International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 4, Special Issue 4, June 2014)

International Conference on Advances in Civil Engineering and Chemistry of Innovative Materials (ACECIM'14)

Geopolymer Concrete Using Different Source Materials

Sonal P. Thakkar[1], Darpan J. Bhorwani[2], Rajesh Ambaliya[3]

[1]Assistant Professor, Department of Civil Engineering, Institute of Technology, Nirma University
[2,3]Post-Graduate Students, Institute of Technology, Nirma University

[1] sonal.thakkar@nirmauni.ac.in
[2] bhorwanid@gmail.com

Abstract— **Concrete is the most abundant used manmade material in the world. One of the main ingredients of concrete mixture is Ordinary Portland Cement (OPC) which is the second most utilized material after water. The amount of the CO_2 released during the manufacturing of OPC is nearly one ton for every ton of OPC produced and is responsible for approximately 7% of the world's carbon dioxide emissions. In order to create a more sustainable world, innovators are developing and using a greener building material, one of them is geopolymer Concrete. This paper discusses various combination of Ground Granulated Blast Furnace Slag (GGBFS) and Fly Ash, as source material, to produce geopolymer concrete at ambient temperature. It has been generally accepted that heat treatment is required for producing geopolymer concrete which is considered a drawback affecting its applications. In this paper variation of source material i.e. various combination of Fly ash and GGBFS is done to achieve compressive strength for medium grade of concrete of M-25. Oven and ambient curing is done. It is found that geopolymer concrete with GGBFS in Fly ash as increases it gains strength and shows good strength at 3, 7 and 28 days even at ambient curing with increase in GGBFS content. While only slag based geopolymer concrete has higher strength at oven curing while rate of gain of strength is slower at ambient temperature as period increases.**

Keywords— **Ambient Curing, Fly Ash, Geopolymer, GGBFS**

I. INTRODUCTION

It is widely known that the production of Portland cement consumes considerable energy and at the same time contributes a large volume of CO_2 to the atmosphere. However, Portland cement is still the main binder in concrete construction prompting a search for more environmentally friendly materials [1]. One possible alternative is the use of alkali-activated binder using industrial by-products containing silicate materials.

Davidovits proposed that an alkaline liquid which can react with the silicon (Si) and aluminum (Al) in a source material of geological origin or industrial by product can be used to produce binders. Since chemical reaction in this process is of polymerization therefore, he coined it as "Geopolymer" [2, 3]. Thus geopolymer constitutes of two main compounds namely source materials and alkaline liquids. The alkaline liquids are from soluble alkali metals which are mainly sodium or potassium based. Sodium hydroxide (NaOH) or Potassium Hydroxide (KOH) and Sodium silicate or Potassium silicate are most widely used alkaline liquid. The primary difference between concrete produced using Portland cement and geopolymer concrete is the binder. Geopolymer consists of silicon and aluminum atoms bonded via oxygen into a polymer network. Geopolymer are prepared by dissolution and poly condensation reactions between alumino silicate binder and an alkaline silicate solution such as a mixture of an alkali metal silicate and metal hydroxide is obtained. Like Portland cement concrete, the coarse and fine aggregates occupy about 75% to 80% of mass of geopolymer concrete. Therefore the influence of aggregates, such as grading, angularity and strength, are considered to be the same as in case of Ordinary Portland concrete. [4]

The most common industrial by-products used as binder materials are fly ash (FA) and ground granulated blast furnace slag (GGBFS). GGBFS has been widely used as a cement replacement material due to its latent hydraulic properties, while fly ash has been used as a pozzolanic material to enhance the physical, chemical and mechanical properties of cements and concretes. Increasing emphasis on the environmental impacts of construction materials such as Portland cement has provided immense thrust in recent years to the increased utilization of waste and by-product materials in concretes.

Activation of alumina silicate materials such as fly ash, blast furnace slag, and metakaolin using alkaline solutions to produce binders free of Portland cement is a major advancement towards increasing the beneficial use of industrial waste products and reducing the adverse impacts of cement production.

It has been reported that fly ash and ground granulated blast furnace slag (GGBFS) are very effective as starting materials for cement- free binder concretes because of the soluble silica and alumina contents in these materials that undergo dissolution, polymerization with the alkali, condensation on particle surfaces, and solidification that eventually provides strength and stability to these matrices.[4]

This study aims to synthesize geopolymer concrete using combination of fly ash and GGBFS. Fly ash was replaced in varying percentages by GGBFS to understand the effect on compressive strength [4, 5, 6].

II. Experimental Program

A. Materials

Fly ash used in this study is low calcium class F Fly ash from Dirk India private limited under the name of the product POZZOCRETE 60. Ground granulated blast furnace slag used is obtained from JSW cements. The chemical and physical properties of GGBFS and Fly Ash used are shown in the Table I and Table II respectively [7, 8]. The most commonly used alkaline activators are a mixture of sodium hydroxide (NaOH) with sodium silicate (Na_2SiO_3). For preparation of alkaline liquids, sodium hydroxide with 98% purity in the form of flakes and sodium silicate were obtained from local manufacturer. Locally available 10 mm and 20 mm crushed aggregates have been used as coarse aggregates. Locally available river sand is used as fine aggregate in the mixes [9, 10].

TABLE I
CHEMICAL PROPERTY OF GGBFS

Sr. No.	Property	Value
1	Loss on Ignition %	0.07
2	Silica (SiO_2) %	35.00
3	Iron oxide (Fe_2O_3) %	0.5
4	Aluminum (Al_2O_3) %	10
5	Calcium oxide (CaO) %	37.00
6	Magnesium oxide (MgO) %	8
7	Manganese oxide (MnO) %	0.07
8	Sulfur (S_2) %	0.54

TABLE II
PHYSICAL PROPERTY OF FLY ASH

Sr. No.	Property	Value
1	Colour	Light grey
2	Specific surface area (Blaine) m^2/kg	340
3	Lime reactivity N/mm^2	5.48
4	Loss on ignition (max) %	1.60
5	$SiO_2 + Al_2O_3 + Fe_2O_3$	92.49
6	SiO_2	57.30
7	MgO	2.13
8	SO_3	1.06
9	Na_2O	0.73
10	Total Chlorides	0.029

B. Mix design and specimens preparation

Geopolymer concrete was casted for M 25 grade of compressive strength. Generally, geopolymer concrete mix design is based on achieving density of 2400 kg/m^3.

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 4, Special Issue 4, June 2014)
International Conference on Advances in Civil Engineering and Chemistry of Innovative Materials (ACECIM'14)

Mixing of Fly ash and GGBFS with 375 kg per cubic meter was designed. The alkaline liquid was sodium silicate, while sodium hydroxide was used as alkaline activator. The liquid/binder ratio was kept at a constant of 0.4. The fly ash/slag ratios was varied from 90/10, 70/30 and 50/50 with symbols A, B, and C respectively. The mix design shown in Table III details the quantities used for casting different mix with varying percentage of fly ash and slag. The alkaline liquid ratio was kept constant at 2[4,5].The specimens were cast and kept in steel moulds for 1 day as the rest period, and then kept in oven at 90^0 C for two different period of time viz. 24 h and 48 h. Then the specimens were demoulded and kept at room temperature. Ordinary Portland cement concrete cubes were casted for same grade for comparison.

TABLE III
MIX DESIGN

Materials		A (kg/m^3)	B (kg/m^3)	C (kg/m^3)	D (kg/m^3)
Coarse Aggregate	20 mm	614.25	614.25	614.25	614.25
	10 mm	409.5	409.5	409.5	409.5
Fine Aggregates		551.25	551.25	551.25	551.25
Fly Ash		337.5	262.5	187.5	0
Slag		37.5	112.5	187.5	375
Sodium hydroxide		50(10 M)	50(10 M)	50(10 M)	57(8 M)
Sodium Silicate		100	100	100	114
Extra water added		33.75	33.75	33.75	42.86
Superplasticizer		3.375	3.375	3.375	4.29

C. Compressive Strength Test

The compressive strength of geopolymer concrete has been evaluated on hydraulic testing machine. For the compressive strength test, cubes of size 150mm x 150mm x 150 mm are tested in compression in accordance with the test procedures given in IS : 516-1959[11].

III. RESULTS AND DISCUSSION

In this investigation, to study the compressive strength properties of geopolymer concrete, four different mixes were prepared by replacing fly ash with slag and their results are presented below.

TABLE IV
COMPRESSIVE STRENGTH FOR OVEN CURING

Mix	3 Days (MPa)	7 Days (MPa)	28 Days (MPa)
Mix A	4.9	6.02	9.35
Mix B	8.61	11.67	19.85
Mix C	14.8	22.22	30.67
Mix D	22.2	27.1	33.8
Control Concrete	12.6*	22.12*	31.64*

**Normal curing procedure is followed*

Different curing techniques were applied on the casted specimen i.e., Oven Curing and ambient Curing. Control concrete was casted according to IS 10262: 2009 and cured in water.

It is observed in Table IV & Table V, in oven curing and ambient curing as the slag content increases, the compressive strength also increases. The geopolymer concrete synthesized with only slag as the sole binder develops at 3 days strength of normal control concrete at 7 days. However, the strength gain is little slow at later stages. Table V shows results for ambient cured samples for 3 days, 7 days and 28 days respectively for combination of fly ash and GGBFS.

TABLE V
COMPRESSIVE STRENGTH FOR AMBIENT CURING

Mix	3 Days (MPa)	7 Days (Mpa)	28 Days (Mpa)
Mix A	1.3	2.8	10.67
Mix B	3.70	5.56	19.41
Mix C	11.9	14.4	27.80
Mix D	18.2	21	24.84
Control Concrete	12.6*	22.12*	31.64*

**Normal curing procedure is followed*

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 4, Special Issue 4, June 2014)
International Conference on Advances in Civil Engineering and Chemistry of Innovative Materials (ACECIM'14)

It is observed that at ambient temperature the rate of gain of strength is slow, but it is nearer to target strength at 28 days for combination of fly ash and slag geopolymer concrete, while faster for slag in initial period but gain of strength over age is slow after 7 days at ambient curing. Figure 1 and 2 represent 3 days compressive strength for oven and ambient curing, Figure 3 and 4 represent 7 days compressive strength and Figure 5 and 6 represent graphical comparison of compressive strength of oven cured and ambient cured samples 28 days respectively. It is seen that oven curing gives more strength as compared to ambient curing.

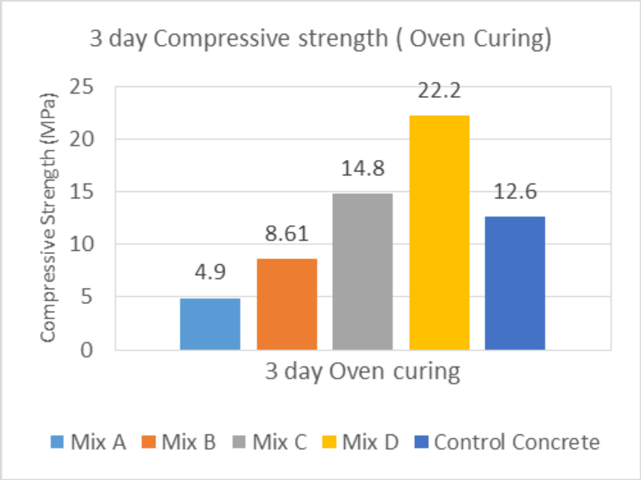

Figure I: 3 days compressive Strength (Oven Curing)

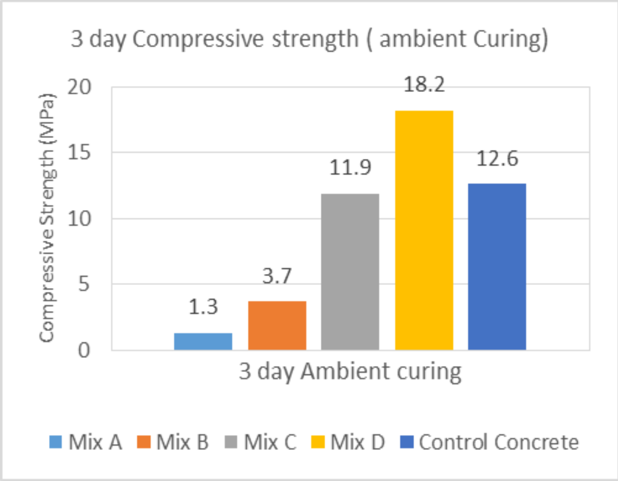

Figure II: 3 days Compressive Strength (Ambient Curing)

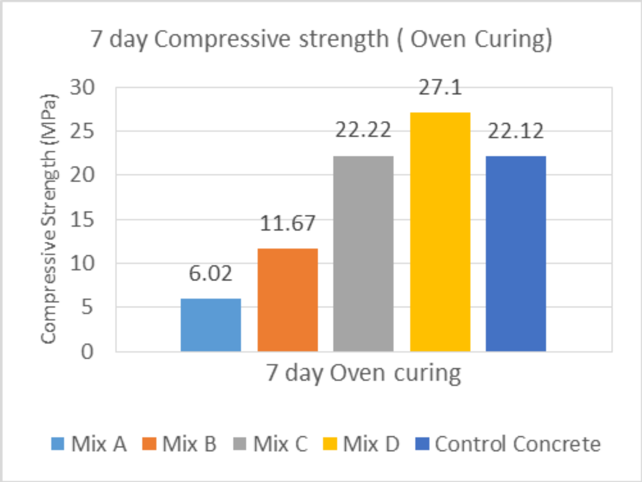

Figure III: 7 days Compressive Strength (Oven curing)

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 4, Special Issue 4, June 2014)
International Conference on Advances in Civil Engineering and Chemistry of Innovative Materials (ACECIM'14)

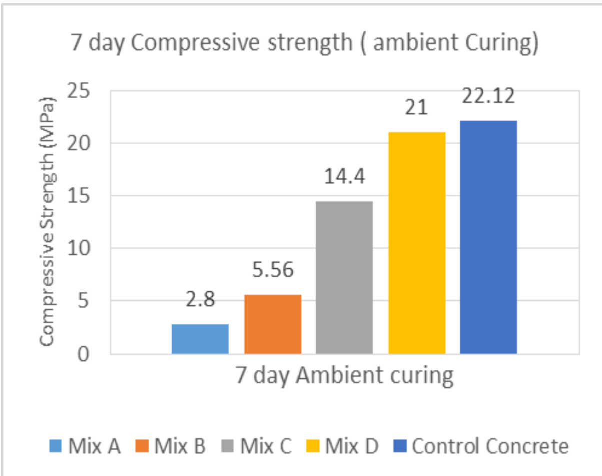

Figure IV: 7 days of Compressive strength (Ambient Curing)

Also the mix with 50:50 ratio, shows higher compressive strength than that of the normal control concrete under heat curing.

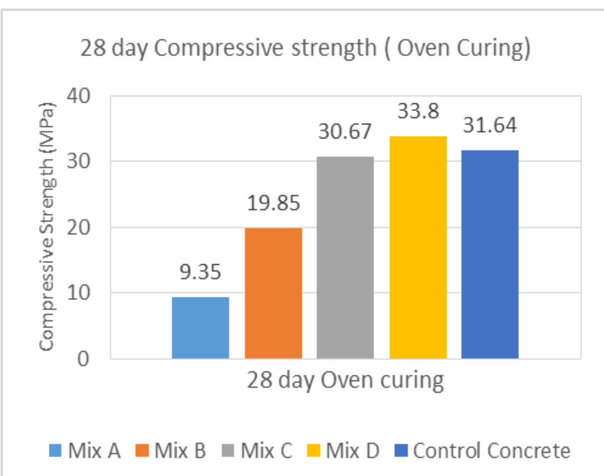

Figure V: 28 days Compressive strength(Oven curing)

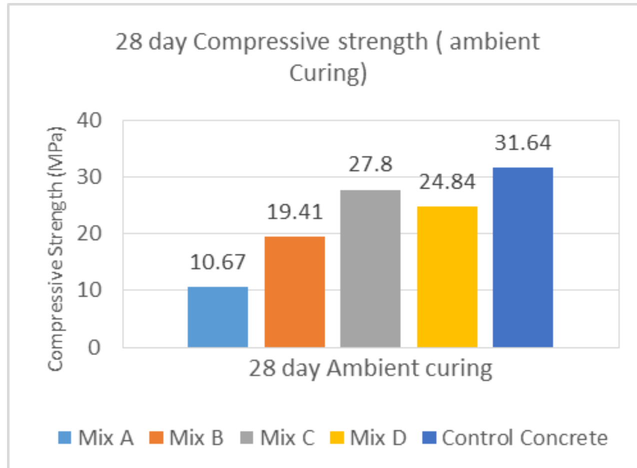

Figure VI: 28 days Compressive Strength (Ambient Curing)

This study shows that within current mix-design trends, geopolymer concrete made from FA and GGBFS used in combination shows better compressive strength for ambient curing. As following graphs indicate that ambient curing achieved for geopolymer concrete with equal proportions for fly ash and GGBFS have strength in range for control concrete for same grade.

But the geopolymer concrete with fly ash/slag ratio of 90/10 and 70/30 shows low strength as compared to that of normal control concrete at both ambient and oven curing. The normal control concrete of M-25 grade has been casted and its compressive strength at 3 days, 7 days and 28 days is shown below in fig 7.

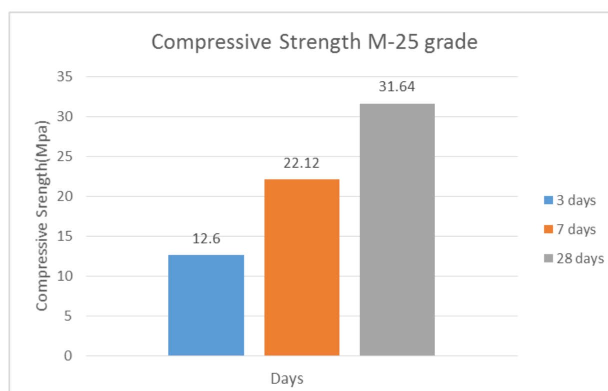

Figure VII: 3, 7 and 28 days strength of control concrete

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 4, Special Issue 4, June 2014)

International Conference on Advances in Civil Engineering and Chemistry of Innovative Materials (ACECIM'14)

The summary of the ambient and oven cured specimens compressive strength is shown in figure 8 and 9.

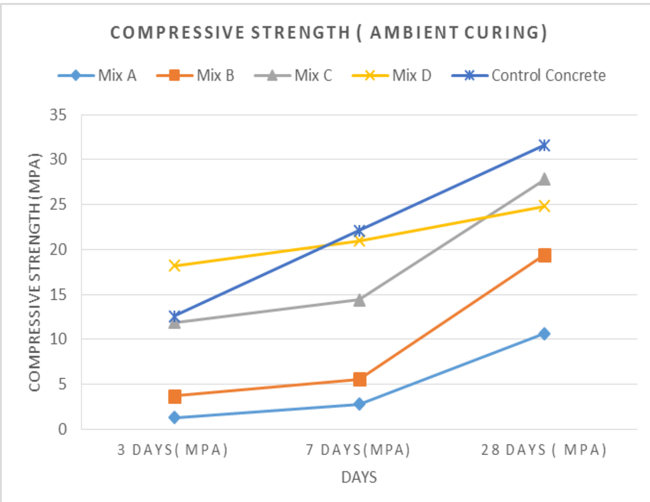

Figure VIII: Compressive strength in Ambient curing

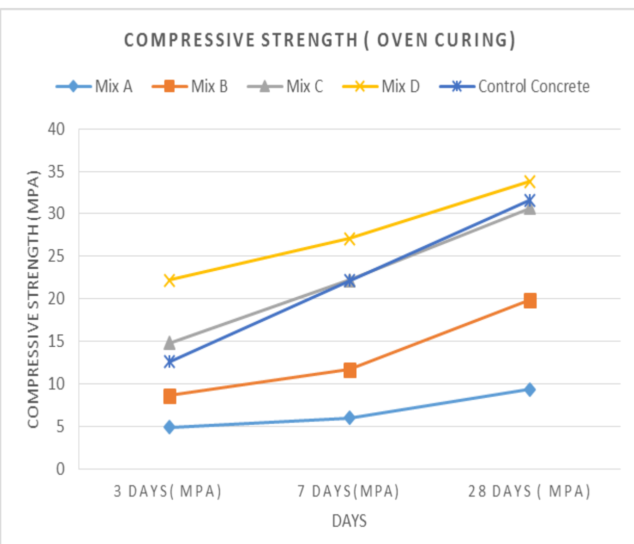

Figure IX: Compressive Strength in Oven curing

IV. CONCLUSION

The following conclusions can be drawn from the study carried out:

1. Strength of geopolymer concrete for oven curing is more than ambient cured geopolymer concrete at 3, 7 and 28 days.
2. The geopolymer concrete using GGBFS as a sole binder achieves more strength than that of normal control concrete when oven curing is done. A higher concentration of GGBFS result in higher compressive strength of geopolymer concrete.
3. At 7 days when combination of 50:50 Fly ash and GGBFS content is used the strength is nearly equal to control concrete of same age with oven curing.
4. Geopolymer concrete using various combinations of fly ash and GGBFS gives optimum dosage at 50:50 proportion of each of GGBFS and fly ash.
5. As the percentage of slag increase, its strength also increases and significant strength can be achieved even at ambient curing.
6. At 28 days for 50:50 Fly Ash and GGBFS combination content the oven cured and ambient cured samples yield strength that is nearly equal to 25 MPa indicating that geopolymer concrete can achieve desired strength at ambient curing.

Thus judicious mixture of GGBFS and Fly ash can be used to make geopolymer concrete at ambient temperature for practical field applications.

Acknowledgement

Authors express sincere thanks to Nirma University for providing necessary funds and equipment to carry out research work.

REFERENCES

[1] Malhotra V. M., 2002, Introduction: Sustainable development and concrete technology, ACI Concrete International, 24(7).

[2] The Proceedings of Geopolymer 2005 World Congress**,** 4th Int. Conference on geopolymers, edited by J. Davidovits, Geopolymer Institute, France 2006

[3] Davidovits J, 1994, "Properties of Geopolymer cement,", Proceedings first international conference on Alkaline cements and concretes, scientific research institute on binders and materials", Kiev state technical university, Kiev, Ukraine, pp. 131-149.

[4] D. Hardjito and B. V. Rangan, 2005,"Development & Properties of Low calcium Fly ash based Geopolymer concrete" Research report Curtin University, Australia.

[5] Adam, A.A, 2009, "Strength and Durability Properties of Alkali Activated Slag and Fly Ash-Based Geopolymer Concrete", Thesis. RMIT University.

[6] Talling, B and Brandstetr, J.,1989," Present state and future of alkali-activated slag concretes, Proceedings of the Third International Conference, Trondheim, Norway "ACI SP-114, Vol. 2, pp 1519-1546

[7] IS: 3812-1981, Specification for fly ash for use as pozzolana and admixture, Bureau of Indian Standards, New Delhi, (1981).

[8] Catalogue of POZZOCRETE 60, Dirk India private limited, www. Pozzocrete.co.in

[9] IS: 383-1970, "Specification for coarse and fine aggregates from the natural sources for concrete", Bureau of Indian Standards, New Delhi Sannella, M. J. 1994 Constraint Satisfaction and Debugging for Interactive User Interfaces. Doctoral Thesis. UMI Order Number: UMI Order No. GAX95-09398., University of Washington.

[10] IS: 2386-1963, "Methods of test for aggregate for concrete, Bureau of Indian Standards", New Delhi, 1963. Brown, L. D., Hua, H., and GAO, C. 2003. A widget framework for augmented interaction in SCAPE.

[11] IS: 516- 1959, "Methods of tests for strength of concrete," Bureau of Indian Standards, New Delhi, 1959.