BEHAVIOUR OF STEEL FIBRE REINFORCED GEOPOLYMER CONCRETE USING M-SAND AND INFLUENCE OF ASPECT RATIO OF STEEL FIBRES

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Abstract - *Steel fibre reinforced Geopolymer concrete is a 'new' Concept that does not need the presence of Portland cement as a binder.Fly ash is the basic material to be activated by the geopolimerization process to be the concrete binder, to totally replace the use of Portland cement. Steel fibres were added to the mix in the volume fractions of 1.5% of 60 aspect ratio, 1.5% of 80 aspect ratio and hybridization of both i.e. 0.75% 0f 60 aspect ratio and 0.75% of 80 aspect ratio volume of the concrete. Similarly the normal sand is fully replaced by Manufacturing Sand (M Sand), having high content of Silica which activated the production of inorganic molecules, producing good bonding among the materials in the Geopolymer Concrete.The behaviour of concrete specimens reinforced with steel fibres is tested by Compressive strength, split tensile strength and flexural strength of the concrete were determined for the hardened properties. Ambient temperature curing of 60°C is required for 24 hours.*

Key Words: **Geopolymer Concrete, Fly Ash, Steel Fibre, MSand, Sodium Silicate, Sodium Hydroxide, Compression Test, Split Tensile Test.**

1. INTRODUCTION

Now a days the demand for concrete as a construction material increases. So as the production of cement Portland cement will also increase. The production of cement will increases from about 1.5 billion tons in 1995 to 2.2 billion tons in 2010. The production of 1.0 tonne of cement releases around 1.0 tonne of CO_2 in the atmosphere. The Intergovernmental Panel on Climate Change (IPCC) has estimated that cement and ceramic manufacture is responsible for more than 20% of the world's industrial carbon dioxide (CO_2) production. However in construction industry the composite materials of cement and concrete are widely used in world level because of unavoidable in the foreseeable future. To reduce this effect of CO_2 emissions needs to find an alternative material to the existing most expansive cement concrete. These efforts include the utilization of supplementary cemetery materials such as fly ash, silica fume, granulated blast furnace slag, rise husk ash, metakaolin and finding alternative binders to Portland cement.

Geopolymer concrete is an innovative construction material produced without using any amount of ordinary Portland cement. Fly Ash, a by- product of coal obtained from the thermal power plant rich in silica and alumina plays the role of cement in the concrete by the reaction with alkali (Sodium Hydroxide NaOH) and Sodium Silicate (Na_2SiO_3) producing alumino silicate gel that acted as the binding material. Similarly the normal sand is fully replaced by Manufacturing Sand (M Sand), having high content of Silica which activated the production of inorganic molecules, producing good bonding among the materials in the Geopolymer Concrete year due to the increase in the construction industry worldwide means that the aggregates reserves are being depleted rapidly, particularly in desert countries. It has come to our knowledge that, without proper alternative aggregates being utilized in the near future, the concrete industries globally consume 8-10 billion tons of natural aggregates, after some years that will be replenished.

1.1 OBJECTIVES OF STUDY

This study is conducted to achieve the following objectives:

- The main target of this study is to analyze the carbon dioxide free cementitious material, various properties and their effects on Geopolymer concrete.
- Develop the steel fibre reinforced geopolymer concrete without using the cement, instead of OPC it is fully replaced by Fly ash. Hence it is an fly ash based geopolymer concrete.
- Replacement of river sand is fully replaced with M-sand.
- Finding the optimum amount and aspect ratio of steel fibres.

1.2 SCOPE OF STUDY

- ➢ The incorporation of geo-polymer concrete in construction field has led to the total elimination of cement from concrete which ultimately becomes "GREEN CONCRETE"
- ➢ Increase the efficiency of the construction while at the same time maintaining the highest levels of product quality under the conduction of natural sand shortage.

2. LITERATURE REVIEW

Davidovits (1994) proposed that an alkaline liquid could be used to react with the Silicon (Si) and

Aluminium(Al) in a source material of geological origin or in by product materials such as fly ash and GGBS to produce binders. Because the chemical reaction that takes place in this case is a polymerization process, he coined the term geo polymer to represent these binders. The geo polymer concrete has two limitations such as the delay in setting time and the necessity of heat curing to gain strength. These two limitations of geo polymer concrete mix was eliminated by replacing 10% of fly ash by OPC on mass basis with alkaline liquids resulted in Geo polymer Concrete Composite (GPCC mix) The present paper work is aims to study the strength characteristics of geo polymer concrete using fly ash and GGBS with the 100% replacement of cement which are producing at ambient temperature conditions without water curing & also aims to eliminate the necessity of heat curing of concrete. Concrete consist of cement, fine and coarse aggregate, water of this GGBS is factory made, water is naturally available, coarse aggregate is naturally available and factory crushed. Hence these components normally maintain a standard quality. Fine aggregate is often obtained from river beds.

Tiang Sing Ng et al (June 2013) studied the shear strength characteristics of fibre reinforced geopolymer concrete beams. Shear tests were conducted on five sets of 120mm × 250mm beams spanning 2250mm. The beams does not contain any stirrups. Instead the beam is reinforced by hooked and straight steel fibre of various dosages which vary between 0% - 1.5%. The results showed that the shear strength as a well as the crack behaviour improved on addition of fibres. Also, 100mm×100mm×500mm beams and 100mm×200mm cylinder were cast to determine the mechanical properties. The results of the test were compared with the fib Model Code 2010 alternative model for shear strength of steel-fibre reinforced concrete in combination with the variable engagement model for the determination of the tensile strength of steel-fibre-reinforced concrete. It was concluded from the studies that the beams without FRP, arching action is important in determining the failure load and failure mode. Ultimate strength and cracking load increased with increase in fibre volume.

M.I. Abdul Aleem et al., (Dec 2013) Explains the Chemical Formulation of Geopolymer Concrete with M-Sand. Geopolymer concrete is an innovative construction material produced without using any amount of ordinary Portland cement. Fly Ash, a by- product of coal obtained from the thermal power plant rich in silica and alumina plays the role of cement in the concrete by the reaction with alkali (Sodium Hydroxide NaOH) and Sodium Silicate (Na_2SiO_3) producing alumino silicate gel that acted as the binding material. Similarly the normal sand is fully replaced by Manufacturing Sand (M Sand), having high content of Silica which activated the production of inorganic molecules, producing good bonding among the materials in the Geopolymer Concrete. This paper describes the chemical reaction involved in the formation of new compound in geopolymer concrete and its formulation. The compound formation has been corroborated by physical methods, powder XRD, SEM & EDX Spectrum analysis.

Prof.More Pratap Kishanrao (May 2013) Explains the Design of Geopolymer Concrete. Reducing the greenhouse gas emissions is the need of the hour. Five to eight percent of the world"s manmade greenhouse gas emissions are from the Cement industry itself. It is an established fact that the green house gas emissions are reduced by 80% in Geopolymer concrete vis-a-vis the conventional Portland cement manufacturing, as it does not involve carbonate burns etc. Thus Geopolymer based Concrete is highly environment friendly and the same time it can be made a high-performance concrete. In the present study, fly ash, blast furnace slag and catalytic liquids have been used to prepare Geopolymer concrete mixes. This study is continued to investigate the behaviour of such Geopolymer concrete under high temperatures ranging from 1000C to 5000C. Cubes of size 100mm x 100mm x 100 mm are tested for their residual compressive strengths after subjecting them to these high temperatures.

G.Ramkumar et al., (March 2015) Explains the development of steel fibre reinforced geopolymer concrete. Geopolymer concretes (GPCs) are new class of building materials that have risen as an elective to Ordinary Portland cement concrete (OPCC) and have the potential to change the building development industry. Significant research has been done on improvement of Geopolymer concretes (GPCs), which include ambient temperature curing and use of stainless steel fibre and mild steel fibre. In this paper an attempt is made to study steel fibre reinforced geopolymer concrete. Three GPC mixes of fly ash(50%) and GGBS(50%) in the binder stage were considered.with control GPC mix , GPC mix with added stainless steel fibre and mild steel fibres. The studies showed that the load carrying capacity of most of the GPC mix was in most cases more than that of the conventional OPCC mix.The deflections at diverse stages including service load and peak load stage were higher for GPC beams.

A.M. Shende et al ., (Sep 2012), Experimental Study on Steel Fibre Reinforced Concrete for M-40 Grade. Critical investigation for M-40 grade of concrete having mix proportion 1:1.43:3.04 with water cement ratio 0.35 to study the compressive strength, flexural strength, Split tensile strength of steel fibre reinforced concrete (SFRC) containing Fibres of 0%, 1%, 2% and 3% volume fraction of hook tain. Steel Fibres of 50, 60 and 67 aspect ratio were used. A result data obtained has been analyzed and compared with a control specimen (0% fibre). A relationship between aspect ratio vs. Compressive strength, aspect ratio vs. flexural strength, aspect ratio vs. Split tensile strength represented graphically. Result data clearly shows percentage increase in 28 days Compressive strength, Flexural strength and Split Tensile strength for M-40 Grade of Concrete.

T. G. Ushaa et al., (Aug 2015) Explains the flexural behavior of self compacting geopolymer concrete using ggbfs with various replacements of r-sand and m-sand. This paper presents an experimental investigation on flexural response of self-compacting geopolymer concrete (SCGC) beams by partial replacement of fly ash by GGBFS and various replacement of River sand by M-sand under two point loading. Mixtures were prepared with alkaline liquid to binder ratio by mass value is 0.33 for mix M1, M2, M3, M4, M5.The molarity of sodium hydroxide is 12M and replacement of fly ash by GGBFS of 30% is kept as constant for all mix. The ratio between sodium hydroxide to sodium silicate solution is 1:2.5. The specimen was cured for 48 hrs of heat curing and 28 days of ambient curing. Super

Plasticizer is added to achieve the properties of self-compacting geopolymer concrete (SCGC). It is found that the SCGC beams have shown good improvement in flexural strength.

2.4 LITERATURE SUMMARY

From the above literature reviews, it was evident that fly Ash can be used as a cement replacement, M sand also be used as a fine aggregate replacement The behaviour of steel fibres was identified for the optimum performance of the concrete for two different aspect ratios (l/d) of 60 and 80.

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3 MATERIAL CHARACTERIZATION

The various strength properties of steel fibre reinforced geopolymer concrete are dependent on fly ash content, aggregate gradation, preparation of alkaline solution, and influence of aspect ratio of steel fibres.

3.1 MATERIALS USED

3.1.1 FLY ASH

Fly ash is a by-product of electricity generating plant using coal as fuel. It is an extremely fine ash formed from the inorganic components of the coal that remains after combustion of the carbonaceous part of the coal. Fly ash consist particles of silica, alumina, oxides of iron, calcium, magnesium and toxic heavy metals like lead, arsenic, cobalt, and copper. Fly ash can be divided into two categories according to the calcium content. The ash containing less than 10% CaO (from bituminous coal) is called low-calcium fly ash (Class F) and the ash typically containing 15% to 30% of CaO (from lignite coal) is called high-calcium fly ash (Class C).

Table 3.1: Constituents of Fly Ash

Element	Weight%
C	8.34
O	50.95
Mg	0.37
Al	13.98
Si	21.54
K	0.81
Ca	0.51
Ti	1.26
Fe	2.24

Table 3.2 properties of flyash compared with cement

Observation	Flyash-Class F	cement
Physical Propeties		
Type	Class F	OPC 53 Grade
Initial & Final Setting	-	45 min & 1Hr & 45 min resp.
Consistency Test	-	31 %
Specific Gravity	2.01	3.14
Chemical Properties		
SiO_2	56.8	18.5
Al_2O_3	25.8	5.24
Fe_2O_3	6.8	5.9
CaO	3.67	60.9
MgO	1.67	1.1
SO_3	0.47	1.5
Na_2O	2.06	-

3.1.2 STEEL FIBRES

There are three different types of steel fibres i.e. hook ended steel fibre (HK), crimped type steel fibre(CR), straight type steel fibre(SF) with various of aspect ratios (45, 55, 60, and 80).

For improving the mechanical bond between the fibre and matrix, indented, crimped, machined and hook ended fibres are normally produced. Fibres made from mild steel drawn wire conforming to IS: 280-1976 with the diameter of wire 0.5 mm has been used.

Fig 3.1: Hooked end steel fibres

Table 3.3 : Properties of steel fibres

FIBRE PROPERTIES	STEEL FIBRES
Length (mm)	35 mm
Shape	Hooked End
Size / Diameter (mm)	0.5 mm
Aspect Ratio	60
Density (kg / m^3)	7850
Young's Modulus (GPa)	210
Tensile strength (MPa)	532

3.1.3 MANUFACTURED SAND

Due to the depletion of natural resources and restriction due to environmental consideration has made concrete manufactures to look for suitable alternative fine aggregate. One such alternative is " Manufactured sand". M-sand is crushed aggregates produced from hard granite stone which is cubically shaped with grounded edges, washed and graded with consistency to be used as a substitute of river sand. It improves both compressive strength and flexural strength through better bond compared to river sand.

Fig 3.2 : Manufactured sand

Table 3.4: Properties of M-Sand

S.NO	PROPERTY	VALUE
1	Bulk density of loose sand	1898 kg/m^3
2	Bulk density of compacted sand	1645 kg/m^3
3	Specific Gravity	2.61
4	Water Absorption	3.6%

3.1.4 SODIUM HYDROXIDE (NaOH)

The most common alkaline activator used in geopolymerisation is a combination of sodium hydroxide (NaOH) or potassium hydroxide (KOH) and sodium silicate or potassium silicate. The type and concentration of alkali solution affect the dissolution of fly ash. Leaching of

Al3+ and Si4+ ions are generally high with sodium hydroxide solution compared to potassium hydroxide solution. Alkali concentration is a significant factor for controlling the leaching of alumina and silica from fly ash particles, geopolymerization process and mechanical properties of hardened geopolymer

Fig 3.3: Sodium hydroxide pellet form

Table 3.5: Physical properties of sodium hydroxide

PROPERTIES	COLOUR LESS
Specific gravity	2.13
PH	14

Table 3.6: Chemical properties of sodium hydroxide

CONSTITUENTS	PERCENTAGE
Carbonate(Na_2Co_3)	2%
Chloride(Cl)	0.01%
Sulphate(SO_2)	0.05%
Lead(Pb)	0.001%
Iron(Fe)	0.001%
Potassium(K)	0.01%

3.1.5 SODIUM SILICATE SOLUTION (Na_2SiO_3)

Sodium silicate is the common name for a compound sodium metasilicate, Na_2SiO_3 , also known as water glass or liquid glass. It is available in both aqueous solution and solid form and is used in cements, passive fire protection, refractories, textile and lumber processing, and automobiles. Sodium carbonate and silicon dioxide react in molten state to form sodium silicate as well as carbon dioxide.

Table 3.7 : Physical and chemical properties of sodium silicate.

CONSTITUENTS	PERCENTAGE
Na_2O	15.9%
SiO_2	31.4%
H_2O	52.7%
Appearance	Liquid(gel)
Colour	Light yellow liquid (gel)
Boiling point Solution	102 C for 40% aqueous
Molecular weight & Specific gravity	184.04 1.6

3.1.6 COARSE AGGREGATE

A majority of the volume of concrete (60 – 80%) is occupied by aggregate. In fact, for most conventional concretes, more than 75% of the volume is aggregate. Aggregates are essential in concrete from the point of view of economy (since cement is expensive), dimensional stability (aggregates do not easily creep or shrink), stiffness, and abrasion resistance. Aggregates fraction larger than 4.75mm are termed as coarse aggregates. The fraction of aggregates used in the experimental work passed in 20mm sieve and retained on 10mm IS sieve conforming to IS: 383-1970.

Table: 3.8 Properties of Coarse Aggregate

S.NO	PROPERTY	VALUE
1	Particle Shape	Angular
2	Specific Gravity	2.67
3	Fineness modulus	7.15
4	Water Absorption	0.33%

5	Bulk Density	1562 Kg/m^3
6	Impact Value	8.5%

3.2 ALKALINE SOLUTION

Sodium hydroxide (NaOH) in the form of flakes and sodium silicate are used as alkaline activators to give a good binding solution for the geopolymeric mix.The alkaline liquid used in geopolymerisation is a combination of sodium hydroxide (NaOH) and sodium silicate as activators. Sodium silicate solution was purchased from a local supplier in bulk. The sodium hydroxide in flakes or pellets was purchased from a local supplier in bulk.

- Alkaline liquid is prepared by mixing sodium silicate solution and sodium hydroxide solution with proper proportion.
- Sodium-based solutions were selected because they were cheaper than potassium based solutions.
- The sodium hydroxide solids were a commercial grade in pellets form (3 mm).

3.3 MIX DESIGN OF STEEL FIBRE REINFORCED GEOPOLYMER CONCRETE

In the present study, method for mix design is the Indian Standard Method. The geopolymer consist primary binder as fly ash. The ratio of alkaline liquid to fly ash is 0.5. To obtain mass of sodium hydroxide and sodium silicate solution, the ratio of sodium hydroxide to sodium silicate was fixed at 2.5.

Table3.9 . Mix Design.

ID Mix	GPC 0% fibre	GPC1 1.5% Fibre of A.R. 60	GPC2 1.5% fibre of A.R. 80	GPC3 0.75% fibre of 60 + 0.75% fibre of 80
Fly Ash(Kg/m^2)	368.91	368.91	368.91	368.91
Fine Aggregate(Kg/m^2)	581.03	581.03	581.03	581.03
Coarse Aggregate(Kg/m^2)	1171.29	1171.29	1171.29	1171.29
NaoH Soln(Kg/m^2)	52.86	52.86	52.86	52.86
Na_2SiO_3 Soln(Kg/m^2)	132.14	132.14	132.14	132.14
Steel Fibres(Kg/m^2)	0	117.75	117.75	58.88+58.88

3.4 PREPARATION OF GEOPOLYMER CONCRETE

To prepare 16 molarity concentration of sodium hydroxide solution, 640 grams (molarity x molecular weight) of sodium hydroxide flakes was dissolved in distilled water and makeup to one liter. The sodium hydroxide solution thus prepared is mixed with sodium silicate solution one day before mixing the concrete to get the desired alkaline solution After dry mixing, alkaline solution was added to the dry mix and wet mixing was done. In case of steel fibre reinforced GPC mixes fibres were added to the wet mix in three different proportions such as 1.5% of aspect ratio 60, 1.5% of aspect ratio 100 and hybridization of both i.e. 0.75% of aspect ratio 60 + 0.75% of aspect ratio 80.

4. TESTING AND RESULT

Test specimens are cured in oven at a temperature of 60^0C for 24 hours

4.1 TEST FOR CONCRETE

4.1.1Compressive strength of concrete cubes

The compression test is carried out according to determine the characteristic strength of the concrete. In this test, 150 mm standard cube mould is used for concrete mix. The apparatus should be clean and free from hardened concrete and superfluous water before testing. The test is carried out for each cube. The reported compressive strength is the average of 3 measurements tested at the age of 7days, 14days and 28 days. specimen of cube tested in compression testing machine.

Formula:

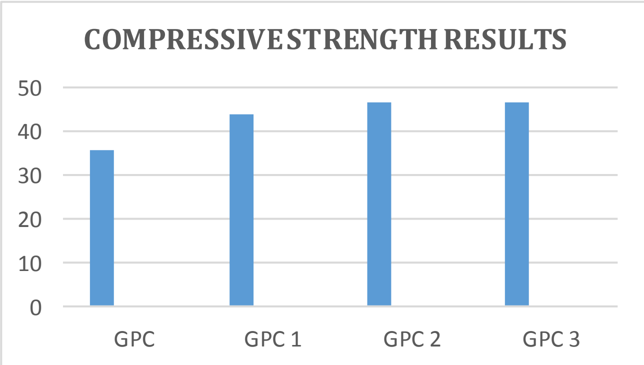
$$\text{Ultimate Compressive Strength} = \frac{\textit{Ultimate load}}{\textit{Area of cross section}}$$

Fig 4.1 : Compression test

Table 4. 1 : Compressive Strength of Geopolymer Concrete with and without fibres

Mix ID	Avg. Comp. 'P' load in KN	Avg. Comp. strength in Mpa	% increase in strength
GPC (0% fibre)	806.37	35.68	-
GPC 1 (1.5% Fibre of 60 A.R)	998.95	44.18	19.15%
GPC 2 (1.5% Fibre of 80 A.R)	1045.97	46.51	22.35%
GPC 3 (0.75% fibre of 60 A.R + 0.75% fibre of 80 A.R	1025.05	46.88	22.63%

chart 4.1 compressive strength results



4.1.2 Split tensile strength of concrete cylinders

The cylindrical specimens of diameter 100mm and height 200mm were used to determine the split tensile strength. The specimens were tested in computerized universal testing machine of capacity 1000 kN. The cylinders were placed in the machine horizontally. Load was applied gradually at a uniform rate until the specimens failed. Split tensile strength was taken as the average strength of three specimens

Formula:

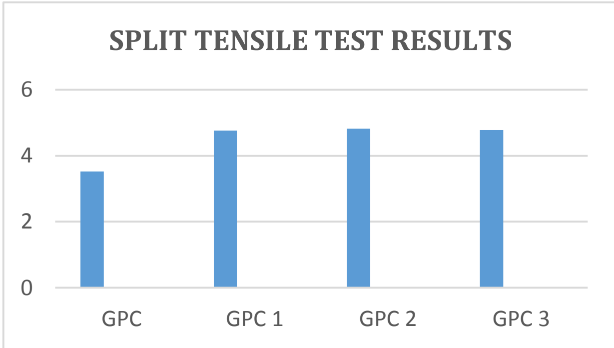
$$F = \frac{2P}{\pi d l}$$

Fig 4.2 : split tensile test

Table4.2 : Split Tensile Strength of Geopolymer Concrete

Mix ID	Avg. Comp. 'P' load in KN	Avg. Split Tensile strength in Mpa	% increase in strength
GPC (0% fibre)	256.8	3.52	-
GPC1 (1.5% Fibre of 60 A.R)	335.8	4.76	23.31%
GPC2 (1.5% Fibre of 80 A.R	340.70	4.82	24.27%
GPC3 (0.75% fibre of 60 A.R + 0.75% fibre of 80 A.R	338.8	4.78	23.64%

chart 4.2 : split tensile strength test



5. CONCLUSIONS

1. Geopolymer concrete with M sand is an excellent alternative to Portland cement concrete.
2. Based on the compressive strength resuts, the maximum strength at all age of testing was obtained at GPC 2 of 80 aspect ratio steel fibres
3. While comparing the split strength results, GPC 2 mix containing steel fibres of 80 (l/d) aspect ratio gives high performance when compared to 60 aspect ratio.

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