AN EXPERIMENTAL STUDY ON STRENGTH ANALYSIS OF GEOPOLYMER CONCRETE

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ABSTARCT

Concrete is the most abundant manmade material in the world. One of the main ingredients in a normal concrete mixture is Portland cement. The production of cement from industries emits greenhouse gases and CO_2. The production of 1ton of cement emits approximately one ton of CO_2 and it is responsible for 65% of global warming. In order to reduce the usage of cement, supplementary cementing materials like fly ash and GGBS and instead of water, Alkali solution have been introduced in the name of Geopolymer concrete. Geopolymer concrete is also much more durable that ordinary concrete due to its resistance to corrosion. It is also much stronger than ordinary concrete. Geopolymer concrete is a revolutionary sustainable building material that will pave the way for green building. In this paper an attempt is made to study flexural and elastic properties of geopolymer concrete using low calcium fly ash replacing with GGBS in 5 different percentages as (100% : 0%), (90% :10%), (80% : 20%), (70% : 30%), (60% : 40%). Sodium silicate (103 kg/m^3) and sodium hydroxide of 8 molarity (41kg/m^3) solutions were used as alkaline solution in all 5 different mixes. The investigations were carried for the Compressive strength, Split tensile strength, Flexural strength test, Modulus of Elasticity, Poisson's ratio on the concrete specimens. The specimens were cured at ambient temperature and tested at 7th and 28th days.

INTRODUCTION

Concrete is one of the most widely used construction material, it is usually associated with Portland Cement as the main component for making concrete. Ordinary Portland Cement (OPC) is conventionally used as the primary binder to produce concrete.

Production of Portland cement is currently exceeding 2.6 billion tons per year worldwide and growing at 5 percent annually. Portland cement production is a major contributor to carbon-di-oxide emissions as an estimated five to eight percent of all human-generated atmospheric carbon-di-oxide worldwide comes from the concrete industry. The global warming is caused by the emission of greenhouse gases, such as carbon-di-oxide, to the atmosphere by human activities. Among the greenhouse gases, carbon-di-oxide contributes about 65% of global warming. The amount of the carbon dioxide released during the manufacture of Ordinary Portland Cement due to the calcinations of limestone and combustion of fossil fuel is approximately in the order of one ton for every ton of Ordinary Portland Cement produced.In terms of reducing the global warming, the geo-polymer technology could reduce the carbon-di-oxide emission to the atmosphere caused by Cement about 80%.

LITERATURE REVIEW

[1] Prof.M.A.Bhosale and Prof.N.N.Shinde.(2012), 'Geopolymer Concrete by Using Fly Ash in Construction'. In this paper, the mechanism of activation of a fly ash (no other solid material was used) with highly alkaline solutions is described. These solutions, made with NaOH, Na2Sio3.This paper, report on the study of the processing of geopolymer using fly ash and alkaline activator with geopolymerization process. The factors that influence the early age compressive strength such as molarities of sodium hydroxide

(NaOH) have been studied. Sodium hydroxide and sodium silicate solution were used as an alkaline activator. These studies comprises the comparison of the ratios of Na2Si03&NaOH at the values 0.39&2.51.The geopolymer paste samples were cured at 60°C for 1 day and keep in room temperature until the testing days. The compressive strength was done at 7 and 28 days. The result showed that the geopolymer paste with NaOH concentration, compressive strength increase with molarities increases.

[2] Dattatreya J K , Rajamane NP , Sabitha D , Ambily P S , Nataraja MC (2011), 'Flexural behaviour of reinforced Geopolymer concrete beams'. In this paper, studies carried out on the behaviour of room temperature cured reinforced GPC flexural members are reported. A total of eighteen beams were tested in flexure. Three conventional concrete mixes and six GPC mixes of target strength ranging from 17 to 63 MPa and having varying combinations of fly ash and slag in the binder phase were considered. The reinforcement was designed considering a balanced section for the expected characteristic strength. All the specimens were tested under two point static loading. The studies demonstrated that the load carrying capacity of most of the GPC beams was in most cases marginally more than that of the corresponding conventional OPCC beams. The deflections at different stages including service load and peak load stage were higher for GPC beams. However, the ductility factor was comparable to that of OPCC beams. The studies showed that the conventional RC theory could be used for reinforced GPCC flexural beams for the computation of moment capacity, deflection, and crack width within reasonable limits The GPC mixes developed compressive strength of 17 to 63 MPa compared to 35 to 52 MPa of OPCC. The flexural strength of GPC mixes is found to be close to that predicted from IS: 456 formula and compares well with the strength of OPCC specimens. The elastic modulus is significantly lower for GPCs and ACI 318 prediction seems to be closer to measured elastic modulus compared to IS: 456. This is attributed to the lower aggregate volume fraction of the GPC mixes used.

[3]**DjwantororHardjito,SteeleE.Wallah,B.Vijayarangan, and DodyM.J.Sumajouw, ACI Materials Journals (2013), ' On the development of Fly ash based Geopolymer concrete'**. The paper presents the higher concentration (in terms of Molar) of sodium hydroxide solution result in a higher compressive strength of Geopolymer concrete. Higher the ratio of sodium silicate to sodium hydroxide liquid ratio by mass, higher is the compressive strength of the Geopolymerconcrete.Longer curing time in the range of 6 to 96 hours (4 days) produces larger compressive strength of the Geopolymer concrete. As the ratio of water to Geopolymer solids by mass increases, the compressive strength of the concrete decreases.

DjwantoroHardjito (2005), 'Studies on Fly Ash-Based Geopolymer Concrete'. Fly ash was chosen as the basic material to be activated by the geopolimerization process to be the concrete binder, to totally replace the use of Portland cement. The binder is the only difference to the ordinary Portland cement concrete. To activate the Silicon and Aluminium content in fly ash, a combination of sodium hydroxide solution and sodium silicate solution was used. Napthalene-based superplasticiser was found to be useful to improve the workability of fresh fly ash-based geopolymer concrete, as well as the addition of extra water. The main parameters affecting the compressive strength of hardened fly ash-based geopolymer concrete are the curing temperature and curing time, the molar H2O-to-Na2O ratio, and mixing time. Fresh fly ash-based geopolymer concrete has been able to remain workable up to at least 120 minutes without any sign of setting and without any degradation in the compressive strength. Providing a rest period for fresh concrete after casting before the start of curing up to five days increased the compressive strength of hardened concrete. The test results showed that the elastic properties of hardened fly ash-based geopolymer concrete, i,e. the modulus of elasticity, the Poisson's ratio, and the indirect tensile strength, are similar to those of ordinary Portland cement concrete. The stress-strain relations of fly ash-based geopolymer concrete fit well with the expression developed for ordinary Portland cement concrete.

[4] S.J.Foster&T.S.Ng, Futures in Mechanics of structures and materials (2009), 'Development of high performance Geopolymerconcrete'.The paper concludes, the equations developed for elastic modulus of conventional concrete cannot be applied to that of GPC, the density and the poison's ratio of Geopolymer concrete are similar to those of OPC concrete. Compressive strength of Geopolymer concrete of 90 MPa, and more , are achievable. The addition of slag in the Fly ash based Geopolymer concrete is found to be beneficial to its strength development . For a given compressive strength, Geopolymer concrete has a significantly low elastic modulus then an equivalent OPC concrete. A model for calculation of the elastic modulus based on a two phase material approach is presented and shown to provide a good correlation.

[5] Ganapati Naidu., A.S.S.N.Prasad, S.Adiseshu3, P.V.V.Satayanarayana(2013), 'A Study on Strength Properties of Geopolymer Concrete with Addition of G.G.B.S'. Based on the experimental work the following conclusions are drawn: Higher concentrations of G.G.B.S (Slag) result in higher compressive strength of geopolymer concrete. Mixing of G.G.B.S was tested up to 28.57%, beyond that immediate setting was observed. There is no necessity of exposing geopolymer concrete to higher temperature to attain maximum strength if minimum 9% of fly ash is replaced by GGBS. Compressive strength of geopolymer concrete increases with increase in percentage of replacement of fly ash with GGBS. Fly ash was replaced by GGBS up to 28.57%, beyond that fast setting was observed. A maximum of 25% loss in compressive strength was observed when geopolymer concrete exposed to a temperature of 500^{o}C for two hours. 90% of compressive strength was achieved in 14 days. The average density of geopolymer concrete was equal to that of OPC concrete.

[6] **R. B. Khadiraniakar and Shankar H. Sanni (2014), 'Stress Strain Characteristics for Geopolymer Concrete – An Experimental Approach'**. This study focus the experimental work done in determining the stress, strain, poisson's ratio and modulus of elasticity for geopolymer concrete. The molarity used for the preparation of geopolymer specimens was 12. The grade chosen for the investigation were M-30, M-40, M-50 and M-60. The alkaline solution used for present study is the combination of sodium silicate and sodium hydroxide solution with the ratio of 2.50. The test specimens were 150x150x150 mm cubes, 100x200 mm cylinders cured in ambient room temperature. The experimental results reveal that the poisson's ratio was in the range of 0.20 to 0.24 and modulus of elasiticity was in the range of 27 to 29 N/mm^2. The obtained values are hence in par with the equations developed for ordinary Portland cement concrete in compression.

[7] **Dr.P.Priya Rachel (2015), 'Study on Geopolymer Concrete Block'**. An experimental investigation was conducted to study the durability properties of fly ash-based geopolymer concrete and also to critically assess a stress-strain model using masonry prisms constructed from different bricks. Behaviour of unreinforced geopolymer masonry prism is compared with ordinary clay brick masonry prism. Unreinforced clay brick prism and geopolymer brick prism using brick size of 225 x 105 x 70 mm were cast with 10M and12M NaOH concentration for different aspect ratio. The test results showed that residual compressive strength for GPC specimenafter immersion in acid solution for both curing conditionwas found to vary from 15.09 MPa to 20.14MPa and20.09Mpa to 28.1MPa. The residual split tensile strength for GPC specimen afterimmersion in 3% sulphuric acid for both curing conditionwas found to vary from 1.81MPa to 3.36MPa and from2.45MPa to 3.99MPa. Using linear regression analysis a simple relationships have been identified for obtaining the modulus of elasticity of bricks and masonry prism from their corresponding compressive strengths. It was observed from the results that geopolymer brick masonry prism possess higher load carrying capacity.

ANALYSIS OF DATA

Fly ash

Fly ash is one of the most abundant materials on the Earth. It is also a crucial ingredient in the creation of geopolymer concrete due to its role in the geopolymerization process. Fly ash is a powdery pozzolan. A pozzolan is a material that exhibits cementitious properties when combined with calcium hydroxide. Fly ash is the main byproduct 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 is created from the burning of either anthracite or bituminous coal. This Class of fly ash has little to no self-cementing properties and contains very little calcium oxide (also known as lime). In order to apply Class F fly ash in concrete, it must be combined with some type of cementing agent, such as Portland cement, and must also be combined with an air-entraining admixture. This is not a very economic process if it is going to be made into ordinary concrete. Class C fly ash, on the other hand, is produced through the combustion of lignite or sub bituminous coal. Unlike Class F fly ash, it has self-cementing properties and a much higher lime concentration which makes it ideal for use in ordinary Portland cement based concrete.

Fig 1.1 Flyash

Table 1.1 Chemical Composition OfFly Ash

Oxides	**Percentage**
Sio_2	52.0
Al_2O_3	33.9
Fe_2O_3	4.0
CaO	1.2
K_2O	0.83
Na_2O	0.27
SO_3	0.28
LOI	6.23
SiO_2/Al_2O_3	1.5

Table 1.2 Properties of Fly ash

SNo.	**Property**	**Value**
1	Specific Gravity	2.44
2	Fineness	227.8 g/m^2
3	Fineness Modulus	5
4	Density	1029.7 Kg/m^3

FRESH GEO-POLYMERS AND MANUFACTURING PROCESS

Several factors have been identified as important parameters affecting the properties of geo-polymers. Palomo et al (1999) concluded that the curing temperature was a reaction accelerator in fly ash-based geo-polymers, and significantly affected the mechanical strength, together with the curing time and the type of alkaline liquid. Higher curing temperature and longer curing time were proved to result in higher compressive strength. Alkaline liquid that contained soluble silicates was proved to increase the rate of reaction compared to alkaline solutions that contained only hydroxide.

Van Jaarsveld et al (2002) concluded that the water content, and the curing and calcining condition of kaolin clay affected the properties of geo-polymers. However, they also stated that curing at too high temperature caused cracking and a negative effect on the properties of the material. Finally, they suggested the use of mild curing to improve the physical properties of the material. In another study, van Jaarsveld et al (2003) stated that the source materials determine the properties of geo-polymers, especially the CaO content, and the water-to-fly ash ratio.

Based on a statistical study of the effect of parameters on the polymerization process of metakaolin-based geo-polymers, Barbosa et al (1999; 2000) reported the importance of the molar composition of the oxides present in the mixture and the water content. They also confirmed that the cured geo-polymers showed an amorphous microstructure and exhibited low bulk densities between 1.3 and 1.9.

Based the study of geo-polymerization of sixteen natural Si-Al minerals, Xu and van Deventer (2000) reported that factors such as the percentage of CaO, K_2O, and the molar Si-to-Al ratio in the source material, the type of alkali liquid, the extent of dissolution of Si, and the molar Si-to-Al ratio in solution significantly influenced the compressive strength of geo-polymers.

Table 1.3 Proportion Of Adding Cementitious Materials For Preparation Of Geopolymer Concrete

MIX ID	BINDER (%)	
	FLYASH	GGBS
M1	100	-
M2	90	10
M3	80	20
M4	70	30
M5	60	40

RESULTS AND DISCUSSIONS

GENERAL

In this chapter, results and discussion based on the experimental investigation carried out on the compressive, split tensile, flexural strength, modulus of elasticity and poison's ratio tests on Geo-polymer concrete were presented.

COMPRESSIVE STRENGTH TEST

From the test results, it was observed that the maximum compressive strength was obtained for mix with 30% GGBS and 70% flyash.

Table 5.1 Compressive Strength Test results

MIX ID	FL YA SH (%)	GGB S (%)	Compressive strength N/mm^2	
			7th Day	28th Day
M1	100	-	11.88	17.55
M2	90	10	17.09	22.97
M3	80	20	24.85	35.32
M4	70	30	38.33	44.58
M5	60	40	40.77	46.55
CM	-	-	26.67	37.85

SPLIT TENSILE STRENGTH TEST

It was observed that the maximum split tensile strength was obtained for mix M2 with 30 % GGBS and 70% flyash.

Table 5.2 Split Tensile Strength of Geopolymer Concrete

MIX ID	Binder (%)		Split tensile strength (N/mm^2)
	FLYASH	GGBS	28th Day
M1	100	-	2.15
M2	90	10	4.25
M3	80	20	4.97
M4	70	30	5.67
M5	60	40	7.13
CM	-	-	5.25

FLEXURAL STRENGTH TEST

The results of flexural strength of concrete at the age of 28 days are presented in Table. It is observed that when the percentage of GGBS increases, the flexural strength of concrete also increases. On the contrary, the strength decreases when the percentage of flyash increases.

Table 5.3 Flexural strength values of Geopolymer Concrete

MIX ID	Binder (%)		Flexural strength (N/mm^2)
	FLYASH	GGBS	28th Day
M1	100	-	3.16
M2	90	10	4.47
M3	80	20	5.28
M4	70	30	6.10
M5	60	40	6.97
CM1	-	-	5.65

Fig 5.3 Bar chart of Flexural strength for Geopolymer Concrete

ELASTIC PROPERTIES :

MODULUS OF ELASTICITY

MIX ID	Binder (%)		Modulus of Elasticity (GPa)
	FLYASH	GGBS	28th Day
M1	100	-	27.33
M2	90	10	30.73
M3	80	20	32.54
M4	70	30	33.76
M5	60	40	35.68

Table 5.4 Modulus of Elasticity values of Geopolymer Concrete

CONCLUSIONS

Based on the experimental investigation the following conclusions are listed below:

[1] From the test results, it was observed that the maximum strength was obtained for mix with 30% GGBS and 70% flyash.

[2] As the strength of concrete increases, there is decrease in the average value of Poisson's ratio.

[3] The Modulus of elasticity values increases with increase in compressive strength of geopolymer concrete.

SCOPE FOR FUTURE WORK

[1] Studies can be made on its durability properties.

[2] Fiber reinforced Geopolymer composites may be considered a solution to improve flexural strength and fracture toughness.

[3] Different structural elements like Geopolymer Concrete Beam, Reinforced Geopolymer Concrete Beam, Reinforced Geopolymer Concrete Columns, Reinforced Beam Column joints shall be cast for the above mentioned concentrations of Sodium Hydroxide solution and curing conditions and tested.

REFERENCES

1. R.Anuradha, R.Venkatasubramani and B.V.Rangan(2012)"Modified guidelines for geopolymer concrete mix design using Indian Standard" – Asian Journal of Civil Engineering(Building and Housing), Volume 13.

2. M. I. Abdul Aleem, P. D. Arumairaj,(2013) "GEOPOLYMER CONCRETE-A REVIEW", International Journal of Engineering Sciences & Emerging Technologies, Feb 2012. ISSN: 2231 – 6604 Volume 1, Issue 2.

3. T.Bakharev ,J.G.Sanjayan and Y.B.Chen**,**(2003)**,** Resistance of alkali-activated slag concrete to acid attack, Cement Concrete Research 33 pp. 1607–1611.

4. Prof.M.A.Bhosale, Prof.N.N.Shinde(2012), **"**Geopolymer Concrete by Using Fly Ash in Construction", IOSR Journal of Mechanical and Civil Engineering (IOSRJMCE) ISSN : 2278-1684 Volume 1, Issue 3 (July-August 2012), PP 25-30.

5. D. Bondar, C. J. Lynsdale, N. B. Milestone, N. Hassani, and A. A. Ramezanianpour. "ENGINEERING PROPERTIES OF ALKALI ACTIVATE NATURAL POZZOLAN CONCRETE". Second International Conference on Sustainable Construction Materials and Technologies June 28-June 30, 2010.

6. Dattatreya J K, Rajamane NP, Sabitha D, Ambily P S, Nataraja MC(2011), "Flexural behaviour of reinforced Geopolymer concrete beams", INTERNATIONAL JOURNAL OF CIVIL AND STRUCTURAL ENGINEERING Volume 2, No 1, 2011, ISSN 0976 – 4399

7. DjwantoroHardjito, Steenie E. Wallah, Dody M.J. Sumajouw, and B.V. Rangan(2004) "FACTORS INFLUENCING THE COMPRESSIVE STRENGTH OF FLY ASH-BASED GEOPOLYMER CONCRETE" Civil Engineering Dimension, Vol. 6, No. 2, 88–93, September 2004 .

8. DjwantoroHardjito, Steenie E. Wallah, Dody M. J. Sumajouw, and B.VijayaRangan(2013) "On the Development of Fly Ash-Based Geopolymer Concrete", ACI materials journal technical paper aci materials journal technical paper.

9. DjwantoroHardjito(2005), "Studies on Fly Ash-Based Geopolymer Concrete" Concrete in Australia, vol. 28, no. 4, pp. 24-29.

10. S.J.Foster, T.S.Ng, Futures in Mechanics of structures and materials (2009) 'Development of high performance Geopolymer concrete'.

11. P.Ganapati Naidu, A.S.S.N.Prasad,P.V.V.Satayanarayana(2012)"A Study On Strength Properties Of Geopolymer Concrete With Addition Of G.G.B.S" International Journal of Engineering Research and

Development Volume 2, Issue 4, PP. 19-28.

12. IS 10262:2009; ‘ Concrete Mix Proportioning – Guidelines’(First Edition), Bureau of Indian Standards,BIS 2009.
13. IS 456:2000; Plain and Reinforced concrete code of Practice (Fourth Revision), Bureau of Indian Standards.
14. IS 383:1970; Specification for coarse and fine aggregates from natural sources for concrete (Second Revision).
15. IS 516: 1959; Methods of tests for Strength of concrete.
16. R. B. Khadiraniakar and Shankar H. Sanni(2014), “Stress Strain Characteristics for Geopolymer Concrete – An Experimental Approach” CACE Volume 2, Issue 2 Apr. 2014 PP. 44-47.
17. Kunalkupwade-patil and ErezAllouche “EFFECT OF ALKALI SILICA REACTION (ASR) IN GEOPOLYMER CONCRETE”. World of cold ash (woca) conference –May 9-12, 2011, in Denver, co, USA. http://www.flyash.info/
18. Prof.PratapKrishnarao(2013), “Design of Geopolymer Concrete” International Journal of Innovation Research in Science, Engineering and Technology (IJIRSET) Volume 2 Issue 5.
19. K.Parthiban,K.Saravanarajamohan,S.Shobana,A.AnchaBhaskar(2013), “Effect of Replacement of Slag on the Mechanical Properties of Fly Ash Based Geopolymer Concrete” International Journal of Engineering and Technology (IJET) Volume 5.
20. Dr.A.Palaniappan,S.Vasantha,S.SivaPrakasan,S.Prabhu(2013) “GGBS as Alternative to OPC in Concrete as an Environment Pollution Reduction Approach” International Journal of Engineering Research and Technology (IJERT) Volume 2 Issue .
21. Dr.P.Priya Rachel (2015) “Study on Geopolymer Concrete Block”, Volume : 5 | Issue : 4 | April 2015 | ISSN - 2249-555X
22. D.B.Rajiwala, H.S.Patil(2011)“Geopolymer Concrete : A Concrete Of Next Decade” Journal of Engineering Studies and Research (JERS) Vol. II Issue.
23. Raijiwala D.B, PatilH(2013) “GEOPOLYMER CONCRETE: A CONCRETE OF NEXT DECADE” Journal of Engineering Research and Studies.
24. S.SundarKumar, J.Vasugi,P.S.Ambily and B.H.Bharatkumar(2013), “Development and Determination of Mechanical Properties of Fly Ash And Slag Blended Geo Polymer Concrete” International Journal of Scientific & Engineering Research, Volume 4, Issue 8.
25. S. Vaidya, E.I. Diaz, E.N. Allouche. “EXPERIMENTAL EVALUATION OF SELF-CURE GEOPOLYMER CONCRETE FOR MASS POUR APPLICATIONS”. World of coal ash (woca) conference –may 9-12, 2011, in Denver,
26. co, USA http://www.flyash.info/.