COMPARATIVE STUDY OF STRENGTH & COST OF FIBRE REINFORCED GEOPOLYMER CONCRETE AND CONVENTIONAL (OPC) CONCRETE

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ABSTRACT-*Geopolymer concrete (GPC) is representing the most promising green and eco-friendly alternative to Ordinary Portland cement concrete (OPC). This paper presents results of an experimental program on the mechanical properties of Fibre Reinforced Geopolymer Concrete (FRGPC) such as compressive strength and split tensile strength. Fibre reinforced concrete (FRC) is cementing concrete reinforced with more or less randomly distributed small fibres. In FRC, a number of small fibres are dispersed and distributed randomly in the concrete at the time of mixing, and thus improve concrete properties in all directions. FRGPC contains flyash, alkaline liquids, fine aggregate, coarse aggregate and fibre. Alkaline liquid to fly ash ratio was fixed as 0.35 with 100% replacement of OPC. For alkaline liquid combination, ratio of sodium silicate to sodium hydroxide solution was fixed as 2.5. Fibre was added to the mix in volume fraction of 1.0% by volume of concrete. Specimens were subjected to 24 hours of heat curing at 60°C in heat curing oven. From the test results we can conclude that using glass fibres is leading to an increase in compressive strength by about 18% and steel fibres are giving remarkable increase in tensile strength of Geopolymer concrete.*

Keywords- **Geopolymer Concrete, Sodium Silicate, Sodium Hydroxide, Fly Ash, Fibre Reinforcement**

I.INTRODUCTION

After wood, concrete is the most often used material by the society. Concrete is conventionally produced by using the ordinary Portland cement as the primary binder. The environmental issues associated with the production of OPC are well known. The amount of the carbon dioxide released during its manufacture due to the calcination of limestone and combustion of fossil fuel is in the order of one ton for every ton of OPC produced. In addition, the amount of energy required to produce OPC is the most after steel and aluminium industry.

On the other side, the abundance and availability of fly ash worldwide create opportunity to utilise this by-product of burning coal, as partial replacement for OPC. Fly ash does not possess the binding properties in itself, except for the high calcium or ASTM Class C fly ash. However, in the presence of water and ambient temperature, fly ash reacts with the calcium hydroxide during the hydration process of OPC to form the calcium silicate hydrate gel. This pozzolanic action happens when fly ash is added to OPC as a partial replacement or as a admixture.

In this work, fly ash-based geopolymer is used as the binder, instead of Portland cement or any other hydraulic cement paste, to produce concrete. The fly ash-based geopolymer paste binds the loose coarse aggregates, fine aggregates and un-reacted materials together to form the geopolymer concrete, with or without the presence of admixtures. The report also includes brief details of effect of fibres when added to concrete.

II LITERATURE REVIEW

N A Lloyd and B V Rangan (2010) presented brief details of fly ash-based geopolymer concrete and a simple method to design geopolymer concrete mixtures. They also stated that Geopolymer concrete has excellent properties and is well-suited to manufacture precast concrete products that are needed in rehabilitation and retrofitting of structures after a disaster.

Raijiwala D.B and Patil H. S (2011) concluded that compressive strength of GPC increases over controlled concrete by 1.5 times (M-25 achieves M-45). Split Tensile Strength of GPC increases over controlled concrete by 1.45 times. Flexural Strength of GPC increases over controlled concrete by 1.6 times.

Ganapati Naidu. P et al. (2012) made an attempt to study strength properties of geopolymer concrete using low calcium flyash replacing with slag in 5 different percentages. Sodium silicate (103 kg/m3) and sodium hydroxide of 8 molarity (41kg/m3) solutions were used as alkalis in all 5 different mixes. With maximum (28.57%) replacement of flyash with slag, achieved a maximum compressive strength of 57MPa for 28 days. The same mix showed 43.56 MPa after exposure of 500°C for 2 hours.

L.Maria Subashini, Shamini Valentina (2015) have carried out the tests on fibre reinforced concrete for various strength like compression, flexural, split tensile strength on the specimens by Destructive and NonDestructive Testing. Fiber reinforced concrete (FRC) is concrete containing fibrous material which increases its structural integrity. Fibre is discrete material having some characteristic properties. Polypropylene is one of the cheapest and abundantly available polymers. Polypropylene fibers are resistant to most chemical attacks and also reduces water permeability ,controls cracking, reduces rebound loss and increases flexibility.

A.Pavani et al. (2016) carried out an experimental investigation to study the material and mixture proportions; the manufacturing processes, the fresh and hardened state characteristics of fly ash based geopolymer concrete to evaluate the compression behaviour of geopolymer concrete. The behaviour was found to be considerably more than that of conventional concrete.

III.EXPERIMENTAL PROGRAMME

Casting of cubes and cylinders on conventional as well as geopolymer concrete with same proportion of various types of fibres in the mix have been carried out. The aspect ratio of fibres was also kept constant. The mix design and casting process for conventional concrete has not been discussed in this paper as it very well known. However the mix design, preparation, casting and curing of GPC has been discussed in detail in the later sections.

A. Mix Design

For design of geopolymer concrete generally some performance criterion are selected. Some guidelines for the design geopolymer concrete have been proposed by previous researchers. The design criteria of geopolymer concrete mixture depends on the application. For clarity, the compressive strength of hardened concrete and workability of fresh concrete are considered as performance criteria.To meet this criteria, water to geopolymer solids ratio by mass, the alkaline liquid to fly ash by mass, the heat curing temperature and curing time are selected as the parameters.

To obtain a strength of 45Mpa concrete mix was designed assuming the density of geopolymer concrete as 2400kg/m^3 when aggregates are in saturated surface dry condition. The combined mass of aggregates is taken as 77% of the mass of concrete i.e equal to 1848 kg/m^3.

The aggregates were taken to match the standard grading curves used in design of portland cement concrete and were modified by trial and error to get a uniform and workable mix. The ratio of coarse to fine aggregates was taken as 1.20 and hence Fine Aggregates equal to 840 kg/m^3; and Coarse aggregates equal to 1008 kg/m^3.

The mass of low calcium fly ash and alkaline liquid equal to 522 kg/m^3. Using Alkaline liquid to fly ash ratio by mass as 0.35, the mass of fly ash equal to 408 kg/m^3 and the mass of the alkaline liquid equal to 144kg/m^3. From the recommendations of the previous researchers the ratio of Sodium Silicate solution to Sodium Hydroxide solution by mass is taken as 2.5. Therefore the mass of Sodium Hydroxide solution equal to 41 kg/m^3. Hence, mass of sodium silicate solution equal to 103 kg/m^3.

The alkali activator solutions used were sodium silicate and sodium hydroxide. Sodium silicate solution comprising Na_2O = 13.72% , SiO_2 = 34.16% and H_2O = 52.12% by mass was used. The sodium hydroxide dry pellets having 97% purity were used. 8 Molar NaOH solution was prepared by adding water to the dry pellets. This solution comprises about 74% water and 26% dry pellets. To adjust the water to geopolymer solids ratio the following calculations are done:

(i) In sodium silicate solution, amount of water equal to 53.68 kg/m^3; and solids equal to 46.32 kg/m^3.

(ii) In 8M sodium hydroxide solution, amount of water equal to 30.34 kg/m^3; and solids equal to 10.66 kg/m^3.

Thus, total water equals to 84.02 kg/m^3 & Geopolymer solids equal to 464.98 kg/m^3. Hence water to geopolymer solids ratio equals to 0.181. But according to the design chart we need a water to geopolymer solids ratio of 0.19 for a compressive strength of 45Mpa. Thus the total water needed equals to 464.98 x 0.19 = 88.35 kg/m^3. Thus extra water required to be added is 88.35 - 84.02 = 4.33 kg/m^3.

From workability considerations, no loss of compressive strength results with use of superplasticizer upto 4% by mass of the source material. Hence, taking superplasticizer about 2% by weight of fly ash which equals to 8.16 kg/m^3.

Table 1- Final Mix Proportions for GPC

Sr. No	Materials	Quantity(kg/m^3)
1	Coarse Aggregates (20mm)	1008
2	Fine Aggregates (10mm)	840
3	Fly Ash (class 'F')	408
4	8M NaOH solution	41
5	Sodium Silicate solution	103
6	Extra water	4.33
7	Super-Plasticizer	8.16

B. Preparation of Alkaline Solution

To prepare 8 Molar sodium hydroxide solution, 320 grams of dry sodium hydroxide pellets are dissolved in 1 litre of water. The sodium hydroxide solution was prepared 24 hours prior to casting so as to allow it to react with water and the reaction being exothermic in nature, releases a lot of heat. Just about 30 minutes before casting, sodium silicate solution was added to the sodium hydroxide solution and stirred well.

C. Mixing and casting Procedure

Firstly the dry contents including the fine and coarse aggregates and the source material fly-ash were dry mixed for about 2-3 minutes in a mixer. After dry mixing the alkali activators solution and superplasticizer were added in 2 to 3 installments and the wet mixing was carried out for about 4-5 minutes. The concrete after mixing was uniform and stiff and was a bit tougher to handle compared to conventional concrete. It was then filled into the standard 150mm cube moulds and 150mm x 300mm cylinders in three layers and compacted 60 times per layer (as per recommendations of Hardjto et.al., 2005) using the 16mm dia. tamping rod. The surface was finished with the help of a trowel and the cubes and cylinders were then allowed to rest in ambient atmosphere for a period of 24 hours.After the so called 'rest period' of 24 hours it was found that the concrete was not completely set and so the specimens along the moulds were placed in the oven for curing.

D. Curing

Heat curing of geopolymer concrete is recommended by previous researchers. Strength of geopolymer concrete is influenced by curing time and temperture. The temperature of oven was set to 60°C for 24 hours after which specimens were kept in ambient temperature for curing.

IV.TESTS, RESULTS AND DISCUSSIONS

In the following section test results for compressive strength and split tensile strength of geopolymer concrete and conventional (OPC) concrete have been compared at 7 days and 28 days by adding fibres to concrete.

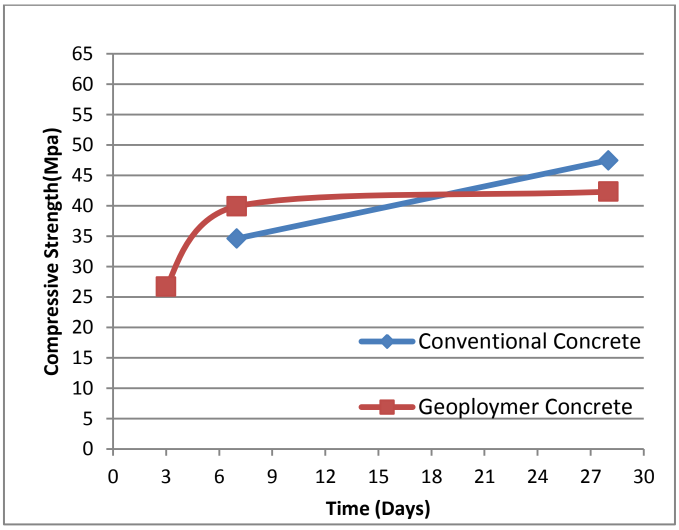

Fig.1 Comparison graph of Geopolymer concrete and Conventional concrete without fibre

From Fig.1, we can see that the conventional cement concrete gains strength progressively upto 28 days where as geopolymer concrete shows high early strength gain in the initial stages upto 7 days after which the strength gain is almost negligible.

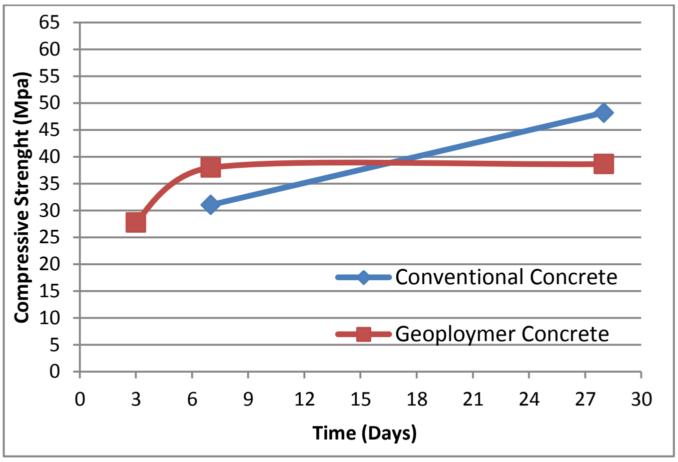

Fig.2 Comparison graph of Geopolymer concrete and Conventional concrete with Polypropylene Fibres

From Fig.2 we can conclude that Geopolymer concrete gains early high strength during 3 to 7 days. Conventional Concrete keeps on gaining strength after 7 days where as Geopolymer Concrete slows down in attaining strength after 7 days. There is not much of difference noticed in strength of 7 days and 28 days in Geopolymer Concrete after using Polypropylene fibres.

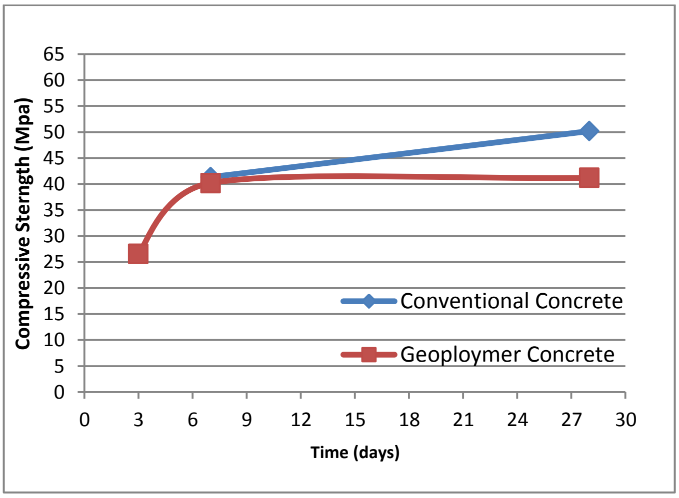

Fig.3 Comparison graph of Geopolymer concrete and Conventional concrete with Steel Fibres

From Fig.3 we can conclude that Geopolymer concrete gains early high strength during 3 to 7 days .Conventional Concrete keeps on gaining strength after 7 days where as Geopolymer Concrete slows down in attaining strength after 7 days. There is a minute difference in 7 days strengths of both concrete using Steel fibres.

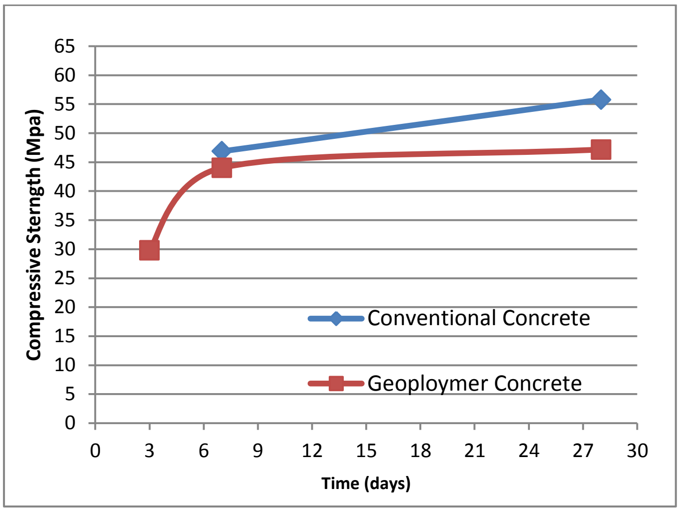

Fig.4 Comparison graph of Geopolymer concrete and Conventional concrete with Glass Fibres

From Fig.4 we can conclude that Geopolymer concrete gains early high strength during 3 to 7 days where as Conventional Concrete keeps on attaining the strength after 7 days. There is a slight difference in strengths of 7 days and 28 days in Geopolymer Concrete even after the use of Glass fibres. There is a minute difference in 7 days strength of both concrete using Glass fibres. The 7 days and 28 days strength in Geopolymer Concrete is less than Conventional Concrete using Glass fibres.

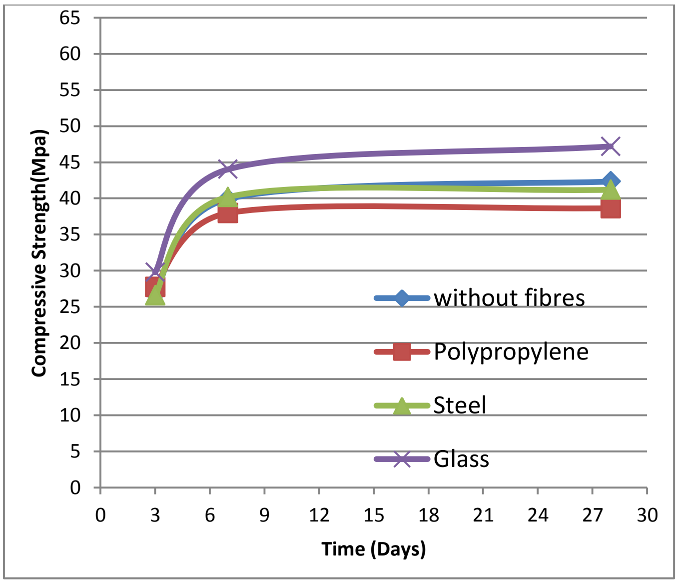

Fig.5 Comparison graph showing effect of fibres on Compressive strength of Geopolymer concrete

From Fig.5 we can compare compressive strength of geopolymer concrete with various types of fibres at 3, 7 and 28 days. We can conclude that use of glass fibres is giving a remarkable increase in compressive strength compared to other fibres. Using glass fibres is leading to an increase in compressive strength by about 18%.

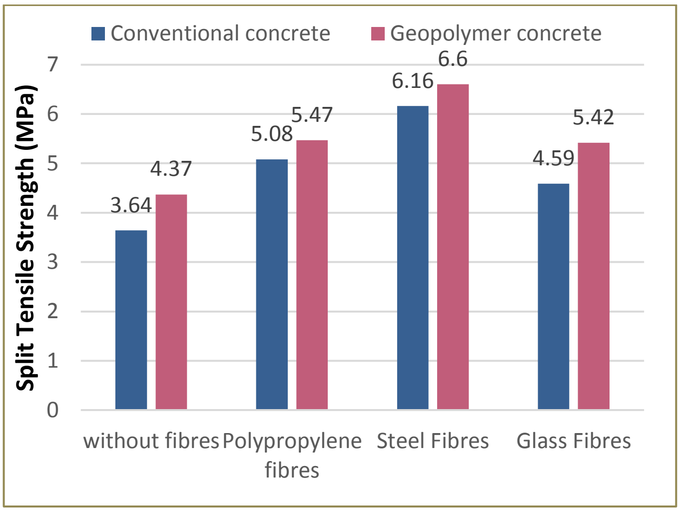

Fig.6 Comparison graph showing Split Tensile Strength of Conventional concrete to Geopolymer concrete with various fibres

From Fig.6 we can conclude that the Split Tensile Strength of Geopolymer concrete is more as compared to Conventional Concrete. The difference between the strengths is almost constant in comparison of all types of fibres. It can be seen from the chart that use of steel fibres are giving remarkable increase in tensile strength of Geopolymer concrete.

V.COST ANALYSIS

The essential feature of any upcoming construction material or construction technique in the market is feasibility. The arrival of new material, though has potentiality, may be blocked due to lack of cost effectiveness in its usage. So, this chapter aims at studying the total cost incurred in manufacturing high strength Geopolymer concrete. It is compared with the manufacturing cost of OPC concrete, accounting the market rates of different constituents of concrete.

Table.1 Cost per m3 for conventional concrete (M40)

Sr.No	Material	Rate (per kg)	Quantity (kg/m³)	Cost (per m³)
1.	Cement	7.00	450	3150.00
2.	Natural Sand	1.50	312	468.00
3.	Crush Sand	0.80	312	249.60
4.	Coarse Aggregate (10mm)	0.60	434	260.40
5.	Coarse Aggregate (20mm)	0.60	650	390.00
6.	Superplasticizer	30.00	4	120.00
			Total	4638.00

Table.2 Cost per m3 for Geopolymer concrete (M40)

Sr.No	Material	Rate (per kg)	Quantity (kg/m^3)	Cost (per m^3)
1.	Flyash	1.20	408	489.60
2.	Natural Sand	1.50	840	1260.00
3.	Coarse Aggregate (20mm)	0.60	1008	604.80
4.	Sodium Hydroxide (dry pellets)	45.00	10.66	479.70
5.	Sodium Silicate Solution	17.00	103	1751.00
6.	Superplasticizer	30.00	8.16	244.80
7.	Oven Dry Curing	4.67/ unit	24 units	112.08
			Total	4941.98

The cost analysis for both Conventional and Geopolymer concrete done has been worked out on the basis of the market rates in which we have obtained the materials. As per the analysis we can observe that the cost per m^3 for GPC is almost same as that of conventional cement concrete. But these rates are very much variable from region to region and country to country. Some researchers have reported the cost of GPC almost 30% less to its conventional counterpart.

VI.CONCLUSIONS

1. Water to geopolymer solids ratio for geopolymer concrete is similar to water cement ratio in cement concrete and is the main parameter governing the strength of geopolymer concrete mix.

2. Geopolymer concrete is susceptible to climate changes while carrying out the mixing process. Hence, care must be taken while experimental work, to carry out the casting at location where there is not much variation in temperature and humidity with change in atmospheric condition.

3. The final setting time of geopolymer concrete is quite long when compared to conventional concrete. Even after 24 hours of exposure to ambient atmosphere, it does not set completely.

4. The process of geopolymerization is quite faster than the hydration of cement concrete and almost total design strength of the mix is achieved in 7 days after which the gain in strength is negligible.

5. Another important parameter affecting the strength gain of the geopolymer concrete is the curing regime. Care must be taken to keep the samples in oven for curing upto predetermined time period and temperature only.

6. The compressive and split tensile strength of cement concrete and geopolymer concrete are affected in similar manner by the use of various kinds of fibres.

7. Similar to cement concrete, even geopolymer concrete is relatively weak in tension. The indirect tensile strength obtained is about 10% of the compressive strength.

A. Recommendations for future research

Many researchers appeal geopolymer concrete as the concrete of the new age and consider as a potential replacement for the conventional cement concrete due to its reduced environmental impact. But there are still many major limitations to implementing wide use of geopolymer concrete in construction practices. The main drawback of geopolymer concrete is requirement of elevated temperature for curing without which it does not set and gain strength soon enough. The challenge for the coming generation or researchers would be finding a way to eliminate this drawback so that geopolymer concrete can find an even wider application base like use for construction of buildings and other large structures rather than only road construction and repairing purposes.

There are a lot of waste materials other than fly ash which have cementitious properties and can be put to use in creating geopolymer concrete. Also the costly alkali activator solutions may be replaced by combinations of some other chemicals to cut the cost of the geopolymer concrete.

Coming to the mix design aspect, many researchers have worked over years on developing a rational mix design process for geopolymer concrete. But still the results do not resemble the actual design and still a lot of research work is needed to be carried out. In a country with a hot climate like India geopolymer concrete can be used advantageously for its application in precasting industry. Unfortunately there is no standard code developed for Geopolymer concrete mix design, but if encouragement is to be given for use of such eco friendly concrete, efforts will be required to put forward code of practice for design and usage of Geopolymer concrete.

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