 1.2% and 1.4% respectively after 5 cycles which indicate that the material is sound enough to be used as coarse aggregate

C. Workability of Concrete

No issues was found in achieving workability of concrete when scrap steel slag was used as coarse aggregate. Absorption capacity of steel slag did not affect the workability. Since Superplasticizer was used, the workability of concrete was easily achievable.

D. Unit Weight of Concrete

The unit weight of fresh concrete varied from 2215kg/m^3 to 2250 kg/m^3 which is lesser than the conventional aggregate concrete and is advantageous as the dead load of the overall construction will get reduced when scrap steel slag is used as coarse aggregate.

E. Compressive Strength of Concrete

Compressive strength of all the three grades of concrete at 28 days is listed in Table 6. Characteristic compressive strength is exceeded in all three grades of concrete.

Table 6 Compressive Strength Report

Grade of Concrete	Compressive strength at 28 days in Mpa
M20	26.52
M40	49.92
M60	68.59

F. Splitting Tensile Strength of Concrete

Splitting tensile test was carried out on cylindrical specimens . Table 7 reports the tensile strength of concrete mixes studied.

Table 7 Tensile Strength Report

Grade of Concrete	Tensile strength at 28 days in Mpa
M20	2.52
M40	4.98
M60	7.78

The tensile strength of concrete made with scrap steel slag as coarse aggregate was found good and found to be around 12% of its compressive strength.

G. Flexural Strength of Concrete

Flexural strength values of plain cement concrete prisms are reported in Table 8.

Table 8 Flexural Strength Report

Grade of Concrete	Flexural strength at 28 days in Mpa
M20	4.75
M40	9.53
M60	13.55

Flexural strength of concrete obtained was found around 23% of its compressive strength.

H. Failure Surface of Concrete

The failure surface of concrete was found to cross through the aggregate when the specimens after crushing were examined.

VII. CONCLUSION

Based on this experimental study on ordinary, standard and high strength concrete using scrap steel slag as coarse aggregate, the following conclusions are made.

1. The specific gravity of scrap steel slag is lesser than that of conventional gravel aggregate.
2. The higher crushing value of scrap steel slag makes it unsuitable for wearing surfaces.
3. The absorption capacity of scrap steel slag not seem to affect the properties of concrete.
4. The workability of concrete was good for all three grades of concrete.
4. The unit weight of concrete is of the range 2215kg/m^3-2250kg/m^3, which is lesser than conventional aggregate concrete.
5. Compressive, Tensile and Flexural strength of concrete were achieved as per mix design at 28 days.

Published By:
Blue Eyes Intelligence Engineering & Sciences Publication

6. Splitting tensile strength was found to be 12% of its compressive strength at 28 days.
7. Flexural strength of concrete was found 23% of its compressive strength at 28 days.

From the observations made, it is clear that scrap steel slag can be used as coarse aggregate in all grades of concrete except for wearing surfaces.

ACKNOWLEDGMENT

The authors sincerely acknowledge the support by University Grants Commission, New Delhi for sponsoring the research project, *(MRP- MAJOR- CIVIL-2013-36977).*

REFERENCES

1. R. Padmapriya, V.K. Bhupesh Raja, V. Ganesh Kumar and J. Balamurugan, "Study on Replacement of Coarse Aggregate by Steel Slag and Fine Aggregate by Manufacturing Slag in Concrete", International Journal of Chemtech Research, Vol.8, No.4, PP1721-1729, 2015.
2. Tarek U. Mohammed, Md N. Rahman, Aziz H. Mahmood, Tanveer Hasan and Shibly M Apurbo, "Utilization of Steel Slag in Concrete as Coarse Aggregate", SCMT4, Las Vegas, USA, August 7-11, 2016.
3. Shekhar Saxena and A.R. Tembhurkar, "Impact of Useof Steel Slag as Coarse Aggregate and Waste water on Fresh and Hardened Properties of Concrete", Construction and Building Materials, Volume 165, 20 March 2018, Pages 126-137.
4. R. Karolina and A A A Putra, "The effect of steel slag as coarse aggregate and Sinabung volcanic ash a filler on high strength concrete", IOP Conference Series: Materials Science and Engineering 309 (2018) 01 2009.
5. Gozde Inan Sezer and Mert Gulderen," Usage of Steel slag in concrete as fien and/or coarse aggregate", Indian Journal of Engineering and Material Sciences, Vol.22, June2015, PP 339-344.
6. RA.B. Depaa and Dr. T. Felix Kala, "Experimental Study on Steel Slag as Coarse Aggregate in Concrete", International Journal on Recent Researches in Science, Engineering and Technology, Volume 5, Issue 4, April 2017.
7. ERavikumar H, J.K. Dattatreya and Dr. K. P. Shivananda," Experimental Investigation on Replacement of Steel Slag as Coarse Aggregate in Concrete", Journal of Civil Engineering and Environmental Technology, Volume 2, Number 11, April – June 2015 PP 58-63.

AUTHORS PROFILE

Author-1 Photo

First Author personal profile which contains their education details, their publications, research work, membership, achievements, with photo that will be maximum 200-400 words.

Author-2 Photo

Second Author personal profile which contains their education details, their publications, research work, membership, achievements, with photo that will be maximum 200-400 words.

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 8, Issue 6, June 2018)

Steel Slag as Coarse Aggregate in Concrete

Suganya. N[1], Thirugnanasambandam. S[2]

[1]Research Scholar, Department of Civil & Structural Engg., Annamalai University, Tamil Nadu, India
[2]Associate Professor, Department of Civil & Structural Engg., Annamalai University, Tamil Nadu, India

***Abstract* - This experimental study is carried out to replace the natural coarse aggregate in concrete by steel slag. The steel slag used in this study is obtained from scrap steel processing plant which otherwise is dumped as waste. This experimental work investigates clearly the physical, chemical and mechanical properties and behavior of steel slag as coarse aggregate in concrete by replacing natural gravel by 100%. The test results show that behavior of steel slag as coarse aggregate in concrete shows no notable difference from behavior of natural gravel. Started with preliminary feasibility studies, the final results and recommendations are based upon the mechanical behavior of concrete mainly on the performance under compression. From this work, it is vivid that steel slag has potential application in concrete, as coarse aggregate.**

***Keywords* – Properties of steel slag – Physical, Chemical Mechanical, Replacement for Coarse aggregate, Strength study.**

I. INTRODUCTION

This Steel is the most recycled material worldwide. Obsolete ferrous scrap is recovered from automobiles, steel structures, household appliances, railroad tracks, ships, farm equipment and other sources. In addition, prompt scrap, which is generated from industrial and manufacturing sources, accounts for approximately half the ferrous supply. Both are processed by scrap recycling industry into commodity grade material on a large scale.

India imported five million tonnes (mt) of steel scrap in 2013-14, making it the world's third largest importer of the metal. There is no official data on the amount of steel scrap being produced in The country; rough estimates put the figure at around 10 mt a year. With this abundant availability of steel scrap and its effective recycling opportunities, tones of slag are generated from these scrap steel manufacturing plants which find hardly less than 40% usage in construction materials and are otherwise dumped as waste.

With growing interests in replacing natural aggregate by waste materials, this paper presents the replacement of natural gravel by slag of scrap steel, as coarse aggregate.

II. LITERATURE STUDY

Sultan Tarawneh et al, (2014) [1] - Concluded from investigation that steel slag has potential application as replacement to coarse aggregate and the development strength is greater at 28 days compared to conventional aggregate concrete.

Khalid Raza et al, (2014) [2] - Reported that though there is decrease in workability of concrete with addition of steel slag as coarse aggregate, the compressive strength increases by 5 % to 8%.

Narasimha Raj et al, (2014) [3] **-** Investigated and aid in proportioning of coarse aggregate of size 12.5 mm and 20 mm by particle packing method to attain maximum packing anf improving compressive strength.

Chinnaraju1,Ramkumar(2013) [4] - Reported that the optimum level of 60% replacement of coarse aggregate by steel slag gives strong and durable concrete , however the replacement level may vary with the source of steel slag.

IJETAE
EXPLORING RESEARCH AND INNOVATIONS

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 8, Issue 6, June 2018)

Mohammed Nadeem, Arun Pofale (2012) [5] – The investigation revealed improvement in compressive strength, split tensile and flexure strength over control mixes by 4 to 8 %. The replacement of 100 % steel slag aggregate increased concrete density by about 5 to 7 % compared to control mix. The study concluded that compressive strength of concrete improved by 4 to7 % at all the % replacements of normal crushed coarse aggregate.

III. EXPERIMENTAL WORK

A. MATERIALS

This study utilized single source of scrap steel slag *(Figure 1)* - slag obtained during the process of recycling used steel units from steel recycling plants, collected at a time. The steel slag was obtained as irregular shaped big balls and then crushed down to required units with mechanical jaw crusher. 20mm and 12.5mm steel slag was used as coarse aggregate (60% and 40%). Commercially available river sand (zone II) was used as fine aggregate. Cement used is OPC Grade 53. CONPLAST SP430 was added as superplasticizer.

FIGURE 1 SCRAP STEEL SLAG

B. PROPERTIES OF SCRAP STEEL SLAG

The scrap steel slag was put to physical test *(Table I)*, Chemical test *(Table II)* and SEM analysis *(Figure 2, 3)* and analysed for its chemical composition *(Figure 4)* and the results obtained revealed that it can be used effectively as coarse aggregate in concrete.

TABLE I
PHYSICAL PROPERTIES OF SCRAP STEEL SLAG

S. No	Description	Result
1	Crushing value	50% by weight
2	Impact value	38% by weight
3	Abrasion value (Los Angles)	32% by weight
4	Water absorption	1.5% by weight
5	Flakiness index	6.2
6	Elongation index	24.8
7	Specific gravity	2.18

TABLE II
CHEMICAL PROPERTIES OF SCRAP STEEL SLAG

S. No	Description	Result
1	Soundness(after 5 cycles) (a) Sodium sulphate (b) Magnesium sulphate	1.2% by weight 1.44% by weight
2	pH value	7.91
3	Alkali aggregate reactivity (a) Reduction in alkalainity of 1.0N NaOH (b) Silica dissolved	110.00 millimoles /ltr 21.64 millimoles/ltr

IJETAE
EXPLORING RESEARCH AND INNOVATIONS
International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 8, Issue 6, June 2018)

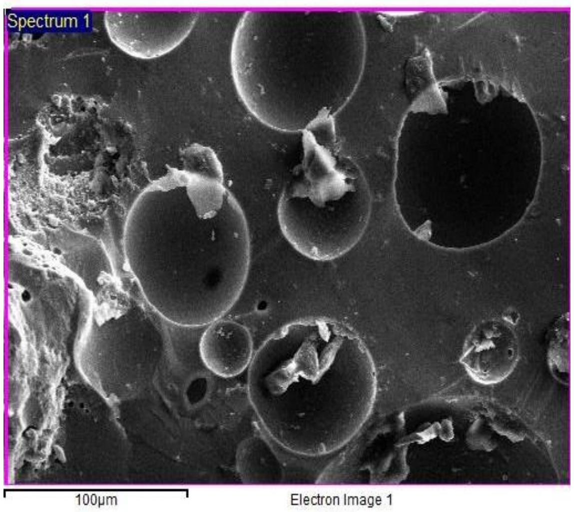


FIGURE 2 SEM IMAGE OF SCRAP STEEL SLAG

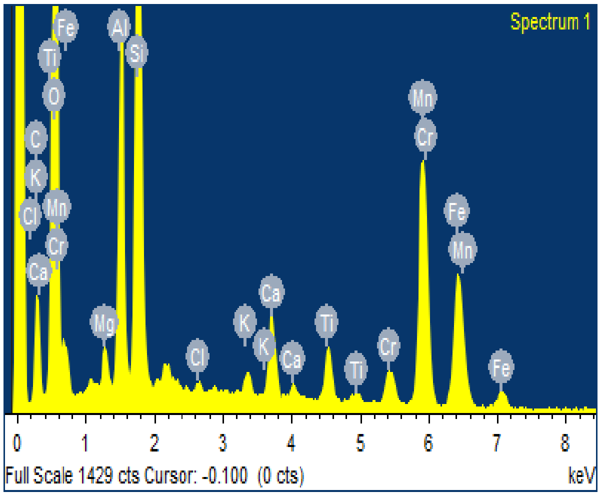


FIGURE 3 EDX SPECTRUM ODF SCRAP STEEL SLAG

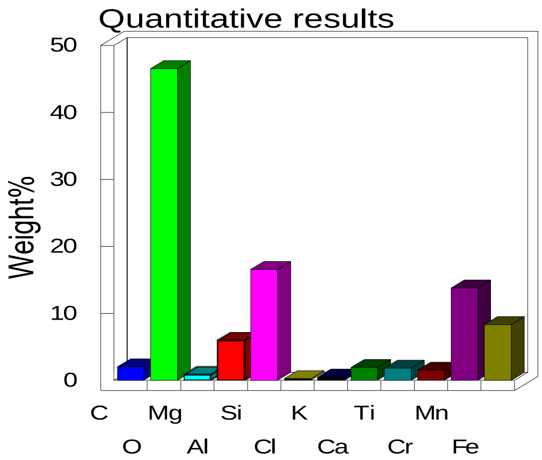


FIGURE 4 CHEMICAL COMPOSITION OF SCRAP STEEL SLAG

C. MIX PROPORTION

Mix design was made proportioning ingredients to give M40 grade concrete*(Table III).*

TABLE III MIX PROPORTION

S. No	Description	Kg/m^3
1	Cement	430
2	Coarse Aggregate (Steel Slag) 20 mm 12.5 mm	 611 407
3	Fine Aggregate (River Sand)	754
4	W/C ratio	0.4

D. TESTING OF SPECIMENS

Standard cubes (150x150x150mm), cylinders (300mm length x 10 mm dia) were casted for carrying out compressive and split tensile strength. For studying flexural strength, prism specimens (100X100X500mm) were casted *(Figure 5)*. The specimens were put to test after 28 days of water curing. Standard testing procedures were followed while testing the sample specimens *(Figure 6, 7, 8, 9)*

FIGURE 5 MANUFACTURED TEST SPECIMENS

FIGURE 6 COMPRESSION TEST ON CUBE

FIGURE 7 SPLIT TENSILE TEST ON CUBE

FIGURE 8 SPLIT TENSILE TEST ON CYLINDER

FIGURE 9 FLEXURAL TEST ON PRISM

E. RESULTS & DISCUSSION

TABLE IV
STRENGTH
RESULTS

S. No	Test Conducted	Result at 28 days (MPa)
1	Compressive Strength	49.25
2	Tensile Strength	5.20
3	Flexural Strength	10.4

From material testing and concrete testing *(Table IV)*, it is clear that scrap steel slag shall be used as an alternative material for natural gravel coarse aggregate, as the performance of the scrap steel slag aggregate has the same behavioral scheme as that of the natural gravel. Further long term research work is needed to support this short term work.

IV. CONCLUSION

From this experimental work it is clear that scrap steel slag shall be well used as coarse aggregate in concrete. Scrap steel slag meets physical, chemical requirements to be used as coarse aggregate and yields required strength to be used in structural applications. Works on alternatives to coarse aggregate remains a research poor region. Hence long term research works are recommended to use scrap steel slag as aggregate in concrete in structural practice.

Acknowledgement

We, the authors sincerely acknowledge the support and encouragement provided by the University Grants Commission, New Delhi by sanctioning a research project, *(MRP- MAJOR- CIVIL-2013- 36977)* entitled *'Development of geopolymer concrete and testing of elements'* to Annamalai University.

References

[1] Sultan Tarawneh, Emhaidy Gharaibeh and Falah M. Saraireh (2014) , Effect Of Using Steel Slag Aggregate On Mechanical Properties Of Concrete, American Journal of Applied Sciences 11 (5): 700- 706.

[2] Khalid Raza, Sharda Sharma, Ritesh Mall and Patel (2014), Comparative Strength Analysis Of Concrete By Using Steel Slag As An Alternative To Normal Aggregates (Coarse) In Concrete, - International Journal of Civil Engineering ISSN 2347 – 8527 Volume 3, Issue 5.

[3] Narasimha Raj, Suresh Patiland and Bhattacharjee (2014), Concrete Mix Design By Packing Density Method, IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) e-ISSN: 2278-1684,p- ISSN: 2320-334X, Volume 11, Issue 2 Ver. I (Mar- Apr. 2014), PP 34-46.

[4] Chinnaraju1,Ramkumar(2013), Study On Concrete Using Steel Slag As Coarse Aggregate Replacement And Eco sand As Fine Aggregate Replacement , International Journal of Research in Engineering & Advanced Technology, Volume 1, Issue 3.

[5] Mohammed Nadeem, Arun Pofale (2012),Experimental Investigation Of Using Slag As An Alternative ToNormal Aggregates (Coarse And Fine) In Concrete,International Journal Of Civil And Structural Engineering, Volume 3, No 1.

Flexural Behaviour of Geopolymer RC Beam with Scrap Steel Slag Coarse Aggregate

Suganya. N, Thirugnanasambandam. S

Abstract*: *This research work aims adding further sustainability to the cement - less geopolymer concrete by replacing its natural gravel coarse aggregate by an industrial by-product, scrap steel slag. Geopolymer RC beam of grade M40 with 100% scrap steel as coarse aggregate was studied for its flexural behavior and compared with conventional reinforced cement concrete beam with gravel coarse aggregate. The specimens were tested under two-point static loading. The analysis was also carried out using ANSYS software. The study derived that in all stages, the performance of the geopolymer beam with scrap steel slag was marginally better than the conventional beam with gravel coarse aggregate. The ultimate load carrying capacity, deflection, service load and ductility factor of geopolymer RC beam with scrap steel slag coarse aggregate was comparable to the conventional cement concrete RC beam and is marginally higher. It is also found that conventional RC theory can be used in the calculation of moment capacity, deflection and crack width of the geopolymer beam of study and FE modeling and analysis using ANSYS were comparable to the experimental results.

Keywords* : *Flexural behavior, geopolymer concrete, scrap steel slag coarse aggregate, ANSYS.

I. INTRODUCTION

With the concern to meet present need of the environment, economy and society many efforts are being made and are successfully applied in the field of construction engineering to reduce the carbon footprint of concrete. Such a resilient form of concrete is the geopolymer concrete [1] which suspends completely the usage of cement. Also its green benefits include ambient curing of the concrete which indeed makes it a revolutionary concrete technology. Since zero carbon built is the need of the hour, this inorganic geopolymer paves the way to future addressing also the water scarcity issues all around by suspending completely the need of water for its curing. Many proven research works of geopolymer concrete [2], [3] are published from all directions and its field application is extending progressively.

In view of adding more sustainability to this green concrete, it was decide to replace its coarse aggregate, the natural gravel which accounts 60-80% of its volume. For which the scrap steel slag was chosen for its more similar properties as that of gravel and is also available in abundance. Steel slag is the solidified complex solution of silicates and oxides obtained as by-product of steel making process. Different types of steel slag are obtained based on the type of furnace in which they are produced. The classification includes, BF (Blast furnace) slag, BOF (Basic Oxygen furnace) slag, EAF (Electric Arc Furnace) slag, LF (Ladle Furnace) slag.

In India 16-18 million tons of steel slag is generated annually and is estimated to reach as high as 200 million tons in near future. But the effective usage of steel slag is not practices in our country and is mostly dumped or landfilled. Securing lands for disposal of steel slag is already an arising problem.

Considering the inherit advantage of steel slag over natural gravel in both usage and environment perspective [4], [5], this research work was done replacing the natural gravel coarse aggregate in geopolymer concrete by steel slag. The flexural behavior of such a reinforced geopolymer concrete with scrap steel slag coarse aggregate is presented in this paper.

II. RESEARCH SIGNIICANCE

Approximately no research data on the flexural behavior of reinforced concrete using scrap steel slag coarse aggregate in geopolymer concrete is cited at present. Reinforced geopolymer concrete with scrap steel slag coarse aggregate attains comparable strength and serviceability and in cases, marginally higher than that of the conventional reinforced cement concrete with natural gravel coarse aggregate. This research work provides satisfactory detailed experimental data on the same and compares the flexural behavior with the conventional cement concrete.

III. EXPERIMENTAL PRORAMME

MATERIALS USED

A. Cement

Ordinary Portland cement of grade 43 with specific gravity 3.15 was used. Material complies with the IS 8112-2013requirementss.

B. Fly Ash

Low calcium fly ash – Class F type, obtained in dry state with specific gravity 2.39 from a local coal burning thermal power station was used. Material complies with ASTM C 618 specifications.

Revised Manuscript Received on November 22, 2019

Suganya. N*, Research Scholar, Department of Civil and Structural Engg., Annamalai University, Tamil Nadu, India. Email: suganyanatarajan22@gmail.com

Thirugnanasambandam. S, Professor, Department of Civil and Structural Engg., Annamalai University, Tamil Nadu, India. Email: agstsai@gmail.com.

C. GGBS

Commercially available Ground Granulated Blast Furnace Slag (GGBS) was purchased from a local supplier which had specific gravity 2.8 and complied with IS 12089-1987 specifications.

D. Sand

River sand conforming to Zone II of IS 383-1970 with specific gravity 2.6 was used.

E. Gravel

Gravel aggregate of maximum size 20mm conforming to IS 383 – 2016 with specific gravity 2.66 was used.

F. Scrap Steel Slag

Scrap steel slag was obtained from a local Electric arc furnace based scrap steel re-rolling mill. The uneven sized slag balls were crushed down using jaw type crusher to the required grading with maximum aggregate size of 20mm. Figure I shows the scrap steel slag after crushing down to 20 mm size. The aggregate shows a rough surface texture with sharp points. Chemical composition of scrap steel slag is stated in Table I. Table II gives the physical properties of scrap steel slag and gravel aggregate.

Figure I Scrap steel slag

Table- I: Chemical Composition o Scrap Steel Slag

Constituent	%
CaO	48
SiO_2	18
Al_2O_3	7
FeO	10
MnO	15

Also traces of oxides o K, Cl, Cr, M, Ti was found. Free calcium constitutes 2%.

Table- II: Physical Properties of Scrap Steel Slag and Gravel Aggregate

	Scrap steel slag	Gravel
Bulk density, kg/m^3	1260	1380
Fineness Modulus	6	6.23
Specific gravity	2.18	2.66
Water absorption , %	1.5	1

G. Alkaline Activator Solution

The alkaline activator solution was obtained combining 8M Sodium hydroxide solution with sodium silicate solution at a ratio of 2.5. Commercially available high pure materials were used.

H. Super plasticizer

Conplast SP 430 was used as super plasticizer to achieve required workability in this study.

I. Steel Reinforcement

Longitudinal reinforcement was formed with deformed, high yield strength bars of 12 mm and 10 mm diameter. Stirrups are of same bars with 8mm dia. The average yield stress of 12 mm, 10 mm and 8 mm bars are 395 Mpa, 380 Mpa and 245Mpa respectively.

MIX DESIGN

Table III gives the material mix design details. M40 grade of concrete was designed based on IS 10262 – 1982. M 1 – Conventional cement concrete with gravel aggregate. M II – Geopolymer concrete with Scrap Steel slag Coarse aggregate.

Table- III: Mix Design

Material	M I (Kg/m^3)	M II (Kg/m^3)
Cement	311	-
Fly Ash	-	311
GGBS	133	133
Sand	815	815
Gravel CA	1061	-
Scrap steel slag CA	-	870
Water	148	-
Activator solution	-	200
Super plasticizer	7.4	7.4

RC BEAM DETAILS, INSTRUMENTATION AND TESTING

Two beams were casted – M I and M II. M I is the control beam made of cement concrete with gravel coarse aggregate and M II is geopolymer beam made with scrap steel slag coarse aggregate. The beams were 3.2 m long with 125 mm x 250 mm cross section. The beams were designed to be under reinforced. The tensile zone reinforcement consisted two 12 mm bars and the compression zone had two 10 mm bars. Shear reinforcement was made with 8mm stirrups at 150 mm spacing along the length of the beam.

M I was cast and cured underwater for 28 days. M II after casting was let to open sunlight for ambient curing of 28 days. No water curing was done or M II. Both beams were tested at age of 28 days.

The test beams were simply supported on the testing frame as shown in Figure II . Load was applied through a slender beam to transmit load equally at two points through bearings on the top of the beam. Load was increased gradually and the corresponding deflection in the beam was measured at the middle and two loading points by high accuracy dial gauges. Loading was continued and data were recorded until the beam suffered flexural failure by crushing in the compression zone. Figure III and V show the beams loaded in test setup. Figure IV and VI clearly show the failure pattern of beams.

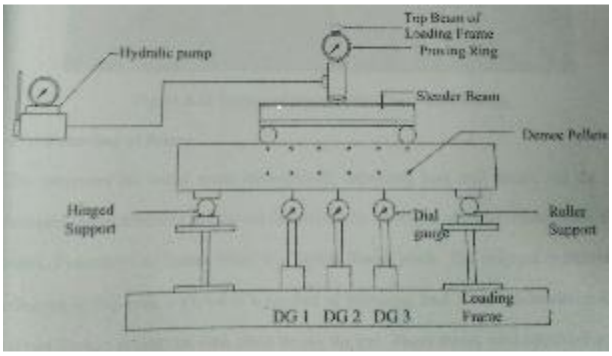


Figure II Beam Test Setup

Figure III MI Beam in Test Setup

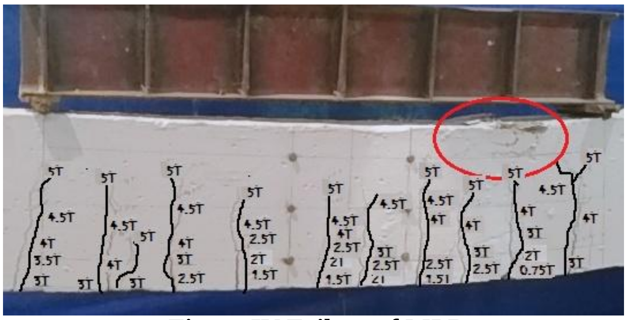


Figure IV Failure of MI Beam

Figure V M II Beam in Test Setup

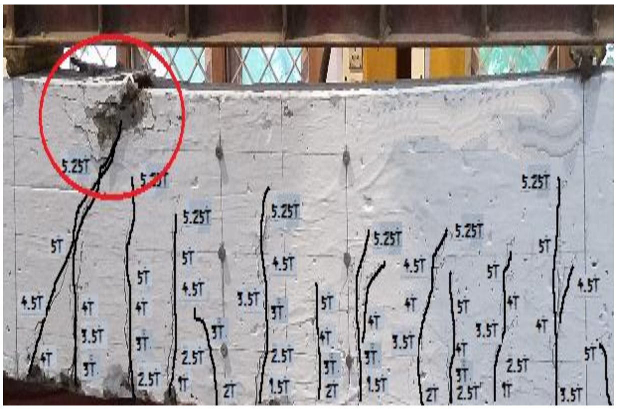


Figure VI Failure of M II beam

IV. RESULTS AND DISCUSSION

A. Compressive strength

The 28 days cube compressive strength of M I and M II was respectively 49 Mpa and 50 Mpa. This gives fairly equal compressive strength values.

B. Crack Pattern and Failure Mode.

Both the beams suffered the same failure response. Their structural response was typical with cracks arising from the tension zone and propagating vertically to the compression zone. No horizontal cracks was found which is indicative of the fact that no bond failure has occurred.

In both the beams, yielding of tension steel followed by the crushing of concrete in the compression zone with spalling of concrete cover was found resulting in a ductile tension failure. The geopolymer concrete beam with scrap steel slag aggregate had the same failure mode and no significant changes was found when compared with the failure mode of conventional cement concrete beam with gravel coarse aggregate.

Buckling of the longitudinal steel in the compression zone was found in both the beams indicating that the tensile steel has attained its yield strength before failure.

C. Ultimate Load and Deflection

The Failure load and deflection of the beams are presented Table IV. In all the stages of loading, M II sustained higher loads prior to failure compared to M I which indicates superior flexural behavior. Excessive deflection was suffered by M II indicating its improved ductility.

Table- IV: Load and Deflection of Beams.

Parameter	M I	M II
First crack load	1 T	0.75 T
Service Load	3 T	3.25 T
Yield Load	4.25 T	4.5 T
Ultimate Load	5.25 T	5.5 T
Max. Deflection	66 mm	76 mm

D. Ductility Behavior

Ductility indicates the capacity of the structural member to undergo deformation inelastically with energy absorption. Displacement ductility which is the ratio of deflection at ultimate load to the deflection at yield load was measured or the beams. M I had ductility of 3.39 and M II had 3.8. This indicates that the geopolymer concrete with scrap steel slag coarse aggregate has improved ductility behavior compared to the conventional cement concrete with gravel aggregate.

E. Numerical Analysis

ANSYS was used to calculate the load displacement response of the beams numerically. Table V reports the ANSYS results which when compared to the results in Table IV show that it has close agreement with the experimental data. Figure VII and VIII show the deflected shape of beams obtained from ANSYS.

Table- V: ANSYS report

Parameter	M I	M II
Ultimate Load	5 T	5.25 T
Max. Deflection	60 mm	71 mm

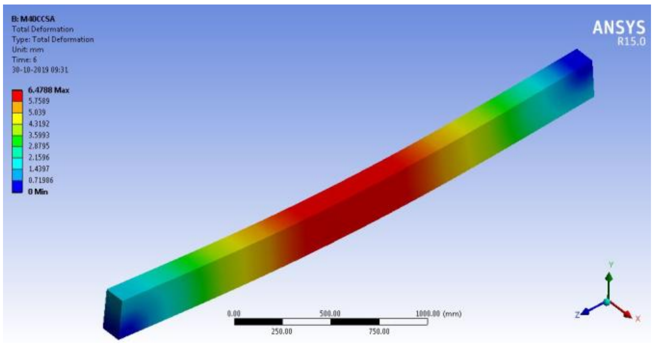


Figure VII Deflected shape of M I

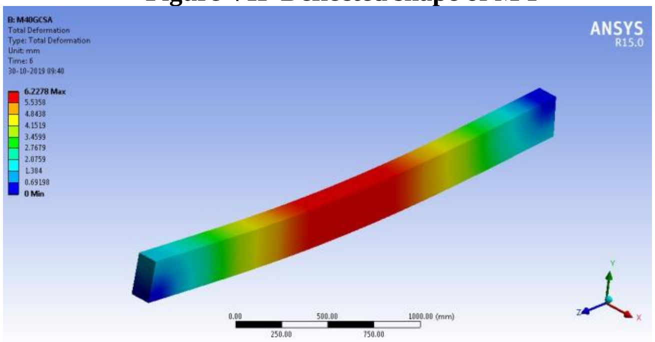


Figure VIII Deflected shape of M II

V. CONCLUSION

- From the experimental and numerical investigations, it is concluded that the flexural behavior of steel slag coarse aggregate geopolymer concrete is comparable and marginally superior to the conventional Cement concrete with gravel coarse aggregate.
- They have close aggrement in terms of compressive strength and has superior flexural response. Failure pattern for both the reinforced concrete were similar and the ultimate load at failure and ultimate deflection were higher for geopolymer concrete with scrap steel slag coarse aggregate than the conventional reinforced cement concrete.
- Geopolymer beam reports improved ductility behaviour in terms of displacement ductility.
- This experimental work encourages the use of scrap steel slag as coarse aggregate in concrete with its inherent structural advantage, easy availability and low cost, if not free.
- This work also recommends long term study of this scrap steel slag coarse aggregate concrete.

ACKNOWLEDGMENT

The authors acknowledge the sanction of research project under the title Development of Geopolymer concrete and testing of elements (MRP – MAJOR – CIVIL – 2013-36977) to Annamalai University which was very helpful in carrying this research work.

REFERENCES

1. N A Lloyd and B.V. Rangan (2010), Geopolymer concrete with fly ash, Second international conference on sustainable construction materials and technologies, ISBN 978-1-4507-1490-7, http://www.claisse.info/Proceedings.htm .
2. D. Hardjito and B. V. Rangan (2005), Development and Properties of Low-Calcium Fly Ash-Based Geopolymer Concrete by Research Report GC 1,Faculty of Engineering, Curtin University of Technology,Perth, Australia
3. D. Hardjito and B. V. Rangan (2006), Development and Properties of Low-Calcium Fly Ash-Based Geopolymer Concrete by Research Report GC 2,Faculty of Engineering, Curtin University of Technology,Perth, Australia
4. Gozde Inan Sezer and Mert Gulderen," Usage of Steel slag in concrete as fien and/or coarse aggregate", Indian Journal of Engineering and Material Sciences, Vol.22, June2015, PP 339-344.
5. RA.B. Depaa and Dr. T. Felix Kala, "Experimental Study on Steel Slag as Coarse Aggregate in Concrete", International Journal on Recent Researches in Science, Engineering and Technology, Volume 5, Issue 4, April 2017.

Durability of Geopolymer Concrete with Scrap Steel Slag Coarse Aggregate

Suganya N., Thirugnanasambandam S. T.

Abstract: ***Use of environmental friendly materials in concrete to make concrete sustainable is gaining importance, as the growth of the construction sector is rapid and massive in India. Such a sustainable concrete is the geopolymer concrete with scrap steel slag coarse aggregate. The concrete replaces cement and natural coarse aggregate by fly ash and scrap steel slag. Mechanical Strength of the concrete of M20 grade was evaluated and found suitable. Concrete strength has no role without the concrete being durable. Experimental tests were carried out to check the durability of the concrete and the results are presented in this paper. M20 grade geopolymer concrete with scrap steel slag coarse aggregate was tested after ambient curing for 28 days and the results are compared with M20 grade cement concrete with conventional Coarse aggregate. Durability was checked based on Water absorption, Acid resistance, Sulphate resistance and Sorptivity. The experimental results indicate that geopolymer concrete exhibit excellent durability than conventional cement concrete.***

Keywords: ***Durability, Short – term, Geopolymer, Ambient Curing, Scrap Steel Slag Coarse Aggregate.***

I. INTRODUCTION

The degree of durability of concrete required depends mainly upon the environment of their exposure. The ingredients of concrete, manufacturing process and their interaction with the exposed environmental elements determine the durable life of any concrete. Durability is the main property of the concrete besides its mechanical properties. Geopolymer concrete conserves the use of natural resources by replacing cement by flyash. This experimental work evaluates the short-term durability performance of geopolymer concrete made with class F type flyash and GGBS as binder. Scrap steel slag, slag obtained as by-product from steel re-rolling mill was used as coarse aggregate. The addition of GGBS in concrete aids the concrete to be cured under ambient conditions.

This paper presents the short-term durability report on the geopolymer concrete with scrap steel slag coarse aggregate. First the scrap steel slag was checked for its soundness, pH and Alkali Aggregate Reactivity as a measure of its durability and then used in making concrete. Then the concrete at the age of 28days was tested for its compressive strength, water absorption, sorptivity, acid resistance and sulphate resistance. Due to time constrains only the short-term durability properties of the concrete was studied and the results was compared with the same grade cement concrete with conventional coarse aggregate.

Revised Manuscript Received on February 26, 2020.

Suganya N., Research Scholar, Department of Civil & Structural Engineering, Annamalai University, Tamil Nadu, India.

Dr. Thirugnanasambandam S., Professor, Department of Civil & Structural Engineering, Annamalai University, Tamil Nadu, India.

II. LITERATURE REVIEW

Monita Olivia and Hamid R. Nikraz [(1)] reports that the water absorption of geopolymer concrete is less than 5 %. Water absorption can be reduced by decreasing the water-solid ratio, increasing the alkaline-fly ash ratio and increasing the aggregate-solids ratio. Permeable voids were less than 12 %. The void content of geopolymer concrete varies from 8.2 % to 13 %. The alkaline to fly ash ratio of 0.3 reduced porosity of concrete. Though aggregate to binder ratio of 3.5 gave higher strength, it has to be increased to 4.7 to achieve low porosity.

Sreevidya et al [(2)] evaluated the acid resistance of fly ash based geopolymer mortar specimens. Ratio of alkali activator solution to fly ash was varied as 0.376, 0.386, 0.396 and 0.416. Both hot cured specimens @ 60^0C for 24 hours and ambient cured specimens were taken for study. Specimens were immersed in 5% sulphuric acid and 5% hydrochloric acid for 14 weeks and their performance was assessed on the basis of change in weight and compressive strength. The samples suffered very little weight change and the reduction in compressive strength was similar to that of the strength loss of cement concrete mortar.

Aradhana Mehta and Kuldeep Kumar [(3)] studied the durability of geopolymer concrete and reports that geopolymer is highly acid resistant. After 28 days of sulphuric acid exposure under 2%, 4% and 6% concentration, the geopolymer specimens were found without any significant change in shape and mass.

Whereas cement concrete under same conditions suffered surface damage and noticeable bulging.

Bapugouda patil et al [(4)] studied the durability of geopolymer concrete under acid test, chloride test, sulphate test, fire resistance test and water absorption test. The test report shows that very minute change was observed in acid test. Weight gain was more compared to control concrete for geopolymer under NaCl and $MgSO_4$. Geopolymer was less porous and absorbed 10.9% less water than control concrete. Geopolymer exhibited excellent fire resistance at 300^0C and 600^0C.

III. MIX DESIGN

A.Cement Concrete

Conventional mix for cement concrete of grade M20 was arrived according to IS 10262- 2009. Table I represents the mix design of M20 grade cement concrete.

Table I - M20 Grade Cement Concrete.

S.No.	Ingredients	kg/m^3
1	Cement	311
2	GGBS	-
3	Water	140
4	Fine Aggregate	727
5	Coarse Aggregate (Conventional)	1267
6	Chemical admixture	6.22
7	W/C ratio	0.45

B. Geopolymer Concrete

Geopolymer concrete mix for M20 grade was arrived based on the cement concrete mix. Variables of the mix design were fixed based on the previous literatures. The following are the constant values used for variables in the mix design.

- Fly Ash to GGBS ratio = 70:30
- Activator solution to binder ratio = 0.45
- Molarity of NaOH = 8M
- Sodium hydroxide to Sodium silicate ratio = 2.5

Table II represents the mix design of M20 grade geopolymer concrete.

Table II - M20 Grade Geopolymer Concrete.

S. No.	Ingredients	kg/m^3
1	Fly Ash	218
2	GGBS	93
3	Activator solution	140
3	Sodium Hydroxide solution	40
4	Sodium silicate solution	100
5	Fine Aggregate	727
6	Scrap Steel slag Coarse aggregate	1038
7	Chemical admixture	6.22

IV. DURABILITY TEST ON SCRAP STEEL SLAG

Tests on scrap steel slag followed standard procedures recommended by the codes and the results are reported in Table III.

Table III – Tests on Scrap Steel Slag

S. No	Description	Result
1	Water Absorption	1.5 % by weight
2	pH value	7.91
3	Alkali aggregate reactivity (a) Reduction in alkalinity of 1.0N NaOH	110.00 millimoles /ltr
	(b) Silica dissolved	21.64 millimoles/ltr
4	Soundness(after 5 cycles) (a) Sodium sulphate	1.2% by weight
	(b) Magnesium sulphate	1.44% by weight

V. CASTING AND TESTING CONCRETE

A. Casting and Curing of Specimens

Both cement concrete and geopolymer concrete specimens were cast using the same standard procedure. The ingredients were batched and the dry materials were mixed first. The liquid component was then added to the dry mix and mixing was continued until arriving at a cohesive concrete mass. Concrete cubes of size 150 x 150 x 150 mm were cast to study compressive strength, acid resistance and sulphate resistance. Concrete cylinders of size 100 mm dia and 50 mm height were cast to study sorptivity. Specimens one day after casting were demoulded and cured for 28 days. Cement concrete specimens were water cured and geopolymer concrete specimens were ambient cured.

B. Compressive Strength

Compressive strength was tested using standard procedure in the compression testing machine. The compressive strength of cement concrete was found 27.67 MPa and geopolymer concrete was 29.11 Mpa.

C. Water Absorption

Concrete specimens were dried in oven for not less than 24 hours under elevated temperature of 100^{0}C to 110^{0}C. Specimens were then removed and allowed to air dry under room temperature. The dried samples were weighed and then immersed in water. Wet weight was recorded at every ½ hour interval upto 2 ½ hours and then at 1 hour interval upto 4 hours. Final weights of immersed cubes were recorded at 24 and 72 hours. Test was performed in accordance with ASTM C 642-13 and the water absorption was calculated using formula (1)

$$W_{ab} = ((W_s - W_d) / W_d) \times 100\ \% \qquad (1)$$

Where,

W_{ab} = Saturated water absorption in %

W_s = Weight of fully saturated specimen in kg.

W_d = Weight of oven dried specimen in kg

D. Acid Resistance

Acid resistance of concrete specimens was tested by exposing them to Concentrated Sulphuric acid. 150 mm concrete cubes of cement concrete and geopolymer concrete after their curing period were immersed in 1% H_2SO_4. The specimens were left in acid for 30 days. Periodically, the acid was checked and refreshed. After required days in acid, the specimens were removed, wiped, weighed and then put to compressive strength test under Compression Testing Machine.

E. Sulphate Resistance

For observing the resistance to sulphate attack, 5% of sodium sulphate with 99% purity was dissolved in water to make required amount of sulphate solution to immerse the specimens completely in water.

The specimens after curing were immersed in the solution for a period of 30 days. Solution was checked and refreshed periodically. The specimens were then taken out, cleaned, dried and weighed. Then, the compressive strength of the specimens was recorded.

F. Sorptivity

Sorptivity of concrete is its tendency to absorb and transmit water by capillarity through its pores. The specimens were dried in oven at 100^0C and then cooled at room temperature and weighed. The periphery of the cylinder was given a non absorbent coat to prevent absorption of water when drowned. Then the specimens were drowned in water such that the water level is at 5mm height from the base of the specimen. The quantity of water absorbed after 30 minutes was recorded by measuring the weight of the specimen. Sorptivity was calculated with the formula (2)

$$S = I / t^{1/2} \qquad (2)$$

Where,

$I = (W_2 – W_1) / (Axd)$

W_1 = Oven dry weight of cylinder in g.

W_2 = Weight of cylinder after 30 minutes of capillary suction in g.

A = Water penetration surface area in $mm^{2.}$

d = Density of water in $g/mm^{3.}$

S = Sorptivity in mm.

t = Time taken in minutes.

VI. RESULTS AND DISCUSSION

Results from Table III indicate that the water absorption, soundness and alkali aggregate reaction values of scrap steel slag are all within code limits.

Weight loss after exposure to Sodium sulphate and Magnesium sulphate was 1.2% and 1.44% against the limit of 12% and 18% as per IS 383 : 2016.

The values of alkali aggregate reactivity reported falls under innocuous aggregate conducted as per IS 2386:1963 (VII). The scrap steel slag coarse aggregate do not indicate potential deleterious degree of alkali aggregate reactivity.

The experimental test results reported in Table IV indicate that the durability performance of geopolymer concrete with scrap steel slag coarse aggregate is superior to conventional cement concrete.

Table IV – Test Results

S. No	Parameter of Study	M20CC	M20GC
1	Compressive Strength, MPa	27.67	29.11
2	Saturated Water Absorption	2.9%	3.2%
3	Reduction in Compressive Strength after Acid Attack	9%	0.8%
4	Reduction in Compressive Strength after Sulphate Attack	8.7%	0.5%
5	Sorptivity, $mm/min^{0.5}$	0.13954715	0.11628929

The compressive strength of geopolymer concrete with scrap steel slag coarse aggregate is 5 % higher than conventional concrete. Saturated water absorption for steel slag concrete is 0.3 % higher than cement concrete. But still less than 5 % limit, so it may not affect is performance. Geopolymer concrete exhibit excellent resistance to acid and sulphate attack. The reduction in compressive strength after 30 days of exposure in acid and sulphate are only 0.8 % and 0.5 % respectively. Sorptivity of geopolymer concrete was in the rate of 0.11628929 $mm/min^{0.5}$, which is less than that of the conventional cement concrete.

VII. CONCLUSION

From the experimental results it is clear that the geopolymer concrete is superior in durability performance when compared to cement concrete. The presence of scrap steel slag coarse aggregate was not found to affect its durability performance. Hence geopolymer concrete with scrap steel slag coarse aggregate is durable to be used in construction.

ACKNOWLEDGMENT

The research project under the title *Development of Geopolymer concrete and testing of elements (MRP – MAJOR – CIVIL – 2013-36977)* sanctioned by UGC to Annamalai University, helpful in carrying this research work is thankfully acknowledged by the authors.

REFERENCES

1. Monita Olivia and Hamid R. Nikraz (2011), Strength and Water Penetrability of Fly Ash Geopolymer concrete, *ARPN Journal of Engineering and Applied Sciences*, Vol.6, No.7.
2. Sreevidya V, Anuradha R, Dinakar. D and Venkatasubramani. R (2012), Acid Resistance of Geopolymer Mortar under Ambient Curing and Heat Curing, *International Journal of Engineering Science and Technology*.
3. Dr. Aradhana Mehta and Kuldeep Kumar (2016), Strength and Durability Characteristics of Fly Ash and Slag Based Geopolymer Concrete, *International Journal of Civil Engineering and Technology*, Vol.7, Issue 5, pp. 305 – 314.
4. Bapugouda Patil, Veerendra Kumar. M and H. Narendra (2015), Durability Studies on Sustainable Geopolymer Concrete, *International Research Journal of Engineering and Technology*, Vol.2, Issue 4.

EXPERIMENTAL INVESTIGATION ON LOW CALCIUM FLY ASH BASED GEOPOLYMER CONCRETE USING STEEL SLAG AS COARSE AGGREGATE

Suganya. N[1], Thirugnanasambandam. S[2]

[1]*Research Scholar, Department of Civil & Structural Engg., Annamalai University, Tamil Nadu, India*

[2]*Associate Professor, Department of Civil & Structural Engg., Annamalai University, Tamil Nadu, India*

[1]*suganyanatarajan22@gmail.com*, [2]*agstsai@gmail.com*

ABSTRACT

Geopolymer concrete is produced by replacing cement by alkali activated pozzolanic materials which are rich in silica and alumina. This experimental work involves an attempt to replace the natural coarse aggregate by steel slag. Steel slag obtained from steel rerolling mill is used as coarse aggregate to produce concrete and the performance of the concrete in terms of mechanical strength and durability are studied. This work presents the short – term performance of the geopolymer concrete in various aspects. Standard concrete grade M 40 is taken for the purpose of this study. With increase in demand over decades for a sustainable concrete which would minimize the use of natural sources to a possible limit, this work presents a concrete that would replace both cement and natural gravel in concrete by 100% with fly ash and steel slag, both being the industrial by-products seeking potential way of safe disposal to avoid environmental hazards. Also the availability of this industrial by-product is abundance in India, these can be used to produce eco-friendly concrete. The test results show that geopolymer concrete with scrap steel slag as coarse aggregate excels in performance in terms of mechanical and durability studies. Thus this can be suggested for structural applications widely.

Key Words - Low calcium Fly ash, Geopolymer, Coarse aggregate, Steel slag

INTRODUCTION

Concrete is the indispensible constituent to a nation's development. Being the fastest developing country, India will become the world's third largest construction market by 2025 and thereby the infrastructure sector is a key drive for the Indian economy. Making this development sustainable, it involves the significant reduction of raw materials in the production of concrete, as the topic of global climate change is frequently discussed now-a-days. The international panel on climatic change (IPCC) reports that the increase in concentration of many compounds in the atmosphere will impact global climate. Use of concrete contributes to the emission of greenhouse gases, especially carbon dioxide. All construction processes are energy dependent.

With this basic knowledge, this study involved the selection of geopolymer concrete – the cement free concrete and further adding to its greener value, replacement of its natural gravel coarse aggregate by steel slag is proposed and evaluated experimentally. Though any official data is not available regarding the amount of steel slag produced, it is learnt that India is the third largest importer of the scrap steel and hence large amount of steel slag can be obtained during the process of these imported steel. With abundance availability of the these material, this experimental work presents a report on value added geopolymer concrete in terms of both structural and environmental applications.

OBJECTIVE

- Check feasibility of scrap steel slag as coarse aggregate.
- Make a Low calcium fly ash geopolymer mix proportion for M 40 grade concrete based on trials.
- Replace the gravel aggregate by steel slag – 100% and study of its performance.
- Make the geopolymer concrete more sustainable.

LITERATURE STUDY

B. Vijaya Rangan [(1)] reports about the materials, mix proportion and manufacturing process of low calcium fly ash geopolymer concrete and its fresh and hardened state properties with the parameters influencing the strength. It reports that low calcium fly ash geopolymer undergoes low creep and low shrinkage.

N A Lloyd and B V Rangan [(2)] reports various short – term and long – term properties of fly ash based geopolymer concrete and its engineering applications. States that geopolymer is well suitable for precast applications with sustainability and economic benefits.

Pradip Nath et al, [(3)] studied geopolymer for ambient curing and reports that fly ash geopolymers blended with small percentages of Ground Granulated Blast furnace Slag (GGBS), Ordinary Portland Cement can be a suitable binder for low to moderate strength concrete production at ambient curing condition.

Vinothini et al [(4)], reports that GGBS in binder accelerates the setting time of geopolymer concrete at ambient conditions. Microscopic images show amorphous calcium containing hydrated product with the addition of GGBS.

Chinnaraju1, Ramkumar [(5)] reports 60% as optimum replacement level of coarse aggregate by steel slag for strong and durable concrete, however suggests that the replacement level may vary with the source of steel slag.

Mohammed Nadeem1, Arun D. Pofale [(6)] - Concrete of M20, M30 and M40 grades were considered respectively for the replacements of 0, 30, 50, 70 and 100% of aggregates (Coarse and Fine) by slag. 100 % slag aggregate (coarse) increased concrete density by about 5 to 7 % and the compressive strength of concrete improved by 4 to7 % at all the % replacements of gravel coarse aggregate with crystallized slag.

Maslehuddin, et al [7] compared steel slag and crushed limestone aggregate. Compressive strength of steel slag aggregates increased with 65% coarse aggregates. The flexural strength and split tensile strength also increased. Water absorption was reduced. Shrinkage of steel slag exposed to dry environment is similar to limestone aggregate.

EXPERIMENTAL WORK

(I) MATERIALS

Fly Ash – Low Calcium (Class F) Fly ash obtained from Mettur Thermal Power Station was used. Fly ash was obtained in dry state. Specific gravity of Fly ash was found as 2.3.

Alkaline activator solution – Combination of Sodium silicate and Sodium hydroxide was used. Sodium silicate was obtained in liquid form and sodium hydroxide solution was prepared by mixing its pellets in distilled water at required concentration. 8 Molarity concentration of sodium hydroxide solution was used for this study. Hydroxide solution was prepared, a day before use and it was mixed with sodium silicate solution together just before mixing of concrete.

Coarse aggregate – Locally sourced natural gravel with specific gravity 2.66 was used.

Sand – Local river sand with specific gravity 2.60 was used.

Steel slag – Collected from a local steel re-rolling mill. Irregular shaped slag balls were crushed down using mechanical jaw type crusher. Specific gravity was found as 2.18.

Superplasticizer – Conplast SP 430 with specific gravity 1.22 was used.

(2) MIX PROPORTION

Mix proportion for geopolymer concrete was based on laboratory trial and error method with reference to the conventional concrete mix design. The mix proportion of M 40 grade geopolymer concrete is made and it is given in Table.1. Mix I and Mix II are based on conventional coarse aggregate and steel slag coarse aggregate respectively.

Table 1 – Mix Proportion

Sl. No	INGREDIENTS	Mix I kg/m³	MIX II kg/m³
1	Fly Ash	311	311
2	GGBS	133	133
3	Sodium Hydroxide solution (8M)	57	57
4	Sodium silicate solution	143	143
5	Fine Aggregate	815	815
6	Coarse Aggregate (12.5 mm)	1061 (Gravel)	870 (Steel Slag)
7	Super Plasticizer	7.4	7.4

(3) CASTING AND TESTING OF SPECIMENS

First, all the dry ingredients were mixed and then the activator solution was added to obtain a cohesive mix. Super Plasticizer was also used to improve the workability to get the slump value of 50mm. Standard test specimens of 150 x 150 x 150mm cubes, cylinders of 300mm length x 150 mm dia. and prism of size 100 x 100 x 500mm were used to cast the geopolymer concrete specimens (Figure 1). After 24 hours of casting, the specimens were released from moulds and were exposed to sunlight – ambient temperature. (32^0C ± 2^0C). After three days of ambient curing (Figure 2), the specimens were put to laboratory strength testing. Mechanical (Compressive, Tensile and Flexural strength) and durability (Acid resistance, Sulphate resistance) performance of the concrete were conducted. Standard conventional procedure was followed while testing the concrete specimens (Figures 3 to 7).

The mechanical strength report (Table 2) shows that the steel slag aggregate Geopolymer concrete behaves similar to that of conventional aggregate Geopolymer. The Compressive and tensile strength values are relatively higher for steel slag Geopolymer. But a slight decrease in flexural strength was observed which was understood to happen because of a coarse finishing of the test specimen during casting because of higher angular slag aggregates. This shall be adjusted by increasing the mortar mass slightly, when put to larger structural applications.

Figure 1. Casting of specimens

Figure 2. Speciments under ambient curing

Figure 3. Specimen in Sulphuric acid

Figure 4 Compression test

Figure 5 Tensile test

Figure 6 Flexural test

RESULTS AND DISCUSSION

Table 2 – MECHANICAL PROPERTIES

S. No	Test Conducted	Result at 3 days in MPa	
		M I	M II
1	Compressive Strength	49.92	51.11
2	Tensile Strength	4.98	5.47
3	Flexural Strength	10.88	9.53

Table 3 – DURABILITY REPORT

Sl. No.	Parameter	Result after 30 days immersion in 1% Sulphuric acid		Result after 30 days immersion in 5% Sodium sulphate	
		M I	M II	M I	M II
1	Compressive Strength (MPa)	49.33	50.22	49.55	50.66
2	% reduction in strength	1.20	1.74	0.74	0.88

Durability report (Table 3) shows an excellent resistance to acid and sulphate attack by geopolymer concrete. However, the reduction in strength for slag aggregate Geopolymer is slightly higher as the aggregates were relatively more porous than convention aggregate which led to relatively more active change

CONCLUSION

From this short-term experimental work, it is clear that scrap steel slag can be potentially used as coarse aggregate in low calcium fly ash based geopolymer concrete as it behaves similar to conventional gravel aggregate. This will add to the sustainability of this cementless concrete. Long term research is recommended for implementing this concrete in wide structural applications.

ACKNOWLEDGEMENT

We, the authors sincerely acknowledge the support and encouragement provided by the University Grants Commission, New Delhi by sanctioning a research project, *(MRP-*

MAJOR- CIVIL-2013-36977) entitled *'Development of geopolymer concrete and testing of elements'* to Annamalai University.

REFERENCE

(1) B. Vijaya Rangan (2008), Studies on Fly Ash based Geopolymer Concrete, Article June 2008, ResearchGate DOI 10.1201/9781420007657.ch26.

(2) N A Lloyd and B V Rangan (2010) , Geopolymer Concrete with Fly Ash, Second Interrnational Conference on Sustainable Construction materials and technologies, June 28- 30, 2010, Universita Politecnica delle Marche, Ancona, Italy. ISBN 978-1-4507-1490-7.

(3) Pradip Nath, Prabir Kumar Sarker and Vijaya B Rangan (2015), Early age properties of low- calcium fly ash geopolymer concrete suitable for ambient curing, The 5th International Conference of Euro Asia Civil Engineering Forum (EACEF-5) Surabaya, Indonesia, 15-18 September 2015.

(4) Vinothini.P, Kumaravel. S and Girija. P(2015), Effect of Ambient Curing in Geopolymer Concrete, International Journal of Applied Engineering Research, ISSN 0973-4562 Vol.10 No.51(2015).

(5) Chinnaraju1, Ramkumar(2013), Study On Concrete Using Steel Slag As Coarse Aggregate Replacement And Eco sand As Fine Aggregate Replacement , International Journal of Research in Engineering & Advanced Technology, Volume 1, Issue 3.

(6) Mohammed Nadeem, Arun Pofale (2012),Experimental Investigation Of Using Slag As An Alternative To Normal Aggregates (Coarse And Fine) In Concrete ,International Journal Of Civil And Structural Engineering, Volume 3, No 1.

(7) Maslehuddin.M, AlfarabiM.Sharif, Shameem.M, Ibrahim M, Barry M.S (2002), Comparison of properties of steel slag and crushed limestone aggregate concretes, Journal of Construction and Building Materials, Vol. 17, pp 105-112.

STUDY ON CONVENTIONAL AND GEOPOLYMER BRICKS

Raghulkumar. R[1], Thirugnanasambandam. S[2]

[1]*PG Student, Department of Civil & Structural Engg., Annamalai University, Tamil Nadu, India*

[2]*Associate Professor, Department of Civil & Structural Engg., Annamalai University, Tamil Nadu, India*

[1]*raghulstarone@gmail.com* ; [2]*agstsai@gmail.com*

ABSTRACT

Bricks are widely used for construction and building material around the world. Burnt clay brick is one of the ancient building materials. The use of waste materials in bricks can lessen the consumption of clay material and reduce the environmental burden due to accumulation of waste materials. Furthermore, addition of recycled materials can decrease the high carbon footprint. The various bricks are purchased and also were manufactured using fly ash, ground granulated blast furnace slag and alkaline solution, there is no need of clay and it is called geo-polymer bricks. These geo-polymer bricks are becoming popular in the world now a day. The main constituent of conventional clay bricks contains rich silica and alumina and it replaced with various geo-polymer trial mixes. In this study, the compressive strength of various bricks purchased and the manufactured geo-polymer bricks have been tested. The test results are to be compared with different types of bricks.

KEY WORDS: Various Bricks, Alkaline Solution, Geo-polymer bricks, Compressive Strength.

INTRODUCTION

Brick plays a very important role in the field of civil engineering construction. Bricks are used as an alternative of stones in construction purpose. Bricks are being used for the construction of walls of any size, construction of floors, construction of arches and cornices, construction of brick retaining wall, making broken bricks of required size as aggregates in concrete. Bricks are traditionally manufactured by mixing clay with enough water to form a mud that is then poured into a mould of the desired shape and size, and hardened through fire or sun. Cement is widely used in concrete industry since many decades it releases green house gas i.e. carbon dioxide (CO_2), into the atmosphere while manufacturing it. Geopolymer technology is one of the recent technologies applied to reduce the use of Portland cement. Fly ash and ground granulated blast furnace slag reacts with alkaline solutions to form a cementations material. Fly ash based geopolymer does not emit carbon dioxide.

OBJECTIVES

1. To study the properties of various types of bricks available in market.
2. To develop a method to manufacture of Geopolymer bricks.
3. To carry out the tests on various types of bricks including Geopolymer bricks.

4. Analyzes the various approaches on production of Geopolymer bricks.

LITERATURE STUDY

K. Mahendran [1] compared Chamber Clay bricks, Fly ash bricks, AAC blocks, CLC blocks and Porotherm blocks based on their engineering properties and economic aspects. Various tests were carried out to determine the engineering properties. Cost benefit analysis is made for each building blocks from the obtained results.

P.P. Gadling [2] presented the Fly Ash brick properties, manufacturing process material required for preparing the clay bricks and fly ash bricks as per Indian standard code provisions, inspection and quality control. Use of this additive could have practical implications as a means of recycling and for achieving cost savings in brick production.

C. Antony Jeyasehar [3] conducted research work on "Strength and Durability Studies on Fly ash based Geopolymer Bricks" to improve the quality of geopolymer mortar through special treatments and study the property, particularly the acid resistance. The durability tests such as water absorption test and acid resistance test (HCl and H2SO4) are also conducted.

Safeer Abbas *et al.* [4] investigated brick production using Fly Ash (FA). Mechanical and durability properties of bricks were studied. Utilization of Fly Ash in brick production can lead towards economical and sustainable construction.

Danielle *et al.* [5] compared the environmental impacts of three wall types commonly built in Brazil. Differences in impacts mainly result from the use of distinct natural resources and processes. It has run different sensitivity analyses to test the final results. The concrete manufacturing process has a great impact on Climate Change and Resource Depletion.

EXPERIMENTAL INVESTIGATION

(1) COMPRESSIVE STRENGTH TEST ON PURCHASED BRICKS

The compressive strength of bricks is carried out as per **IS: 1077:1992**, and the result is given in Table 1. In this work, three classes conventional bricks and fly ash bricks are tested (Figures 1 to 4). Compression strength, $\sigma = P/A$.

Table 1 Compressive strength of Bricks

Sl. No.	Specimens	Size of the Bricks (mm)	Average Compressive Strength of Purchased Bricks (N/mm^2)
1	1st Class Clay Bricks	225 × 100 × 75	15.25
2	2nd Class Clay Bricks	210 × 100 × 75	3.59
3	3rd Class Clay Bricks	210 × 95 × 75	2.12
4	Fly Ash Bricks	230 × 105 × 70	9.02

Fig.1 First Class Brick

Fig.2 Second Class Brick

Fig.3 Third Class Brick

Fig.4 Fly Ash Brick

(2) GEOPOLYMER BRICK MORTAR PREPARATION

1. **Fly Ash (Class - F)**

   The fly ash used to manufacture geo-polymer brick in this study low calcium fly ash (Class F) obtained from Mettur Thermal Power Station. Fly ash contain rich amount of silica and alumina. Specific gravity of Fly ash was 2.15.

2. **Ground Granulated Blast Furnace Slag (GGBS)**

   GGBS is partially added with fly ash for making geopolymer bricks. It increases the engineering properties of the material. By-product from the blast-furnaces used to make iron. It contain rich amount of silica and alumina. Specific gravity of GGBS was 2.62.

3. **Fine Aggregate**

   The sand is sieve using 1.18 mm sieve and mix with appropriate proportion. Sand required for the manufacture shall be clean and free from impurities like clay. The grading of fine aggregates, as per **IS: 383-1970** within the limits and described as fine aggregates, Grading Zones II. Specific gravity of sand was 2.67

4. **Sodium Hydroxide (NaOH)**

   Sodium hydroxide is also known as caustic soda, is a caustic metallic base. It is used in many industries, mostly as a strong chemical base in the manufacture of textiles, drinking water, soaps and detergents. It is very soluble in water with liberation of heat.

5. Sodium Silicate (Na_2SiO_3)

Sodium silicate is also known as water glass or liquid glass, available in liquid (gel) form. Silicates were supplied to the detergent company and textile industry as bonding agent.

6. Activator Solution

Generally an alkaline solution is prepared by mixing sodium silicate and sodium hydroxide pellets with water. The strength of concrete depends upon the concentration of sodium hydroxide in terms of molarity.

(3) GEOPOLYMER BRICKS DESIGN

The concentration of NaOH used in the experiment is based on the research of previous researches. All the mortars are designed similar to the normal mortar. Accordingly the performances of geopolymer bricks specimens made with 3M and 4M of NaOH are evaluated.

(4) CASTING OF GEOPOLYMER BRICKS

The alkaline activator is prepared in the laboratory by mixing with the sodium hydroxide solution with the sodium silicate solution about 24 hours before actual mortar mixings to enhance reactivity of the solution. Fine Aggregates, prepared in saturated surface dry condition, and the binders (Fly ash and GGBS) were dry mixed thoroughly in the mixture. Premixed alkaline activated solution is then added gradually in the mixture. Mixing is continued for further 4 to 6 minutes depending on the consistency of the mixture (Figure 5). Curing temperature is an important factor till now for the strength of geopolymer bricks. Generally the curing which is done for geopolymer is after demoulding the specimens are cured under the ambient (atmosphere 25 to 35 degree) curing (Figures 6 and 7).

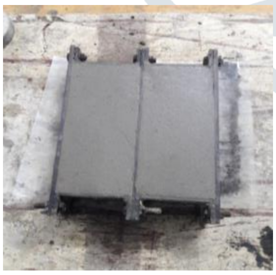


Fig.5 Bricks in Mould Fig.6 Geopolymer Bricks Fig.7 Ambient Curing

(5) TESTING OF GEOPOLYMER BRICKS

All three brick specimens are tested one by one and average result is taken as brick's compressive/crushing strength. The tests on bricks carried out as per **IS 3495: 1992** (Part 1) determination of compressive strength (Figure 8).

Fig.8 Compressive testing of Geopolymer Brick

RESULTS AND DISCUSSION

The compressive strength of different mixes geopolymer bricks is given in Table 2. The concentration of 3 molarity geopolymer bricks with 70 % fly ash and 30% GGBS showed 3.93 MPa and it is suitable for construction purpose.

Table : 2 Trial Mixes of Geopolymer Bricks

Sl. No.	NaOH	FA : GGBS	Average Compressive Strength (N/mm^2)
1	4M	50 : 50	22.28
2	4M	75 : 25	16.78
3	4M	90 : 10	14.84
4	3M	70 : 30	3.93
5	3M	75 : 25	2.77
6	3M	80 : 20	1.90
7	3M	90 : 10	1.31

CONCLUSION

Based on the experimental study carried on conventional burnt clay bricks, Fly ash and Geopolymer bricks the conclusions are derived. The conventional burnt clay bricks of three classes and Fly Ash bricks purchased in the local market tested for compressive strength. As per IS code, minimum strength of compressive strength of bricks is 3.5 N/mm^2.Based on the performances of geopolymer bricks specimens made with 3M and 4M of NaOH, various trial mixes are evaluated. Hence, that ambient cured Geopolymer bricks it is recommended for construction purposes based on this compressive strength, Eco-Friendly and also reduce global warming. since it is satisfying Engineers strength requirements.

ACKNOWLEDGEMENT

We, the authors sincerely acknowledge the support and encouragement provided by the University Grants Commission, New Delhi by sanctioning a research project, *(MRP-MAJOR- CIVIL-2013- 36977)* entitled *'Development of geopolymer concrete and testing of elements'* to Annamalai University.

REFERENCE

1. **Anant L. Murmu, A. Patel,** (2018), Towards sustainable bricks production: An overview, *Construction and Building Materials*, vol. 165 (2018), pp.112–125.
2. **Thirugnanasambandam.S.** (2013), Development of Fly ash based Geopolymer Precast Concrete Elements, *Asian Journal of Civil Engineering* (BHRC) Vol. 14, and No. 4 605-15.
3. **Priya Rachel. P (**2015), Study on Geopolymer Concrete Block. *Indian Journal of Applied Research*, Vol 5, pp 218-222.
4. **K.Mahendran, T.Sivaram, Dr.M.Shahulhameed, R.Logaraja, (2016),** A comparative study on various building blocks as an alternative to conventional bricks, *International Conference On Emerging Trends In Engineering And Management Research*, ISBN:978-81-932074-7-5 (2016), PP. 1097-1109.
5. **Lianyang Zhang,** (2013) , Production of bricks from waste materials, *Construction and Building Materials*, *volume* 47 (2013) pp.643–655.
6. **Chiara Coletti , Lara Maritan , Giuseppe Cultrone , Claudio Mazzoli,** (2016),Use of industrial ceramic sludge in brick production: Effect on aesthetic quality and physical properties, *Construction and Building Materials*, volume124 (2016) pp.219–227.
7. **Dinesh W.Gawatre, Laxmikant N. Vairagade,** (2014), Strength Characteristics of Different Types of Bricks,*International Journal of Science and Research (IJSR)* , Volume 3 Issue 10, October 2014 pp.2247-2252.
8. **Danielle maia de souza,François charron-doucet,** (2016**),** Comparative life cycle assessment of ceramic brick, concrete brick and cast-in-place reinforced concrete exterior walls, *Journal of Cleaner Production*,Volume 137, 20 November 2016, Pages 70-82.
9. **Sh.K. Amin, S.A. El–Sherbiny , A.A.M.AboEl–Magd , A. Belal , M.F. Abadir ,** (2017), Fabrication of geo-polymer bricks using ceramic dust waste, *construction and building* materials, volume 157 (2017) pp.610–620.

DEVELOPMENT OF AMBIENT CURED GEOPOLYMER CONCRETE

Dhinesh, R[1]. and Thirugnanasambandam, S[2]

[1]***PG Student**, Department of Civil & Structural Engg., Annamalai University, Tamilnadu,*
[2]*Associate Professor, Department of Civil & Structural Engg., Annama**lai** University, Tamilnadu,*
Email:[1]*tamildhinesh589@gmail.com* ; [2]*agstsai@gmail.com*

ABSTRACT

Greenhouse gas emission reduction of geopolymer concrete is an excellent engineering material. The manufacturing of Portland cement releases approximately an equal amount of carbon dioxide (CO_2) into the atmosphere. In this regard, it is mandatory to find out a solution to avoid the usage of cement in the construction industry. The geopolymer technology is the alternative method to create a binder instead of cement**.** This study aimed to achieve geopolymers suitable for curing without elevated heat. This work presents a concrete that would replace cement in concrete by 100% with fly **ash** and G**round** G**ranulated Blast furnace** S**lag (GGBS)**. Ground Granulated blast furnace slag was added 50%, the mix to enhance the early age properties of concrete. Ambient curing of concrete at r**oom temperature was adopted.** The results indicate that the reaction product and strength of geopolymer depends on the types on source materials and alkali activator. Thus, the geopolymer concrete is considered to be an environmentally pollution free construction material.

*Key Words:*Geopolymer concrete, Ambient curing, Alkaline solution, Construction material,GGBS, Low calcium fly ash.

INTRODUCTION

Concrete is widely used as one of important construction material around the world due to its good engineering properties. The various ingredients of concrete are cement, fine aggregate, coarse aggregate and water. Although the strength and durability of concrete are mainly based on cement, it is the one of the main causes of global warming due to emission of CO_2. Approximately 5% of global $CO_2$are produced by the industry of ordinary Portland cement (OPC). In this aspect, the great scientist, Joseph Davidovits invented a new binding component instead of cement called geopolymer. Geopolymers are chain of minerals containing silica and alumina in association with an alkaline solution. The by-products obtained from thermal power station and steel industries are fly ash and Ground Granulated Blast Furnace Slag (GGBFS) respectively, that contain rich amount of silica and alumina. An alkaline solution is a mixture of sodium silicate and sodium hydroxide. A hardened binder is obtained by mixing minerals such as fly ash, GGBFS and alkaline solution. Due to this chemical reaction, a polymerization process takes place which produces a chain of molecules. The entire polymerization process is taking place in the presence of heat.It is known that the hydration process takes place when cement is mixed with water, which results in binding of aggregates together to form concrete. Polymerization of geopolymer concrete **is** taken place in presence of a curing of room temperature **for** 24 hours. During the polymerization process of geopolymer concrete, water is expelled from concrete. Heat curing of geopolymer concrete can be done in two ways. One is by maintaining 60^oC temperature in heat/steam curing chamber and other one is curing under sunlight.

SCOPE AND OBJECTIVE

- To study the properties and characteristics of geopolymer concrete.
- To study the process of production of geopolymer concrete.
- The study on geopolymer concrete is an important factor around the world today.
- The approach on this area will lead to production of innovative concrete by using innovative materials in the future.
- It will lead to find out a proper solution for the high emission of carbon dioxide.
- It will lead to easy disposal of hazardous waste materials from the power plants and other industries.

INTERNATIONAL SCENARIO OF GEOPOLYMER CONCRETE

Kunal Kupwade – Patil and Erez Allouche, conducted test on *the effect of alkali silica reaction in geopolymer concrete.* In their study, alkali silica reaction occurs due to chemical reactions between hydroxyl ions in the pore water within the concrete matrix and certain forms of silica. This reaction could lead to strength loss, cracking, volume expansion and potentially failure of the structure.

Lloyd and Rangan, conducted a *Study on geopolymer concrete with fly ash.* For their study, they used low calcium (ASTM Class F) fly ash as their base material. They concluded that geopolymer possess excellent properties and is well suited to manufacture precast concrete products that are needed in rehabilitation and retrofitting of structures after disaster.

Hardjito and Rangan, studied *Fly ash based geopolymer concrete.* They observed the compressive strength data and concluded that fly ash based geopolymer concrete has good compressive strength and is suitable for structural application. Higher concentration (in terms of molar) of sodium hydroxide solution results in a higher compressive strength of geopolymer concrete.

Rangan et al, carried out experiments on *Reinforced low – calcium fly ash based geopolymer concrete beams and columns.* Heat-cured low-calcium fly ash-based geopolymer concrete has advantages such as excellent structural properties, low creep, very little drying shrinkage, excellent resistance to sulphate attack, and acid resistant.

Antony Jeyasekar and Thirugnanasambandam, carried out *experiments on development of fly ash based geopolymer concrete precast elements.* Geopolymer binders have emerged as one of the possible alternative to OPC binders due to their reported high early strength and resistance against acid and sulphate attack apart from its environmental friendliness. The steam cured geopolymer concrete beams with 8 Molarity NaOH solutions attain higher strength.

Thirugnanasambandam and Antony Jeyasekar, carried out E*xperiments on ambient cured geopolymer concrete products.* It is proved that the geopolymer technology is the alternative method to create a binder instead of cement. In this study, geopolymer concrete is made with fly ash, ground granulated blast furnace slag with alkaline solution as binder. The river sand and granite coarse aggregate are used. The geopolymer concrete specimens are cured in ambient temperature. The test results are compared with conventional cement concrete specimens and it is found that the geopolymer specimens are performing better than concrete specimens.

EXPERIMENTAL WORK

(1) MATERIALS

*Fly ash -L*ow-calcium (ASTM Class F) fly ash is used and it is obtained from the Mettur Thermal Power Station, Mettur, Tamilnadu, India. Fly ash class F has therefore been selected as a good raw material for GPC due to lower reactivity rate, which leads to slower setting time, convenient accessibility, and a reduced water demand. In order improves the mechanical properties of class F fly ash GPC. The Specific gravity of fly ash is 2.15.

GGBFS –Ground granulated blast furnace slag (GGBFS) is one of the most common component in geopolymer concrete, due to improved mechanical and microstructural properties. However, adding GGBFS cause poor workability due to higher viscosity. Specific gravity of Ground granulated blast furnace slag is 2.62.

Fine aggregate -Locally available river sand conforming to the code IS: 383-1970 is used for this study. The specific gravity is 2.67.

Coarse aggregate -The Nominal Size of Aggregate is 12.5mm and 20mm is governed by IS:383-1970.specific gravity of coarse aggregate is 2.70.

Sodium hydroxides – it is available in the form of pellets and flakes.it is recommended to use 94% to 96% purity of NaOH.

Sodium silicate –It is also known as water glass or liquid glass and is available in liquid (gel) form. Sodium silicate solution comprised Na_2O=17.7%, SiO_2=29.4%, Water=55.9% by mass.

Alkaline solution -The alkaline solution is prepared by mixing sodium silicate and sodium hydroxide pellets with water. The alkaline solution dissolves Al^{3+} and Si^{4+}ions from the aluminosilicate sources, which subsequently improves compressive strength by forming sodium alumino silicate hydrate (NASH), calcium alumino silicate hydrate (CASH), and/or calcium silicate hydrate (CSH) gels. High viscosity of sodium silicate in the alkaline solution reduces the slump of geopolymer concrete. it is recommended to leave it for about 24 hours thus the alkaline liquid is get ready as binding agent.

Extra water –Fresh GPC possesses poor workability in comparison with fresh Portland cement concrete due to the higher viscosity of the alkaline solution. A better workability can be obtained by adding extra water to the mixture. However, this will reduce the compressive strength of GPC.

(2) MIX PROPORTION

Geopolymer M20 grade concrete was mixed with the ratio of 1: 2.30: 3.58 with alkaline liquid and fly ash ratio of 0.5. The ratio of Na_2SiO_3/NaOH is 2.5 and different molarity was used. This component of geopolymer concrete mixtures is designed using the tools currently available for Portland cement concrete. M20 grade concrete is made (Table 1).

Table.1 Mix Proportion

Description	Quantity (kg/m^3)				
	6 M	6.5 M	7 M	7.5 M	8 M
Fly ash + GGBFS	348.84	348.84	348.84	348.84	348.84
Fine aggregate	802.33	802.33	802.33	802.33	802.33
Coarse aggregate	1248.85	1248.85	1248.85	1248.85	1248.85
NaOH	10.76	11.66	12.56	13.45	14.35
Na_2SiO_3	112.14	112.14	112.14	112.14	112.14
Water	34.08	33.18	32.48	31.38	30.50

(3) CASTING AND TESTING OF SPECIMENS

The fly ash, GGBFS and fine aggregate are mixed dry until the mixture is thoroughly blended and is uniform in colour. The coarse aggregates were prepared in saturated surface dry condition. The coarse aggregate is added and mixed with the fly ash, GGBFS and fine aggregate until the coarse aggregate is uniformly distributed throughout the batch. The alkaline solution is added and the entire batch was mixed until the concrete appeared to be homogenous and had the desired consistency. Cube mould of size 100mm × 100mm × 100 mm is used. Concrete was placed uniformly over the length of the standard steel mould in three layers and compacted satisfactorily (Figure 1). Demoulding was done after 24 hours and the specimens are cured under sun light (Figure 2). After 3 days, the compressive strength was found (Figure 3) and given in Table 2. The compressive strength of geopolymer concrete with different concentration NaOH is shown in Figure 4.

Fig. 1 Casting of Specimen

Fig. 2 Curing under Sunlight

Fig.3 Testing of Specimen

RESULTS

Table. 2 Compressive Strength of Specimens

Molarity	6 M	6.5 M	7 M	7.5 M	8 M
Compressive Strength (N/mm^2)	22.31	25.71	31.05	38.12	42.30

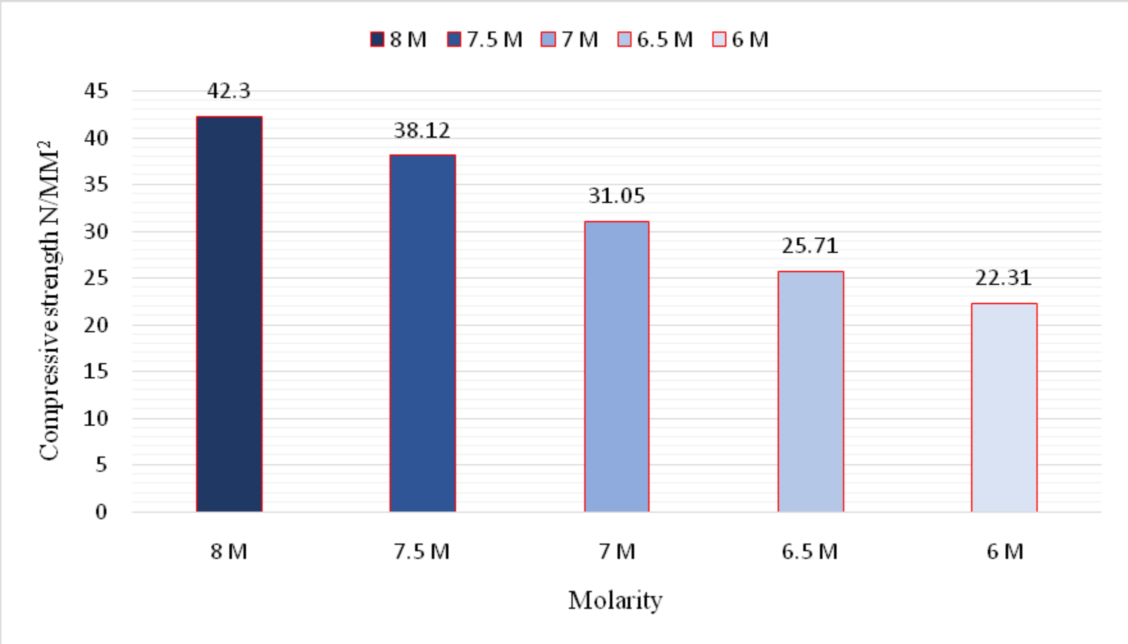


Figure 4. Comparison of Compressive Strength of Geopolymer Concrete

CONCLUSION

The concentration of sodium hydroxide is directly proportional to the compressive strength of geopolymer concrete specimens. In other words, the strength of concrete depends upon the concentration of sodium hydroxide in terms of molarity. The reason for the improvement in compressive strength of geopolymer concrete is the chemical reaction due to the speedy polymerization process and aging of the alkaline liquid.To using GGBS the entire polymerization process is taking place in presence of heat. GGBFS has higher early strength and ambient curing is achieved.

ACKNOWLEDGEMENT

We, the authors sincerely acknowledge the support and encouragement provided by the University Grants Commission, New Delhi by sanctioning a research project, *(MRP-MAJOR- CIVIL-2013-36977)* entitled *'Development of geopolymer concrete and testing of elements'* to Annamalai University.

REFERENCES

1. Antony Jeyasehar,C., Salahuddin,M. and Thirugnanasambandam,S. Development of fly ash based geopolymer concrete precast elements, funded by ministry of environment and forests, Annamalai Nagar, 2013.
2. Bowu and Jiayan (2018) Effect of temperature on bond characteristics of geopolymer concrete, International journal of Engineering structures,vol. 163 (2018), pp. 277-285
3. Fenghong Fan, Zhen Liu, Guoji Xu and Hui Peng, (2018) Mechanical and thermal properties of fly ash based geopolymers,International journal of Engineering structures,vol. 160, pp. 66-81.
4. Lloyd, N.A. and Rangan, B.V (2010) Geopolymer Concrete with Fly Ash, Proceedings ofInternational conference on sustainable construction material and technologies, Italy, June 28-30.
5. Parveen, Dhirendra Singhal, Talha Junaid, Bharat Bhushan Jindal and Ankur Mehta, (2018) Mechanical and microstructural properties of fly ash based geopolymer concrete incorporating Alccofine at ambient curing, International journal of Engineering structures,vol. 180, pp. 298-307.
6. Sumajouw, M.D.J. and Rangan, B.V. low-calcium fly ash-based geopolymer concrete: reinforced beams and columns, Australia, 2006.
7. Vijaya Rangan, B. (2010) Fly Ash-Based Geopolymer Concrete, the International Workshop on Geopolymer Cement and Concrete, pp 68-106.
8. Divya Khale and Rubina Chaudhary, (2007) Mechanism of geopolymerization and factors influencing its development, International journal of Engineering structures,vol. 42, pp. 729-746.
9. Arnoulta and Perronnetb, (2018) How to control the geopolymer setting time with the alkaline silicate solution, International journal of Engineering structures, pp. 59-66.

Performance of Ferrogeopolymer Slab Pannels

Dhavamani Doss S[1], S. Thirugnanasambandam[2].

[1]Research Scholar, [2]Associate Professor.

Dept. of Civil and Structural Engineering, Annamalai University, Annamalainagar-608 002.

Abstract

The world is in quest of innovative and ecological material for erection of buildings due to the amplified ultimatum and unjustified effects of the traditional building materials. The traditional building material such as Portland cement, river sand, blue metal, clay bricks etc. are in practice today. Between these materials, the manufacture of cement embraces a long tiresome process. It also ingests high energy proficiency and crops a lot of carbon dioxide to the atmosphere, which is a principal contributor to ecological inequity by increasing global warming. To overcome these hitch, a novel material so-called ferrogeopolymer is used to create slab panels. Ferrogeopolymer is a combination of geopolymer mortar and different forms of steel mesh as the reinforcement material. In this research ordinary Portland cement is completely replaced by fly ash as a binding material. Alkaline solution is used to enhance the binding property of fly ash. Different forms of steel meshes, such as square woven, square welded and chicken meshes are used. Ferrogeopolymer slab panels of size 1100mm x 350mm x 40mm are cast and tested. The crack behaviour, ductility and load carrying capacity of the slab panels are found, and the test outcomes are adequate.

Keywords: Activator solution, Crack behaviour, Ductility ratio, Ferrogeopolymer, Fly ash, Slab panels, Meshes.

1. Introduction

1.1. General

Need for a sustainable material in the field of construction filed is an emerging issue today. The development in the field of infrastructure of the country, there is a huge demand for construction materials. Especially the use of cement is drastically reaches the peak. Generally concrete is used as a construction material in the modern world. Cement is used as a binding material with sand and crushed aggregate to form concrete. As concrete is weak in tension, reinforcement is provided to hold the tension in reinforced concrete. Due to the need for cement is vastly increasing, the percentage of growth of greenhouse gases emission is also increasing day by day [6]. This made an elevation in the global warming rate [1]. So there is a need for new building material which should eco-friendly and should available in abundant quantity. Current research works are focussed their vision on finding sustainable materials for construction. There is also a need for technology to make thin and light weight concrete structures. This research is focussed on rectifying the emission of greenhouse gas and to create thin concrete elements. This is achieved by using ferrogeopolymer technique. In this work slab panels with ferrogeopolymer mortar is tried. In this technique the use of cement is completely eliminated and the sizes (thickness) of the structure is reduced [8]. This will make the structure eco-friendly and light weight structure.

1.2. Ferrogeopolymer

The term ferrogeopolymer is derived from combining two techniques into one. The geopolymer technique and the ferrocement technique are combined to form ferrogeopolymer. The advantage of the ferrocement technique is, that thin concrete elements are possible in the construction field. The advantage of geopolymer is, the use of cement is completely removed and utilisation of fly ash is elevated [3]. In ferrogeopolymer, the usage of coarse aggregate is not taken into account. It is made up of fly ash, Ground Granulated Blast Furnace Slag and sand with alkaline solution in the form of mortar. This geopolymer mortar is placed with different steel meshes to form ferrogeopolymer. The alkaline solution is added with the fly ash to initiate the binding property [4]. Another advantage of this research is the ferrogeopolymer concrete elements are cured under ambient curing. The curing of concrete under water for 28 days is not needed for ferrogeopolymer concrete elements. For the ferrogeopolymer concrete elements 24 hours curing is sufficiently enough.

2. Materials

2.1. Cement

Ordinary Portland Cement (OPC) 53 grade is used as a binder for conventional ferrocement slab panels. The cement sample used is confirming to the Indian standards requirements stipulated in IS: 4031 - 1988 and IS: 12269 – 1989. The specific gravity of cement sample is 3.12. The Figure 1(a) shows the cement used for casting ferrocement slab panels.

2.2. Fly Ash

The fly ash used in this study is Class – F type obtained from thermal power plant in Mettur. While burning the coal in thermal power plants, it produce fly ash as a waste material [3]. They are less in particle size compared to cement with small surface area. The specific gravity of fly ash determined through conducting test is 2.33. The figure 1(b) shows the fly ash used for making ferrogeopolymer slab panels.

2.3. Ground Granulated Blast Furnace Slag

Addition of GGBS in the ferrogeopolymer mortar will enhance the mechanical properties of ferrogeopolymer mortar and also it will ensure the ambient curing [7]. The by-product from the steel industries are similar to the constituent present ordinary Portland cement with different proportions [5]. It is known as Ground Granulated Blast furnace Slag. It consists of oxides of magnesium, aluminium, calcium oxide, silicon dioxide. The Specific of GGBS used in this research is 2.81. The figure 1(c) shows the GGBS used for making ferrogeopolymer slab panels.

2.4. River Sand

River sand is utilised as fine aggregate in the ferrogeopolymer mortar. The specific gravity of the river sand used in this research is found to be 2.70 and the fineness modulus of river sand is 3. The sieve analysis of river sand used confirms zone II as per IS: 383-1970 [2]. The figure 1(d) shows the river sand used for making ferrogeopolymer slab panels.

2.5. Activator Solution

It is the combination of sodium hydroxide and sodium silicate solution. It will enhance the binding property of ferrogeopolymer mortar by activating the binding property of fly ash. The properties of sodium silicate solution (Na_2SiO_3) and sodium hydroxide (NaOH) is shown in Figure 5. The concentration of the activator solution varies with the sodium hydroxide molarity. The ratio of sodium silicate solution and sodium hydroxide is 2.5 and activator solution to fly ash is 0.42. The figure 1(e) shows the materials used to form activator solution.

(a) Cement (b) Fly Ash (c) GGBS (d) Sand (e) NaOH (f) Na_2SiO_3

(f) Chicken Mesh (g) Welded Mesh (h) Woven Mesh

Fig.1. Materials used for casting slab panels

2.6. Steel Meshes

2.6.1. Chicken Meshes

The hexagonal mesh is commonly known as chicken mesh, and its shape gives the name as hexagonal. The wire mesh used in the ferrocement is usually 0.3mm in diameter and at joints 0.5mm and the mesh opening varies from 15mm to 25mm.The tensile strength of the wire mesh is 50 N/mm^2. Figure 1(f) shows the chicken mesh used in this research.

2.6.2. Welded Mesh

Generally 8 to 19 gauge wire spaced half an inch apart are normally used in the mesh. These wires are of low to medium tensile strength steel and are much stiffer than hexagonal wire mesh, but may develop weak spots at an intersection. The tensile strength of the material 532 N/mm^2. Figure 1(g) shows the chicken mesh used in this research.

2.6.3. Woven Mesh

In this type of mesh, the wire is simply woven into the desired grid size. Tests indicate that this is good ductility property. The tensile strength of woven mesh is 250 N/mm^2. The Figure 4.15 shows the wovened shape of mesh. Figure 1(h) shows the chicken mesh used in this research.

3. Experimental Investigations

3.1. *Compressive Strength of cement mortar and ferrogeopolymer mortar cubes*

The compressive strength of the specimens are determined by casting cubes specimens of size 100mm X 100mm X 100mm. Totally 12 number of cubes are cast, 6 for cement mortar and 6 for geopolymer mortar with mortar ratio of 1:2. The compressive strength of ferrocement mortar cubes after 28 days of curing and ferrogeopolymer mortar cubes after 7 days of ambient curing are shown in Table 1.

Table 1 Compressive Strength of ferrocement and geopolymer mortar cubes

Mix Ratio /Molarity	Curing Days	Compressive strength N/mm^2			Average N/mm^2
		1	2	3	
1:2	28	54.46	53.56	53.12	53.71
8M	07	54.52	55.92	55.75	55.40

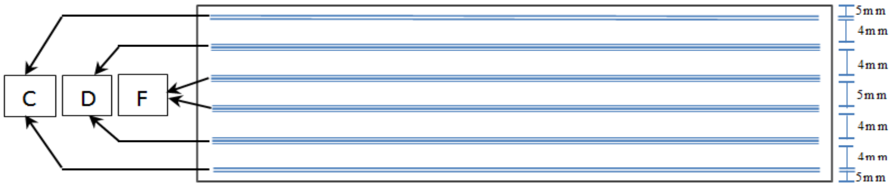
Table 2 shows the details of steel meshes in the slab panels. Each and every one of the meshes was combined with other meshes for convenient purpose.

Table 2 Specification of Slab Panels

Type of Specimen		Ferrocement Slab	Ferrogeopolymer Slab
Welded and woven with chicken mesh	Replaced with meshes	CW1	GW1

3.2. Ferrocement and Ferrogeopolymer slab panel arrangements

The Figure 3 represents the cross section of control ferrocement and ferrogeopolymer slab panels. The mortar cover of 5mm is given at both top and bottom. The mesh type B is placed with a cover mortar of 4mm and then D type mesh is placed with a cover of 4mm. Two F type mesh is placed with central mortar cover of 5mm



C-Welded + Woven, D -Welded +2 chicken meshes,
F -Woven + 2 chicken meshes.

Fig. 2. Cross Section of Slab panel (CW1 & GW1)

. The 4mm mortar cover on D type mesh on both top and bottom and C type is placed and finish cover of 5mm has given with smooth finishing. In this type of slab panel, steel skeletal is replaced by equal amount volume of mesh reinforcement.

3.3. Casting and curing of slab panels

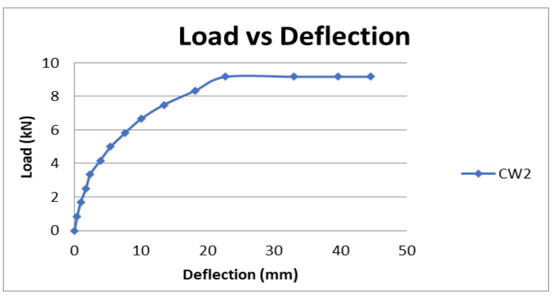
The ferrocement slab and ferrogeopolymer slab panels are cast and cured for 28 days and 7 days respectively. The ferrocement slab panel is cured by water curing and ferrogeopolymer slab panel is cured by ambient curing.

3.4. Testing of slab panels

3.4.1. Testing of Ferrocement slab panel (CW1)

The ferrocement slab containing woven mesh as a replacement for skeletal steel reinforcement takes 9.17 kN ultimate load with 44.6mm of ultimate deflection. The general setup for testing of slab panel is shown in Figure 3(a). The deflected shape of this slab is shown in Figures 3(b & c). The load-deflection curve obtained for CW1 is shown in Figures 3(d &e). The crack pattern of CW1 is shown in Figures 3(f & g). The ferrogeopolymer slab containing woven mesh with replacement for skeletal steel reinforcement takes 11.67 kN ultimate load with 48 mm of ultimate deflection.

Fig.3(a). Test setup of Slab Panel Fig.3 (b). Deflection of CW1 Fig.3 (c) Deflection of GW1 Slab



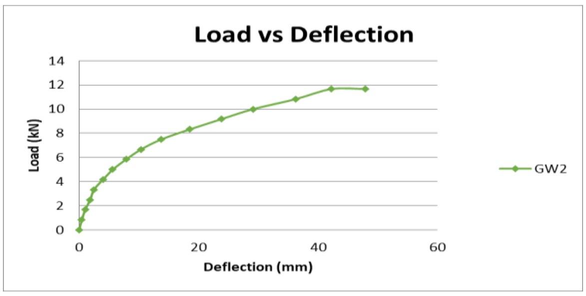


Fig.3 (d) Load Vs Deflection Curve (CW1) Fig.3 (e) Load Vs Deflection Curve (GW1)

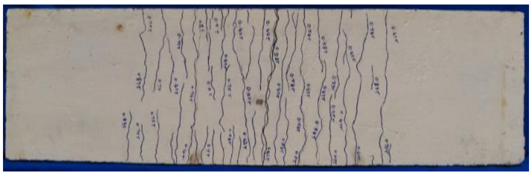


Fig.3 (f) Crack Pattern of (CW1)

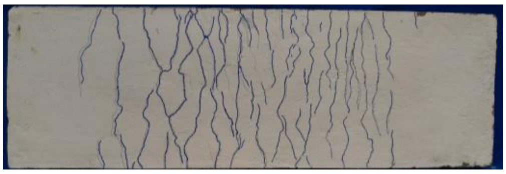


Fig.3 (g) Crack Pattern of (GW1)

4. Results and Discussions

In this study the following results are found by testing ferrocement and ferrogeopolymer slab pannel with woven mesh combined with welded and chicken mesh.

Table 3 Experimental Results of Ferrocement and Ferrogeopolymer Slabs

Specimens	Cracking Load (kN)	Ultimate load (kN)	Max. Central Deflection (mm)	Surface Cracks at Bottom		
				No. of Cracks	Avg. Spacing between cracks (mm)	Distance covered by cracks (mm)
CW1	3.33	9.17	44.6	39	29.6	554
GW1	4.17	11.67	48	37	30.5	727

5. Conclusions

- The ferrogeopolymer slab panel with woven mesh combined with welded and chicken mesh shows 25.23% increase in cracking load when compared to ferrocement slab panel with woven mesh combined with welded and chicken mesh.
- The ferrogeopolymer slab panel with woven mesh combined with welded and chicken mesh shows 27.26% increase in ultimate load carrying Capacity when compared to ferrocement slab panel with woven mesh combined with welded and chicken mesh.
- The ferrogeopolymer slab panel with woven mesh combined with welded and chicken mesh shows 7.62% increase in deflection when compared to ferrocement slab panel with woven mesh combined with welded and chicken mesh.

ACKNOWLEDGEMENT

We, the authors sincerely acknowledge the support and encouragement provided by the University Grants Commission, New Delhi by sanctioning a research project, *(MRP- MAJOR- CIVIL-2013-36977)* entitled *'Development of geopolymer concrete and testing of elements'* to Annamalai University.

References

[1] Gartner E (2004), "Industrially interesting Approaches to Low – CO2 Cements", cement and concrete research, 34(9), 1489 – 1498.

[2] IS 383: 1970 Fine aggregates from natural sources for concrete. Bureau of Indian standards, New Delhi, India.

[3] Joseph Davidovits., 1994. Global Warming Impact on the Cement and Aggregates Industries. Published in World Resource Review, Vol. 6, No.2, pp. 263-278, 1994.

[4] J.Liyana, A.M.Mustafa al bakri, H.Kamarudin, C.M.Ruzaidi and A.R.Azura. (2014). Effect of ratio of fly ash to activator and the ratio of Na2SiO3/NaOH on Flyash Geopolymer coatingstrength: Key Engineering materials vols=594-595, pp.146-150.

[5] Kiran T, et al. 2015, "Impact Test On Geopolymer Concrete Slabs", International Journal of Research in Engineering and Technology, Vol.4: pp.110-116.

[6] Mc Caffrey, R. (2002), "Climate change and cement industry ", Global cement and lime Magazine (Environmental special issue), pp.15 -19.

[7] Paras S. Pithadiya, Abhay V. Nakum, (2015), "Experimental Study on Geopolymer Concrete by Using GGBS", International Journal of Research in Engineering and Technology, Vol.04, pp.185-187

[8] Randhir J. Phalke and Darshan G. Gaidhankar (2014), Flexural Behaviour of Ferrocement Slab Panels Using Welded Square Mesh by Incorporating Steel Fiber in the International Journal of Research in Engineering and Technology", Vol.3,pp. 756-763.