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An Experimental Study of Fibre Reinforced Geo Polymer Concrete using Fly ash, GGBS and Polypropylene Fibres with a Partial Replacement of Normal Sand by Quarry Dust

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***Abstract*—This project deals with the experimental study to determine the properties of fresh and hardened concrete of fibre reinforced geo polymer concrete which contains Low calcium fly ash(class F), Granulated Ground Blast Furnace (GGBS), active alkaline liquids like Sodium hydroxide, Sodium silicate solutions, fine aggregates as natural sand and quarry dust, coarse aggregates and poly propylene fibres. Also this experiment deals with the study of partial replacement of natural sand by quarry dust and effect of change in water content ratio. Geo polymer requires a heat curing which is eliminated by adding Granulated Ground Blast Furnace (GGBS) so that in atmospheric temperature hardening of concrete can be achieved called as ambient curing.**

Keywords— Geo polymer, Fly ash, GGBS, Alkaline liquid, Design mix proportion, Preparation of alkaline solutions, Ambient curing, Strength parameters, Geopolmer concrete

I. INTRODUCTION

1.1 General

The major problem that the world is facing today is the environmental pollution. In the construction industry mainly the production of ordinary Portland cement (OPC) will cause the emission of pollutants which results in environmental pollution. The emission of carbon dioxide during the production of ordinary Portland cement is tremendous because the production of one ton of Portland cement emits approximately one ton of CO2 into the atmosphere. Among the greenhouse gases, carbon-di-oxide contributes about 65% of global warming. Many efforts are being made in order to reduce the use of Portland cement. The global use of concrete is second only to water. As the demand for concrete as a construction material increases, so also the demand for Portland cement. It is estimated that the production of cement will increase from about from 1.5 billion tons in 1995 to 2.2 billion tons in 2010.The geo polymer technology shows considerable promise for application in concrete industry as an alternative binder to the Portland cement. In terms of global warming, the geo polymer concrete significantly reduces the CO2 emission to the atmosphere caused by the cement industries.

Davidovits (1988; 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. This became leads to environmental hazards. The quality of the river sand normally depends on its source and most of the time it varies quite a lot. As the use of fine aggregate in concrete is more than 30% of the composite, its properties affect the quality of

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concrete. The alternative material should be waste materials in the aspects of reduction in environmental load and waste management cost, reduction of production cost as well as augmenting the quality of concrete. Hence crushed sand has been identified as a substitute for river sand thereby solving the issue of mining of sand from river beds and improving the quality of fine aggregate. Quarry dust has been used for different activities in the construction industry such as road construction, and manufacture of building materials such as light weight aggregates, bricks and tiles.

The inclusion of various types of fibres to improve or modify the mechanical properties of concrete results in hence called fibre reinforced concrete (FRC). The reinforcing fibres are randomly distributed in the concrete matrix. Improvement in the mechanical properties of concrete like flexural, compressive strength, ductility, toughness can be attributed to the presence of fibre in concrete matrix. The types of commonly used fibres are steel, glass, polymeric, carbon, asbestos, and natural fibres. The polymeric fibre viz. polypropylene, polyethylene, polyester, acrylic, and aramid fibres are becoming popular these days. With nominal lengths of 6, 12 or 18 mm, polypropylene fibre is the ideal solution for concrete mixtures susceptible to plastic shrinkage, cracking and crazing. The fibres do not replace the steel reinforcement bars or the normal procedures for correct setting of the concrete. It is very often possible to replace meshes by the fibres.

1.2 *Aims & Objectives of the study*

The aim of the research is to evaluate the performance and suitability of fly ash and slag based geo polymer as an alternative to the use of ordinary Portland cement (OPC) in the production of concrete.

To evaluate the different strength properties of geo polymer concrete mixture with G.G.B.S replaced in percentage to fly ash. Making workable, high strength and durable geo polymer concrete containing G.G.B.S & fly ash without usage of ordinary Portland cement

- The primary objective of this project is to study strength characteristics of geo polymer concrete using fly ash and GGBS with usage of activated alkaline solution contains sodium silicate and sodium hydroxide
- To determine the effect of fly ash and GGBS as a replacement of OPC
- By studying the strength properties with usage of fiber in geo polymer concrete
- To determine the economic benefit by using Industrial wastes fly ash and GGBS based geo polymer concrete
- Optimization of mix design for both fly ash and GGBS based geo polymer concrete
- Evaluation of performance of geo polymer concrete with replacement of natural sand by quarry dust with respect to strength parameter.

II. MATERIALS USED

A. *Granulated Ground Blast Furnace (GGBS)*

GGBS is the glassy granular material formed when molten blast furnace slag is rapidly chilled as by immersion in water. The cementations action of a granulated blast furnace slag is dependent to large extent on the glass content.

TABLE 1. Properties of GGBS

SL.No	***Parameters***	***Value***
1.	Apperance	Very Fine Powder
2.	Particle Size	25 Microns -Mean
3.	Colour	White
4.	Odour	Odourless
5.	Specific Gravity	2.82

B. *Low Calcium Fly ash (class F)*

Fly ash is the main by product created from the combustion of coal in coal-fired power plants. There are two “classes” of fly ash, Class F and Class C. Each class of fly ash has its own unique properties. Class F Fly Ash contains calcium hydroxide content is less compared to class C.

TABLE 1.1. Properties of Fly Ash

SL.No	***Parameters***	***Value***
	Apperance	Very Fine Powder
	Particle Size	35 Microns -Mean
	Colour	Grey to Black
	Odour	Odourless
	Specific Gravity	2.17

TABLE 1.2. Chemical properties of Fly ash, GGBS & Ordinary Portland cement (OPC)

nstituents	Fly Ash (%)	GGBS (%)	OPC (%)
CaO	1-3	30-45	55-64
SiO_2	35-60	30-38	20-30
Al_2O_3	10-30	15-25	1-5
Fe_2O_3	4-10	0.5-2	0.5-3
MgO	0.2-5	4-17	1-2
MnO_2	-	1-5	0.5-2
Glass	20-30	85-98	-

C. *Fine aggregate*

The fine aggregate used in mixtures are natural sand and stone dust. Locally available river sand which is the natural sand and stone dust from the quarry passing through 4.75 mm sieve and retained on 75 micron sieve is used. Quarry rock dust crushed sand less than 4.75 mm is produced from hard granite rock using state of crushing plants. Production of quarry fines is a consequence of extraction and processing in a quarry and collected from the near-by quarry. The amount produced depends on the rock type, amount of fragmentation by blasting and type of crushing used. The specific gravity of normal sand & quarry dust is

2.66 & 2.64 respectively. The water absorption of normal sand 6.45% & 5.2% quarry dust is & respectively.

TABLE 1.3. Sieve analysis of fine aggregate

Sieve size (in mm)	Normal Sand (%)	Quarry dust (%)	Zone II Gradation
5	98.0	95.5	90-100
6	93.3	86.65	75-100
8	58.3	62.75	55-90
	23.3	47.15	35-59
	5.8	26.40	8-30
5	1.2	17.70	0-10
75	0.0	0.0	0-5

D. *Coarse aggregate*

Machine crushed granite obtained from a local Quarry was used as coarse aggregate. Aggregates are the important constituents in concrete. They give body to the concrete, reduce shrinkage and effect economy. The aggregates occupy 70 to 80 % of volume of concrete. The aggregates between 4.75 mm to 50 mm are classified as coarse aggregate.

TABLE 1.4. Properties of Coarse aggregate

Property	Value
Specific gravity	2.70
Water absorption	0.67%
Impact value	29.33%
Abrasion value	30.67%
Crushing value	11.1%

E. *Active Alkaline Solution*

The solution of sodium hydroxide and sodium silicate are used as alkaline solutions in the present study. Commercial grade sodium hydroxide in pellets form and sodium silicate solution are used.

For preparation of alkaline solution, in this research work the compressive strength of Geo polymer concrete is examined for the mixes of 6 Molarity of sodium hydroxide. The molecular weight of sodium hydroxide is 40. To prepare 6 Molarity of solution 240 g of sodium hydroxide flakes are weighed and they can be dissolved in distilled water to form 1 litre solution. Volumetric flask of 1 liter capacity is taken, sodium hydroxide flakes are added slowly to distilled water to prepare 1liter solution. Sodium hydroxide solution is prepared before 24 hours of the casting of specimen. Sodium silicate solution (water glass) obtained from local suppliers was used. The chemical composition of the sodium silicate solution was Na_2O=8%, SiO_2=28%, and water 64% by mass. The mixture of sodium silicate solution and sodium hydroxide solution forms the active alkaline solution. Both these solution are mixed together at time of mixing of concrete.

F. *Mechanical action of Super plasticiser*

In this present investigation, a super plasticizer namely CONPLAST SP 430 has been used for obtaining workable concrete at low w/c ratio. CONPLAST SP430 is a based on sulphonated naphthalene polymers and is supplied as a brown liquid instantly dispersible in water.The dosage of plasticizer is 1.5% by the weight of the binder.

G. *Polypropylene Fibre*

Polypropylene fibre, a synthetic carbon polymer, is produced as continuous mono – filaments, with circular cross section. Polypropylene with 20 μm diameter, 4 mm length, and aspect ratio (L/D) is 200 which having 0.91 g/cm3 density were used. Polypropylene fibres are tough but with low tensile strength and modulus of elasticity. They have plastic stress-strain characteristics. In this research we used 0.5% of fibre by the volume of concrete.

III. MIX DESIGN

There is no standard mix design approaches are yet available for geo polymer concrete. While the strength of cement concrete is known to be well related to its water cement ratio, such as simplistic formulation may not holds good for geo polymer concrete. Therefore the formulation of geo polymer concrete has to be done by trial and error basis. A sample of mix design was shown that the aggregates occupy the largest volume,(about 75-80% by mass) in GPCs. The silicon and the aluminum in the fly ash are activated by a combination of sodium hydroxide and sodium silicate. So the materials were added as shown in table 2.

TABLE 2.Materials required for 1m^3

Constituents	Density (Kg/m^3)
GGBS	458.667
Fly Ash	50.963
Fine aggregate	875
Coarse aggregate	875
Sodium Hydroxide	76.45
Sodium Silicate	76.45
Extra water	50.963
Super Plasticizer	7.645
Polypropylene Fibre	2.548

The investigation was done on the proportion 1:1.72:1.72 (GGBS: fine aggregate: coarse aggregate) by replacing the fine aggregate, i.e, natural sand by Quarry dust with the dosage of super plasticizer of 1.5% by weight of binder. The proportions are varied by the replacement of natural sand by quarry dust is shown in table 2.1.

TABLE 2.1.The replacement of natural sand by quarry dust

Mix Id	Natural sand (%)	Quarry dust (%)
FGPC1	100	0
FGPC2	80	20
FGPC3	60	40
FGPC4	40	60
FGPC5	20	80
FGPC6	0	100

For all the proportions, the alkaline binder ratio 0.4 kept as constant. The polypropylene fibres are added 0.5% by the volume of concrete & kept as constant for all proportions.

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IV.CASTING, CURING & TESTING OF THE SPECIMENS

4.1 Casting of the specimens

GGBS, Fly Ash, Fine& Coarse aggregate were taken in mix proportion 1:1.72:1.72 which corresponds to M25 grade of concrete. Cement is replaced with ground granulated blast furnace slag (GGBS) & Fly Ash as **100%**. All the ingredients were dry mixed homogeneously. To this dry mix, required quantity of Alkali solution with required morality was added (alkali solution binder ratio= 0.4) and the entire mix was again homogeneously mixed. This wet concrete was poured into the moulds which was compacted through hand compaction in three layers and then kept into the vibrator for compaction. After the compaction, the specimens were given smooth finishes and were covered with gunny bags. After 24 hours, the specimens were de moulded.

4.2 Curing of the specimens

The de moulded specimens were transferred to curing. The curing is done in by allowing the casted specimens to atmospheric temperature by sunlight which called as ambient curing. This type of curing eliminates the heat curing geo polymer, where in they were allowed to cure for 3, 7 &14days.

4.3 Testing of the specimens

The test specimens for compressive strength test were made of cubes having a size of 150mm x 150mm x 150mm cast iron steel moulds were used. For each mix proportion two numbers of cubes were cast and tested at the age of 3days, 7 days and 14days. The test specimens for split tensile strength test were made of cylinders having a size of 100mm diameter and 300mm high cast iron moulds were used. For each mix proportion two numbers of cylinders were cast and tested at 7 & 14 days.

4.3.1. Compressive Strength Test

Specimens of dimensions 150x150x150mm were prepared. They are tested on 2000kN capacity compression testing machine as per IS 516-1959. The compressive strength is calculated by using the equation,

$$F=P/A$$

Where; F=> Compressive stress in N/mm^2

P=> Maximum load in N

A=> Cross sectional area in mm^2

The average compressive strength of various proportions is given in table 3.

TABLE 3. The average Compressive Strength

MIX Id	Compressive strength (N/mm^2)		
	3rd day	7th day	14th day
FGPC1	26.445	31.995	35.667
FGPC2	17.556	22.335	27.554
FGPC3	20.335	22.567	29.111
FGPC4	17.111	23.444	25.668
FGPC5	23.555	32.995	35.22
FGPC6	22.333	36.556	39.933

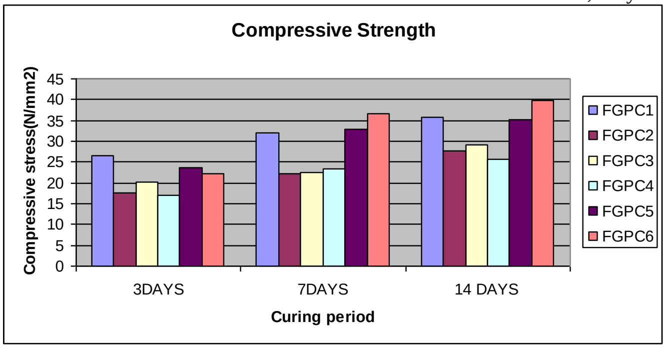

Fig 1. Compressive strength of a fibre reinforced concrete

4.3.2 Split tensile Strength test

Cylindrical specimens of diameter 150mm and length 300mm were prepared. Split tensile test was carried out on 2000 KN capacity compression testing machine as per IS 5816-1999. The tensile strength is calculated using the equation.

$$F=2P/(\pi \times D \times L)$$

Where; F=> Split tensile stress in N/mm^2

P=> Load at failure in N

D=> Dia of the cylindrical specimen in mm

L=> Length of the cylindrical specimen in mm

The average split tensile strength of various proportions is given in table 3.1.

TABLE 3.1. The average Split tensile Strength

MIX Id	Split tensile strength (N/mm^2)	
	7th day	14th day
FGPC1	2.041	2.405
FGPC2	2.155	2.90
FGPC3	2.419	2.716
FGPC4	2.3905	2.566
FGPC5	2.758	3.282
FGPC6	2.674	3.479

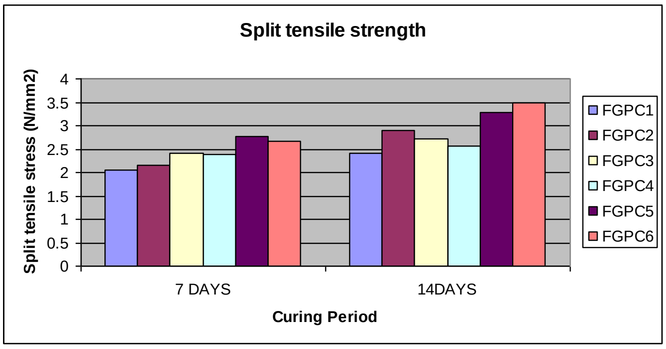

Fig 1.2. Split tensile strength of fibre reinforced geo polymer concrete

V. RESULTS & DISCUSSION

On geo-polymers, a rigorous trial-and-error method was adopted to develop a process of manufacturing GGBS & Fly Ash based geo-polymer concrete following the technology currently used to manufacture substituent for the Ordinary Portland Cement concrete.

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After some failures in the beginning, the trail-and-error method yielded successful results with regard to manufacture of low-calcium (ASTM Class F) GGBS-based geo-polymer concrete. The optimum mix is GGBS: Fine aggregate: Coarse aggregate are 1:1.72:1.72.

The comparison graph shown in **Fig.1 & Fig.1.2** shows the compressive strength of cubes & split tensile strength of cylinders respectively shows for different percentage of quarry dust and sand. For ambient curing of specimens of 100% quarry dust which gives more strength compare to the others specimens using different percentage of quarry dust and sand. The maximum strength achieve within 14 days curing. Using of polypropylene fibres to concrete mix consequently increases the compressive stress and tensile stress as compared to geo polymer concrete without fibres.

Adding of extra water other than solution and super plasticizers improves the workability of concrete mix.

General properties of the fresh geo polymer concrete are dependent on the type and the contents of the materials used in the mixture. As compared with the conventional Portland cement concrete mixes, GPC mixtures exhibit a different rheological behaviour. The geo-polymer concrete gains about 60-70% of the total compressive strength within 7 days.

VI. CONCULSION

User-friendly geo-polymer concrete can be used under conditions similar to those suitable for ordinary Portland cement concrete. These constituents of Geo-polymer Concrete shall be capable of being mixed with a relatively low-alkali activating solution and must be curable in a reasonable time under ambient conditions. The production of versatile, cost-effective geo-polymer concrete can be mixed and hardened essentially like Portland cement. Geo-polymer Concrete shall be used in repairs and rehabilitation works.

- As the Geo Polymer Concrete do not contain any Portland cement, they can be considered as less energy intensive (i.e., low Embodied energy) apart from less energy intensiveness the Geo Polymer Concrete utilize the industrial waste for producing the binding system in concrete.
- Compressive strength & Split tensile strength is more in the percentage of 100% quarry dust compared to others.
- 70 to 80% of the strength is gain with in 7days.
- Full usage of quarry dust can be implement to Geo Polymer Concrete
- The constituents of geo-polymer Concrete shall be capable of being mixed with a relatively low-alkali activating solution and must be curable in a reasonable time under ambient conditions.
- The necessity of heat curing of concrete was eliminated by incorporating GGBS and fly ash in a concrete mix.
- The price of GGBS based geo-polymer concrete is estimated to be about 30 to 50 percent cheaper than that of Portland cement concrete.

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