An Experimentation on Properties of Geo-polymer Concrete with fibres

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Abstract: Geo-polymer concrete, deemed by the researchers as the new age concrete is considered as a replacement to its conventional counterpart Portland cement concrete. Already a lot of research work has gone into development and opportunities for Geo-polymer concrete or cement less concrete as they call it. Everyone is now vary of the environmental impact of usage of cement and still it is worldwide the most broadly used constituent for almost all construction purposes. Geo-polymer concrete uses pozzolans and other cementitious materials to replace completely the Portland cement that is used on a large scale for producing concrete. Apart from water it uses solutions known as alkali activators to react with the source materials to form geocement through a process called Geo-polymerization. This Geo-polymer concrete has been studied by researchers in the past years and these studies conclude that Geo-polymer concrete is superior to the cement concrete from the structural and durability consideration. But Geo-polymer concrete suffers from some major drawbacks like being weak in tension just like its conventional counterpart and it needs accelerated curing for gaining its high early strength. In this research, we had understood the result of different fibres on the inherent properties of Geo-polymer concrete.

Keywords: Cement void concrete, fibres, geopolymer, pozzolans

1. Introduction

The binder is substituted with a polymer inorganic in nature made by mixing strong alkaline solution and an aluminosilicate. The amount of alkaline solution used can affect the overall concrete strength and curing time. Aluminosilicate have more than fly-ash, blast furnace slag, red-mud and kaolin. The Geo-polymer binders and activators make it hard during producing a homogenous and pervasive Geo-polymer concrete standard.

Carbon emissions can be reduced significantly with aluminosilicate binders in place of Portland cement (that generate 1 tonne CO2 for each tonne of concrete production).Geo-polymer of fly ash concrete can decrease carbon emissions by 80% with respect to Portland cement. It has the capability to decrease world emissions by roughly 2100 million tonnes per year. This is the same as eliminating 2/3 of world traffic off the streets each year.

Geo-polymer concrete is devoid of cement concrete. This material works like green substitute for ordinary Portland cement concrete for various uses. For research, we found that concrete of Geo-polymer had excellent engineering properties. Also it has depleted global warming threats by complete replacement of ordinary Portland cement.

2. Experimental programme

2.1 Introduction

Experimental work has been described in detail. Firstly, we carried out the trials on conventional concrete and incorporated the various fibres in the mix in the same proportion. The percentage of fibres as a percentage by mass of the total mix was kept constant and the value was decided based on recommendations of past researchers. The mix design for conventional concrete was obtained from J. Kumar RMC plant and the fibres used by us were Polypropylene fibres, Glass fibres and Steel Fibres.

Table 1. Conventional Concrete Mix Design (Grade M40)

Sr. No.	Material	Quantity(kg/m3)
1	Coarse Aggregate (Metalno.2)	588

2	Coarse Aggregate (Metalno.1)	480
3	Fine Aggregate(Crushed Sand)	438
4	Fine Aggregate(River Sand)	438
5	Cement	400
6	Water	156
7	Admixture(@1%ofcement)	4.0
8	Fibres(1%oftotalweightofmix)	2.4

2.2 Material specifications

The materials used by us in the project work were obtained from locally available sources and we carried out certain tests on the materials ourselves in the laboratory to ascertain their properties wherever required.

2.2.1Fly Ash: The details of fly supplied by manufacturer were as follows: (test methodology adopted was as per IS 1727:2004).

Table 2. Chemical Compositions of Fly Ash in percentage

Oxides	**Percentage**
SiO_2	60.90
Fe_2O_3	31.49
Na_2O	0.68
MgO	0.51
SO_3	0.43
Al_2O_3	31.49
CaO	1.91

Specific Gravity = 2.20, Fineness (by Blaine's Test) = 407 m^2 /kg, Class 'F'(ASTM C-618)

2.2.2Aggregates: Fine aggregate properties are verified as per the code IS2386. The fine aggregate procured in the research were easily available and corresponded to grading zone-II as per IS: 383:1970. Easily available coarse aggregate with the dimensions of 10-20mm. Combined Fineness Modulus for the aggregates worked out in laboratory = 5.7

2.2.3NaOH: It is obtained generally in solid state with shape of pellets and flakes. The quality of NaOH used has 97%.in pellets form. Colour of NaOH is white and specific gravity is 2.13.pH of NaOH was 14.

2.2.4 Sodium silicate solution: Sodium Silicate is in liquid state (gel). The Chemical constituents of solution were: Na_2O = 13.72%, SiO_2 = 34.16% & H_2O = 52.12%.

2.2.5 Super plasticizer: Superplasticizer used in mix design is SNF Endura 28.This superplasticizer is based on Polycarboxylic ether and Synthetic Polymers.

2.2.6 Fibres: We made use of three different types of fibres in our experimental work, namely Polypropylene Fibres, Glass Fibres, & Steel Fibres. They were obtained from local market and all the fibres were chosen to be having the same aspect ratio of 80.

2.3 Methodology

For casting of the Geo-polymer concrete samples, we had to prepare a design mix based upon the empirical charts and data provided by the past researchers. The process of manufacturing and curing was also adopted after consulting some Geo-polymer based concrete experts.

2.3.1 Mix design: The effectiveness of a Geo-polymer concrete measured in relation to strength of compression of hard set concrete and workability of fresh concrete. To achieve the required efficiency, the parameter like alkaline liquid to fly ash ratio by density, water to Geo-polymer solids by density, the curing temperature and duration are designed.

In studying, strength of 40 Mpa is achieved by designing the mixture for M45 grade of concrete. Density of Geo-polymer concrete with aggregates are in saturated surface dry state is 2400kg/m3. The total aggregate mass comes out as 77% of the concrete's mass i.e. equivalent with 0.77 x 2400 = 1848 kg/m3.These aggregates are similar with the codal grading curves used in designing of Portland cement and varied by experimentation to obtain homogenous mixture that is workable. We took the ratio of coarse aggregates to fine aggregates as 1.20 so that Fine aggregates = 1848/ (1+1.2) = 840 kg/m3; and Coarse aggregates = 1008 kg/m3.

The density of low calcium fly ash along with alkaline liquid = 2400-1848 = 522 kg/m3.Using Alkaline liquid to fly ash ratio by density as 0.35(recommended values by previous researchers range from 0.30 to 0.45), the density of fly ash = 552/1.35 = 408 kg/m3 and the mass of the alkaline liquid = 552-408 = 0144 kg/m3.From the recommendations of the previous researchers the ratio of Sodium Silicate solution to NaOH solution by density is taken as 2.5. Therefore the density of NaOH solution = 144/ (1+2.5) = 041 kg/m3. Hence, density of sodium silicate solution = 144 - 41 = 0103 kg/m3.

The alkali activator solutions used were bought from the local market. Locally available sodium silicate solution with Na_2O = 13.72%, SiO_2 = 34.16% and H_2O = 52.12% by mass was used. The NaOH dry pellets with 97% purity used. 8 Molar NaOH solution was made by mixing water to the dry pellets in the laboratory. This solution consist roughly 26% NaOH pellets with 74% water. To settle the water to Geo-polymer solids ratio the steps used are:

(i)Sodium silicate solution, quantity of water = 103 x 52.12/100 = 53.68 kg/m3; and solids 103 - 53.68 = 46.32 kg/m3.

(ii) In 08M NaOH solution, quantity of water = 41 x 74/100 = 30.34 kg/m3; and solids = 41 - 30.34 = 10.66 kg/m3.

Thus, total water = 53.68 + 30.34 = 84.02 kg/m3 & Geo-polymer solids = 408 + 46.32 + 10.66 = 464.98 kg/m3. Hence water to Geo-polymer solids ratio = 84.02/464.98 = 0.181. But as per the design chart, we required the ratio of water to Geo-polymer solids is 0.19 for a compressive strength of 45Mpa grade of concrete. Final water required = 464.98 x 0.19 = 88.35 kg/m3. Thus excess water needed is= 88.35 - 84.02 = 4.33 kg/m3.

From workability point of view, no decline in compressive strength by using superplasticizer upto 4% by mass of the original material. So that, superplasticizer about 2% of density of fly ash is taken= 408 x 2/100 = 8.16 kg/m3.

Table 3. Mix Proportions

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

2.3.2 Preparation of alkaline solutions: When dry NaOH pellets of 320 grams dissolved in 1000ml of water, give 8 Molar NaOH solution. It was kept ready 24 hours earlier to the casting, to react NaOH pellets completely with water. As the reaction releases a lot of heat by being exothermic in nature. Moments before the casting roughly 30 minute's prior, sodium silicate solution was added to NaOH solution and stirred properly.

After dry mixing, the alkali activating solutions along with the superplasticizer were added and the wet mixing was performed for 5-7 minutes. The concrete after mixing was quite homogenous and stiff, difficult to handle with respect to traditional concrete. Concrete was casted in the standard 150mm cube moulds in triple layers and compacted 60 times for each layer (according to Hardjto et.al., 2005) using the standard 16mm dia. tamping rod. Trowel was used further to level the surface and the specimens were kept to rest in ambient atmosphere for duration of 1 day. After 1 day, it was observed that the mix was still unable to set thus the samples and the cube moulds were then oven cured.

2.3.3 Curing: Heat curing is generally recommended for Geo-polymer concrete. Strength of compression of this concrete is governed by curing time and temperature. The result of curing time is shown in figure 1(Hardjito and Rangan, 2005).

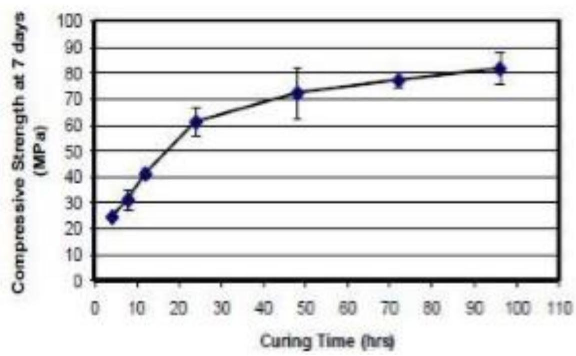

Figure 1. Curing Time vs. Compressive Strength (Hardjito and Rangan, 2005)
Figure 2. Geo-polymer Concrete Cubes Placed for Curing in the Oven along With the Moulds

3. Tests, results and discussions

3.1 Test Regime

Split tensile and compression tests were performed with traditional concrete and Geo-polymer concrete specimens. The following tables give the details regarding number of samples per test and total number of samples with and without fibre.

Table 4. Number of samples per test

Sr. No.	Tests	3days	7days	28days	Total
Conventional Cement Concrete					
1.	Compressive Strength	-	3cubes	3cubes	6cubes
2.	Split Tensile Strength	-	-	3cylinders	3cylinders
Geo-polymer Concrete					
1.	Compressive Strength	3cubes	3cubes	3cubes	9cubes
2.	Split Tensile Strength	-	-	3cylinders	3cylinders

Table 5. Total number of samples with and without fibre

Sr. No.	Description	Cubes(150mm)	Cylinders (150x300mm)

1.	Conventional Concrete without Fibres.	06	03
2.	Conventional Concrete with Polypropylene Fibres.	06	03
3.	Conventional Concrete with Steel Fibres.	06	03
4.	Conventional Concrete with Glass Fibres.	06	03
5.	Geo-polymer Concrete without Fibres.	09	03
6.	Geo-polymer Concrete with Polypropylene Fibres.	09	03
7.	Geo-polymer Concrete with Steel Fibres.	09	03
8.	Geo-polymer Concrete with Glass Fibres.	09	03
	Total Samples Tested	**60 cubes**	**24 cylinders**

3.2 Results and Discussions:-

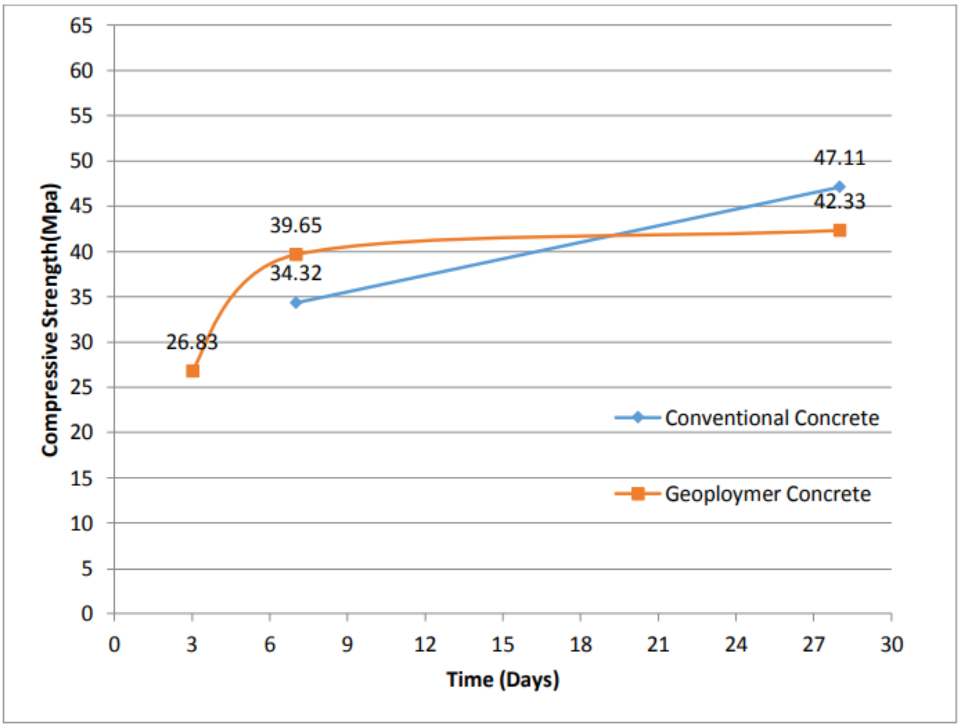

Figure 3. Graph Showing Comparison of Geo-polymer Concrete and Conventional Concrete without Fibres

As per the above graph, it is clear that the traditional concrete develops strength slowly in 28 days whereas Geo-polymer concrete develops huge strength till 7 days past which the increase is insignificant. We can thus see that the strength gained by Geo-polymer concrete in 7 days is almost equal to the 28 days strength of conventional cement concrete.

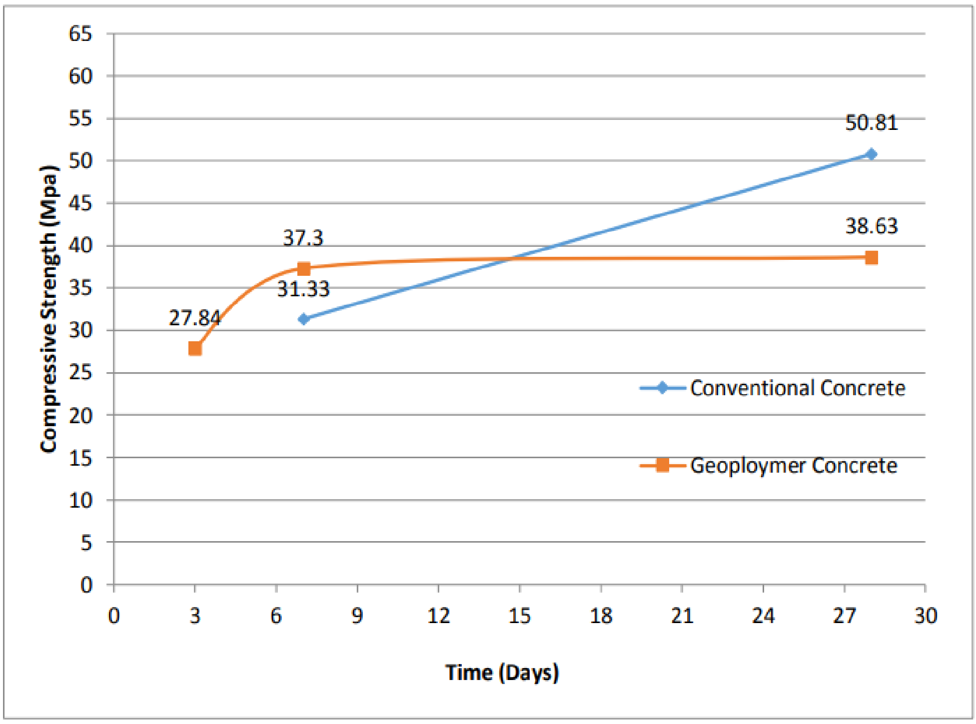

Figure 4. Graph Showing Comparison of Geo-polymer Concrete and Traditional Concrete having Polypropylene Fibres

Observing above graph we can conclude that there is rapid increase in strengths during 3 days to 7 days in Geo-polymer Concrete and Conventional Concrete continuously attaining the strength after 7 days on the other hand Geo-polymer concrete slows down in developing strength past 7th day, having almost the same strengths for 7 and 28 days. The 7 days strength in Geo-polymer concrete exceeds that of traditional concrete after adding Polypropylene fibres.

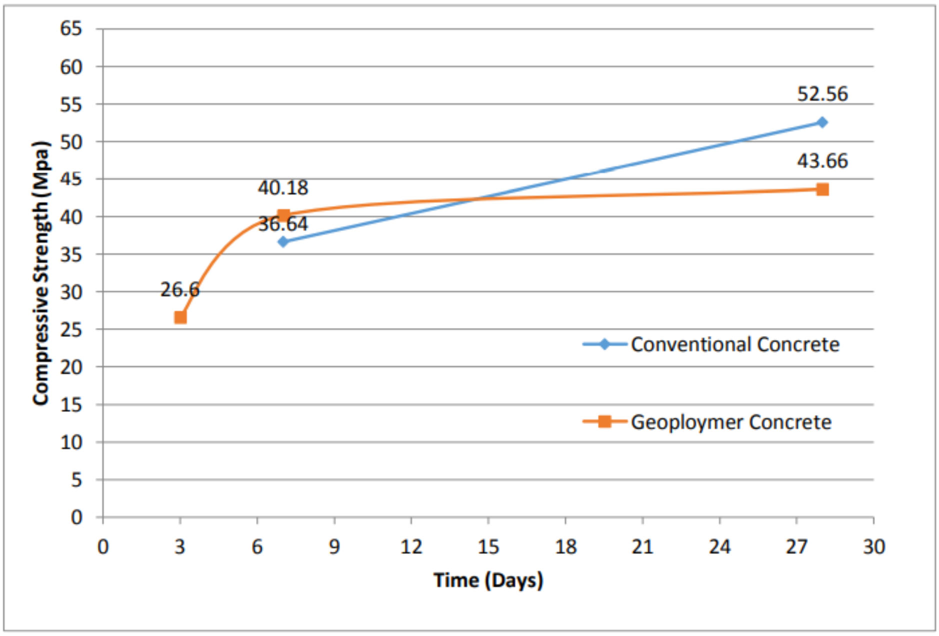

Figure 5. Graph Showing Comparison of Geo-polymer Concrete and Traditional Concrete having Steel Fibres

Observing above graph, we can conclude that there is rapid increase in strengths during 3 days to 7 days in Geo-polymer Concrete and Conventional Concrete continuously attaining the strength after 7 days on the other hand Geo-polymer concrete slows down in developing strength past 7th day, having almost the same strengths of 7 days and 28 days. The 7 days strength in traditional concrete exceeds that of Geo-polymer concrete after adding Steel Fibres.

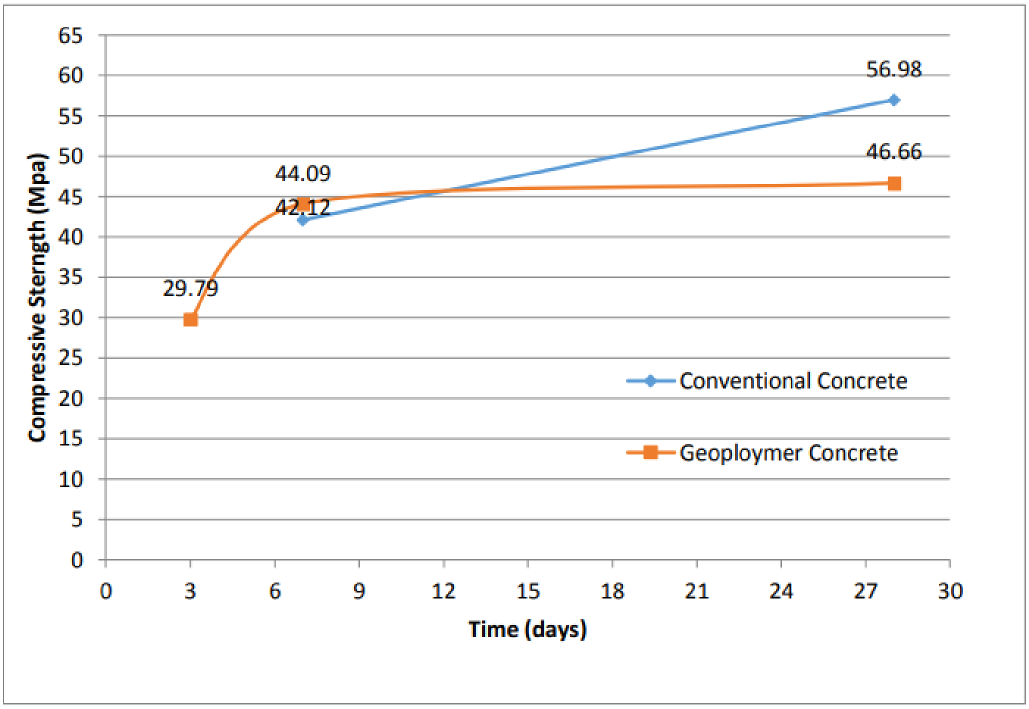

Figure 6. Graph Showing Comparison of Geo-polymer Concrete and Traditional Concrete having Glass Fibres

Observing above graph, we can conclude that there is rapid increase in strengths during 3 days to 7 days in Geo-polymer Concrete and Conventional Concrete continuously attaining the strength after 7 days on the other hand Geo-polymer concrete slows down in developing strength after 7th day, having almost the same strengths of 7 days and 28 days. The 7 days strength in traditional concrete exceeds that of Geo-polymer concrete after adding Glass fibres.

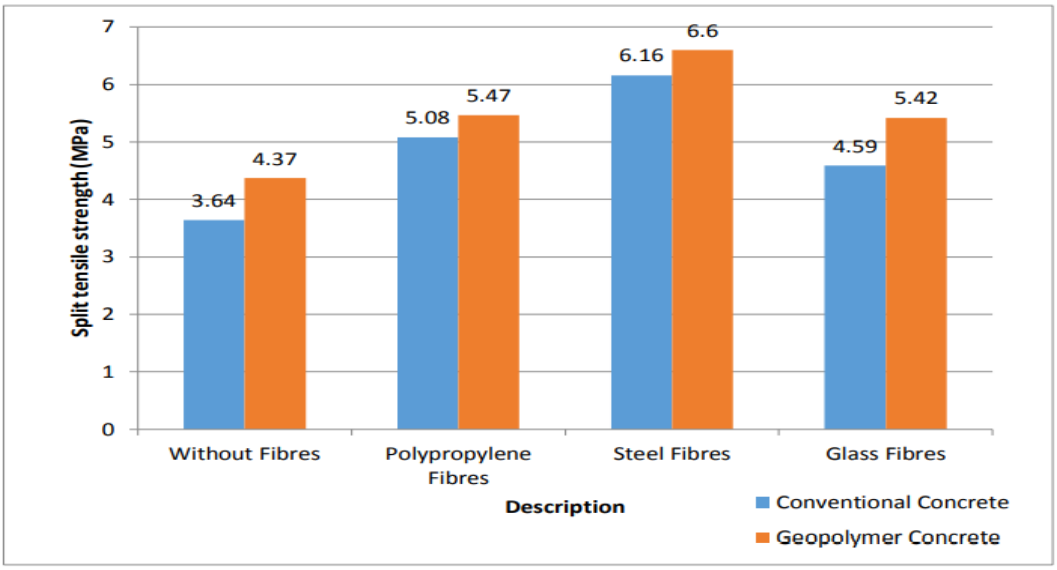

Figure 7. Column Chart Shows Comparison of Split Tensile Strength of Traditional Concrete having different Fibres At 28 Days to Split Tensile Strength Of Geo-polymer Concrete having different Fibres At 28 Days.

Referring above chart, It is clear that Split tensile strength of Geo-polymer concrete exceeds compared to that of traditional concrete. It is showing that the effect of fibres is equivalent on both conventional concrete and Geo-polymer concrete. But even though Geo-polymer concrete has more tensile strength over the conventional concrete, it still is weaker in tension compared to its compressive strength. Using steel fibres however, is increasing the tensile strength by about 40% in GPC.

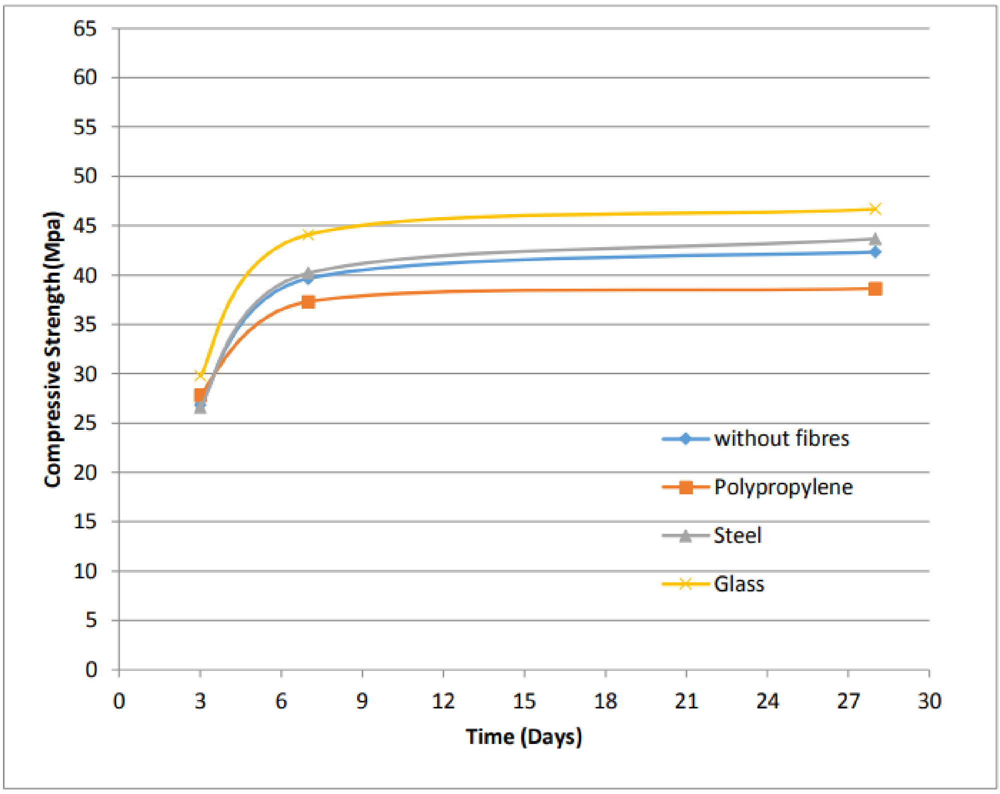

Figure 8. Graph Presenting Result of Fibres on Compressive Strength of Geo-polymer Concrete

Referring the graph above, it shows clear comparison of compressive strength of Geo-polymer concrete having various fibres at 3days, 7days and 28 days duration. Compressive strength with use of glass fibres is giving considerable increase (about 10%) as compared to other fibres.

3. Summary and conclusions:

Further results are presented on the experimental work carried out:

1. The ratio of Water to Geo-polymer solids and water to cement ratio in conventional concrete is analogous to each other and key factor for strength concrete mix.

2. The use of pan/drum mixer is must for casting of Geo-polymer concrete samples since the compressive strength of mix is highly dependent on the effectiveness of mixing. Also, the dry mixing of the source material and aggregates is very important for achieving a uniform and strong concrete mix and hence it should not be neglected.

3. Geo-polymer concrete is quire susceptible to climate changes (temperature and humidity especially) while performing the mixing process. Hence, precautions to be taken while casting at locations where the temperature and humidity remains almost same irrespective of atmospheric change.

4. The final setting time of Geo-polymer concrete is more with respect to conventional concrete. Even after 1 day of exposure to suitable atmosphere (about 27^0c) it did not set fully.

5. In traditional concrete and Geo-polymer concrete with fibres considerably reduced the workability of the mix.

6. The Geo-polymer concrete mix is quite cohesive and it requires use of super- plasticizers to achieve desired workability. The use of sulphonamide naphthalene based superplasticizer upto 2.5% did not lead to any loss of compressive strength.

7. The commonly used super-plasticizers for cement concrete (like ether based or naphthalene formaldehyde based super plasticizers) are not as effective for Geo-polymer concrete.

8. Geo-polymerization reactions takes lesser time than the hydration of cement concrete and there is rapid increase in strengths during 3 days to 7 days in Geo-polymer Concrete, after 7daysincrease in strength is insignificant and Conventional Concrete continuously attaining the strength after 7 days.

9. Moreover, a crucial factor governing the development of strength of the Geo-polymer concrete is the treatment cure regime. Utmost precautions are taken and samples are kept in oven for curing for pre-decided time duration and temperature. The samples must be preferably sealed with plastic bags to prevent moisture loss during curing. After curing period is over, the oven shall be turned off and the samples shall be allowed to stay in the oven for 1-2 hours. Do not remove them and place in the ambient environment because this may create a temperature gradient between the outer surface and inner core portion of the sample leading to additional thermal stresses which may causes cracking of concrete.

10. The mechanical properties inherent to cement concrete and Geo-polymer concrete are influenced in a same way by substituting different types of fibres.

References

[1] Micheal A. Nisbet, Medgar L. Marceau, Martha G. VanGeem; Environment Life Cycle Inventory of Portland Cement Concrete; Portland Cement Association, July 2002; PCA R&D Serial NO. 2137a.

[2] Djwantoro Hardjito, Steenie E. Wallah, Dody M.J. Sumajouw, B. Vijaya Rangan; On the Development of Fly Ash-Based Geo-polymer Concrete; ACI Materials Journal; November-December 2004; Vol: 101, NO.6, MS No.03-367.

[3] A Lloyd and B.V.Rangan; Geo-polymer concrete with Fly-ash; Second International Conference on Sustainable Construction Materials and Technologies, June 28 to June 30, 2010, Italy; ISBN 978-1-4507-1490-7.

[4] Raijiwala D.B, Patil H.S; Geo-polymer Concrete: A Concrete of Next Decade; Journal of Engineering and Research, January-March 2011; eISSN: 0976-7916.

[5] N.A Lloyd and B.V.Rangan; Geo-polymer concrete: A review of development and opportunities; 35thConference on Our World in Concrete & Structures25-27 August 2010, Singapore; Article Online Id: 100035037.

[6] K.A. Anuar, A.R.M. Ridzuan, S. Ismail; Strength characteristics of Geo-polymer Concrete containing Recycled Concrete Aggregate; International Journal of Civil & Environmental Engineering, February 2011; 119601-2323.

[7] D.B Rajiwala and H.S. Patil; Geo-polymer Concrete: A concrete of next decade; Journal of Engineering Research and Studies, March 2011;E-ISSN 00976-7916.

[8] M.I. Abdul Aleem and P.D. Arumairaj; Geo-polymer Concrete - A review; International Journal of Engineering Sciences & Emerging Technologies, Feb 2012; ISSN: 2231-6604.

[9] Matthew Kambic, Joshua Hammaker; Geo-polymer Concrete: The Future of Green Building Materials; University of Pittsburgh, Swanson School of Engineering; March 2012; Reference No: 2099.

[10] Ganpati Naidu, A.S.S.N. Prasad, S. Adiseshu, P.V.V. Satayanarayana; A Study on Strength Properties of Geo-polymer Concrete with Addition of G.B.B.S; International Journal of Engineering Research and Development, July 2012; eISSN: 2278-067X53.

[11] B.J. Mathew, M. Sudhakar, C. Natarajan; Strength, Economic and Sustainability Characteristics of Coal Ash - GGBS Based Geo-polymer Concrete; International Journal of Computational Engineering Research, January 2013; ISSN 2250-3005.

[12] Prof. More Pratap Kishanrao; Design of Geo-polymer Concrete; International Journal of Innovative Research in Science, Engineering and Technology, May 2013; ISSN: 2319-8753.

[13] M.C.M. Nasvi, P.G. Ranjith, J. Sanjayan; Effect of different mix compositions on apparent carbon dioxide permeability of Geo-polymer: Suitability as well cement for sequestration wells; June 2013; ISSN: 0306-2619.

[14] S.H. Sanni, R.B. Khadiranaikar; Performance of Alkaline Solutions On Grades of Geo-polymer Concrete; International Journal of Research in Engineering and Technology, November 2013;eISSN: 2319-1163.

[15] P. Eswaramoorthi, G.E. Arunkumar; Fibers Study On Properties Of Geo-polymer Concrete With Polypropylene; International Refereed Journal of Engineering and Science, February 2014; eISSN: 2319-183X.