International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 02, February-2016

Studies on the Physical Properties of Ground Granulated Blast- Furnace Slag Incorporating in Geopolymer Concrete

Mr. Ahmed Mohmed Ahmed Blash
Civil Engineering,
University College of Engineering & Technology,
Acharya Nagarjuna Univeristy
India

Dr. T.V. S. Vara Lakshmi,
Asst. Professor,
Department of Civil Engineering,
University College of Engineering & Technology,
Acharya Nagarjuna University
India

***Abstract*—Environmental issues resulted from cement production have become a major concern today. To develop a sustainable future it is encouraged to limit the use of this construction material that can affect the environment. Cement replacement material was proposed to partially replace cement portion in concrete. Geopolymer is the best solution to reduce the use of cement in concrete. Geopolymer is a hardened cementitious paste made from fly ash, alkaline solution and geological source material. In the present study, the physical properties of Ground Granulated Blast furnace Slag (GGBS) in geopolymer concrete were discussed. The results revealed that the GGBS more environmental and ecofriendly by product used in the cement industry**

Keywords— Fly ash, GGBS, Geopolymer

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[1,2]. However, Portland cement is still the main binder in concrete construction prompting a search for more environmentally friendly materials. One possible alternative is the use of alkali-activated binder using industrial by-products containing silicate materials[1]. The most common industrial by-products used as binder materials are Fly Ash (FA) and Ground Granulated Blast Furnace (GGBS)[3,5].It has been widely used as a cement replacement material due to its latent hydraulic properties, while FA has been used as a pozzolanic material to enhance the physical, chemical and mechanical properties of cements and concrete[20].

The climate change due to global warming has become a major concern. The global warming is caused by the emission of greenhouse gases such as carbon dioxide (CO_2) in to the atmosphere by human activities. Among the greenhouse gases, CO_2 contributes about 65% of global warming [23]. The cement industry is held responsible for some of the CO_2 emissions, because the production of one ton of Portland cement emits approximately one ton of CO_2 into the atmosphere[1,23].

Recent research has shown that it is possible to use 100% fly ash or slag as the binder in mortar by activating them with an alkali component, such as caustic alkalis, silicate salts, and non silicate salts of weak acids [1,2,3]. There are two models of alkali activation. Activation by low to mild alkali of a material containing primarily silicate and calcium will produce calcium silicate hydrate gel (C-S-H) similar to that formed in Portland cements but with a lower Ca/Si ratio[2,3,4]. The second mechanism involves the activation of material containing primarily silicate and aluminates using a highly alkaline solution. This reaction will form an inorganic binder through a polymerization process[8,9,10,11]. The term “Geopolymeric” is used to characterise this type of reaction from the previous one and accordingly the name geopolymer has been adopted for this type of binder [Davidovits, 1994]. The geopolymeric reaction differentiates geopolymer from other types of alkali activated materials (such as; alkali activated slag) since the product is a polymer rather than C-S-H gel.

II. GGBS

GGBS is a by-product generated during manufacturing of pig iron and steel and may be defined according to ACI- 116R as “nonmetallic product consisting essentially of calcium silicates and other bases that is developed in a molten condition simultaneously with iron in a blast furnace.” It consists primarily of silicates, alumina-silicate and calcium-alumina- silicates[14,15]. The cooling process of slag is responsible mainly for generating different types of slags required for various end users. The physical and pozzolanic properties of slag vary widely with the process of cooling. GGBS is a non-toxic material and can be a good raw material for making high-value and user friendly cementitious material for different civil engineering applications[12,13]. The various aluminosilicate materials such as FA, Metakaolin, GGBS, Silica fume etc can be used as source materials for alkali-activation. Of late, most of the research on alkali-activation has been used FA as the starting materials. However, studies on Alkali-activated blast furnace slag are still very limited. Thus more study has to be carried out before arriving at any definite conclusion. In order to have complete understanding of the possibilities of applications of alkali activated blast furnace in different fields, a thorough study of its manufacturing processes, synthesizing parameters, mix design are very much essential.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 02, February-2016

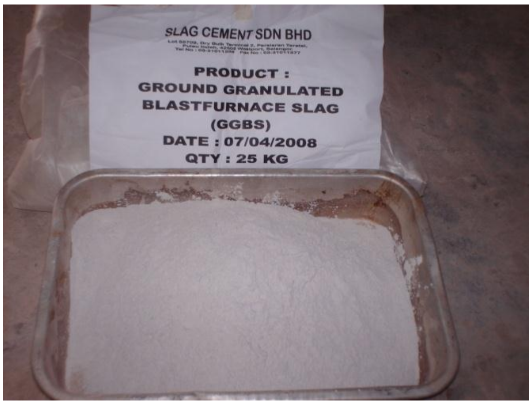


Fig.1 GGBS

A. Geopolymer terminology and chemistry

In 1978, Davidovits 1 proposed that an alkaline liquid could be used to react with the silicon (Si) and the aluminum (Al) in a source material of geological origin or in by-product materials such as FA and rice husk ash to produce binders. Because the chemical reaction that takes place in this case is a polymerization process, Davidovits coined the term "Geopolymer" to represent these binders. Geopolymers are members of the family of inorganic polymers. The chemical composition of the geopolymer material is similar to natural pezeolitic materials but the microstructure is amorphous instead of crystalline.

Water is released during the chemical reaction that occurs in the formation of geopolymers. This water expelled from the geopolymer matrix during the curing and further drying periods, leaves behind discontinuous nano-pores in the matrix which provide benefits to the performance of geopolymers[15,16]. The water in a geopolymer mixture does not play any role in the chemical reaction that takes place. It merely provides the workability to the mixture during handling. This is in contrast to the chemical reaction of water in a portland cement mixture during the hydration process. A geopolymer can take one of the three basic forms: Sialate is an abbreviation for silicon-oxoaluminate. Polysialates are chain and ring polymers with Si_{44+} and Al_{3+} in IV-fold coordination with oxygen and range from amorphous to semi-crystalline.

Geopolymer concrete tests are conducted on the concrete samples at the specific ages. All the strength tests are limited to the ages of 7,14 and 28 days.

III. MIX DESGIN

A. Alkaline Liquids

A combination of sodium silicate solution and sodium hydroxide (NaOH) solution were used as the alkaline liquid. It is recommended that the alkaline liquid is prepared by mixing both the solutions together at least 24 hours prior to use.

B. Sodium Silicate Solution

The sodium silicate solution with SiO_2-to-Na_2O ratio by mass of approximately 2, SiO_2 = 29.4%, Na_2O = 14.7% and water = 55.9% by mass were recommended.

C. Sodium Hydroxide

In this study, NaOH solution with a concentration of 8 Molar consists of 8x40 = 320 grams of NaOH solids per liter of the solution, where 40 is the molecular weight of NaOH.

TABLE I MIX PROPORTIONS

Materials		(kg/m^3)	In Cube	In all Samples (kg/m^3)
Coarse aggregates	20mm	277	0.935	16.83
	14 mm	370	1.249	22.48
	7 mm	647	2.184	39.31
Fine sand		554	1.870	33.66
GGBS		408	1.377	24.79
Sodium silicate solution(SiO_2/Na_2O=2)		103	0.348	6.26
Sodiume hydroxide solution		41(8M)	0.138	2.48
Superplasticizer		6	0.020	0.36
Extra water		None		

IV. RESULTS & DISCUSSION

A SLUMP TEST

This test is widely used in the construction site all over the world. The slump test does not measure the workability of concrete, although ACI 116R-90 describes it as a measure of consistency. The test is very useful in detecting variation in the uniformity of a mix of given nominal proportions the slump test is prescribed by ASTMC 143-90a and BS 1881: Part 102: 1984 [25].

Workability of Fresh Concrete using Slump Test

Table II shows the values of slump test for geopolymer concrete made of GGBS which occurred 72 mm respectively.

TABLE II Slump test

N.O	Samples	Slumps(mm)
1	GGBS	72

B COMPRESSIVE STRENGTH TEST

The study followed the design used in this research according to the British standard, BS: 1881 Part 116: 1984[26] and the experience of a single standard for each mixture at 7, 14 and 28 days. Cubes were tested for compressive at the ages of 7,14 and 28 days to determine the compressive resistance of concrete, taking cubes between superficial machine pressure and the load applied regularly, and then the strength (F) was calculated by the following equation:

$$F = P/a$$

Where: F = Compressive strength (N/mm^2)

P = Applied load (N).

a = Surface area (mm^2).

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 02, February-2016

C PERMEABILITY TEST

Permeability is the ease which liquids or gases can travel through concrete. Although the testing concrete for permeability has not been generally standardized by ASTM[21] and BS but for practical purpose, it is the absorption characteristic of the outer zone of concrete which protect the reinforcement are the greatest interest for that purpose in this paper, preliminary study towards permeability through ISAT (Initiation surface absorption test) test as specified in BS: 1881 Part 5: 1970[27] was developed to determine the initial surface absorption.

The samples testing cube have a size of 150 mm x 150 mm x 150 mm and shall be dried in a well ventilated oven at 105 ± 5^0 C until constant weight is achieved.

D EFFECT OF GGBS ON COMPRESSIVE STRENGTH

In this section, the main concern is to study the compressive strength of geopolymer concrete made of GGBS. Concrete tests are conducted on the concrete samples at the specific ages. All the strength tests are limited in the ages of 7, 14 and 28 days. The cubes with the size of 150 mm x 150 mm x 150 mm were tested at the ages of 7, 14 and 28 days

E Compressive strength

The most important properties in concrete structures are those related with strength, because the strength gives an overall picture of the quality of the concrete. Among the various strength types of concrete strength, compressive strength is the most dominant because the concrete is primarily meant to withstand compressive stress. The details of cube samples tested at the ages of 7, 14 and 28 days are shown in the Table III

TABLE III. Cube test results for different Mix proportions

Material used	Age (days)	Compressive Strength (MPa)
GGBS	7	54.17
	14	66.00
	28	69.43

F GEOPOLYMER CONCRETE CUBE STRENGTH.

The compressive strength test has become a part of the structural testing in construction to determine the grade of concrete, which have to comply with design standards. In this study, 12 cubes had been prepared and tested to the required strength of 7, 14 and 28 days. During the preparation of the cubes, slump tests had been done.

The main concern of the study work the compressive strength of geopolymer concrete contains of the different materials. It's manufactured by sodium silicate solution with SiO_2-to-Na_2O ratio by mass 2, Na_2O = 14.7%, SiO_2 = 29.4%, water = 55.9% by mass and sodium hydroxide solids (NaOH) with 97-98% purity are recommended with GGBS. For water-to-geopolymer solids ratio by mass of 0.19, the design compressive strength is approximately 45 MPa. Cubes with the size of 150 mm x 150 mm x 150 mm were tested at the ages of 7, 14 and 28 days. The results of the compressive strength test are shown in Table III

Compressive strength of geopolymer concrete at the age of 7 Days

The results shows the compressive strength of specimens at a particular age as compared with the compressive strength of specimens from the same batch of the geopolymers concrete tested on the day of 7. After the curing age of 7 days the compressive strength of geopolymers concrete made of GGBS is 54.17 MPa (Mega pascal). As known, the geopolymers are members of the inorganic polymers family. The chemical composition of the geopolymer material is similar to natural zeolitic materials, but the microstructure is amorphous. The polymerization process involves a substantially fast chemical reaction under alkaline condition on Si-Al minerals, those results in a three-dimensional polymeric chain and ring structure consists of Si-O-Al-O bonds1.

The study had been used GGBS with the alkaline solution to produce geopolymers concrete. The GGBS with the following chemical composition: 35.2% SiO2, 37.9% CaO and 10.7% Al2O3. The geopolymer concrete made of GGBS got good compressive strength with the early age. An overdose of CaO binds almost all the available silica to form weak linear chains, therefore insufficient silica is left to nucleate the gel.

Geopolymer concrete strength at the age of 14 days

The result shows the comparative achieved by the cubes as compared to the compressive strength of specimens from the same batch of geopolymer concrete tested at the age of 14 days. The geopolymers concrete made of GGBS was 66 MPa (Megapascal). The results show the compressive strength of the geopolymers concrete made of GGBS harder. According to the result, the compressive strength of the geopolymer concrete made of GGBS is increased with the curing time about 12 MPa. It has shown in Table 3 that the GGBS has 1% Fe2O3. The high Fe2O3 content present in slag may also play an important role during synthesis, since it may react with the activating solution to form phases contributing to strength development.

Also, the study shows the improvement in the geopolymers concrete that made of GGBS while duration curing increases from the age of 7 to 14 days; this means that most inorganic polymer bonds are developed in a short time.

Geopolymer concrete strength at the age of 28 days

The results show at the age of 28 days, it appears that the compressive strength of the geopolymer concrete made of GGBS is 69.43 MPa (Mega pascal).On other hand, the compressive strength geopolymer concrete made of GGBS after curing time of 28 days was more than of 14 days about *3*MPa. There is improving in compressive strength geopolymer concrete by using GGBS with continuing curing time.

G PERMEABILITY TEST

Permeability is a measure of the concrete ability to resist penetration of water or other substances. So that in order to be durable, concrete must be relatively impervious. The more water the concrete contains beyond that necessary for workability, the more pervious it will become. It is important to remember that the permeability of concrete should be kept

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 02, February-2016

low in order to protect the reinforcing steel bar. In general, low permeability concrete is also associated with high strength and high resistance to weathering. In fact the impervious concrete won't allow the aggressive liquids and gases to penetrate. According to literature many tests used to investigate the permeability of concrete ISAT (Intial Surface absorption test). These tests used water and an apparatus flow directly through block of hardened- concrete as specified in BS: 1881 Part 208: 1996[28].

TABLE IV Result of permeability (ISAT) for geopolymer concrete made of GGBS at age 7 Days

Intervals Test	Number of division	Surface Absorption ml/m^2/s
10 min	10	0.1
30 min	12	0.12
60 min	14	0.14

Fig .2: Result of Permeability Test for geopolymer concrete made of GGBS at age of 7 days

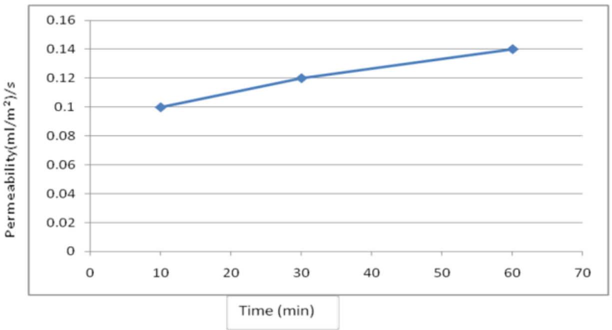
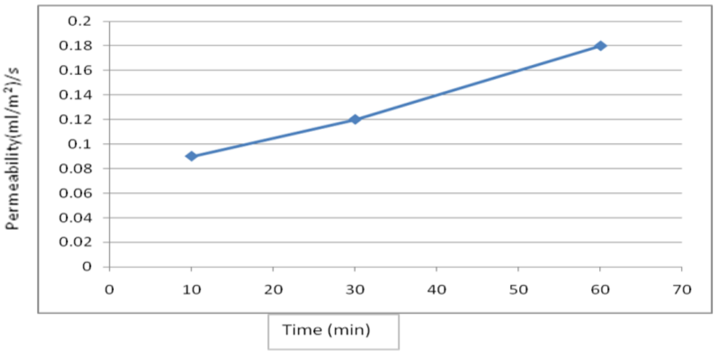


TABLE.V Result of permeability (ISAT) for geopolymer concrete made of GGBS at age 28 Days

Intervals Test	Number of division	Surface Absorption ml/m^2/s
10 min	9	0.09
30 min	12	0.12
60 min	18	0.18

Fig. 3 Result of Permeability test for geopolymer concrete made of GGBS at age of 28 days



Permeability of concrete cubes

In present specifications, durability of concrete is still based on conventional method to satisfy several of the concrete requirements or limit value such as concrete grade, cover thickness, minimum cement content, water-cement ratio and maximum structural crack. Theoretically the permeability is one of the important points which may indicate dur- ability. Low permeability concrete is also associated with high strength and high resistance to weathering.

The ISAT (Intial surface absorption test) study has shown the results of the ages of 7 and 28 days according to the results show the geopolymer concrete cube sample which contained GGBS has low permeability

In this study, an investigation was done to determine the physical properties of the geopolymer concrete, which was produced by a reaction between by-product material (GGBS) and alkaline liquid with presence of aggregate. GGBS was used as source materials to make the geopolymer concrete. Sodium silicate solution and sodium hydroxide solution were mixed together to form the alkaline liquid. The silicon and the aluminum in GGBS reacted with the alkaline liquid to form the geopolymer paste that bound the loose aggregates and other unreached materials to produce the geopolymer concrete. The aggregates consisted of sand and of 7 mm, 10 mm and 14 mm granite-type as coarse aggregates. Also, superplasticiser was used to improve the workability of fresh geopolymer concrete.

The cubes of geopolymer concrete which contained GGBS were tested at ages of 7, 14 and 28 days. This step was aimed to figure out the behavior of the geopolymer concrete results. Furthermore, the strength of geopolymer concrete and the durability were also tested. geopolymer concrete strength increases with curing age, the compressive strength of geopolymer concrete made of GGBS increased about 12 MPa at the curing age of 7 to 14 days and 3 MPa at curing age of 14 to 28 days.

The incorporation of GGBS in the geopolymer concrete mixes resulted in finer pore structure thus produce low permeability concrete. The use of GGBS as a supplementary cement material improved the characteristics of the pore structure when appropriate water curing was carried out. The longer curing durations reduce permeability and result in finer pore structure. It also observed that high performance concrete may be used in term of high strength and durability is significant to special structured such as marine structures.

Permeability is one of the most important requirements for good concrete. This study has also conducted tests to study the permeability of the geopolymer concrete made of GGBS . It was found that low permeability.

V. Conclusion

In this study concluded that progress and current status on the development of Geopolymer concrete using by-products GGBS. Investigations about GGBS geopolymer have found a potential material for replacing the used of OPC in infrastructure development. However, it must be noted that different samples of GGBS may give different reactivity due to their varying chemical compositions. The current knowledge shows that the influence of NaOH molarity, alkaline activator ratio, Na2SiO /NaOH ratio, and curing temperature are essential for achieving the optimum strength of geopolymer. Moreover, the durability of the GGBS based geopolymer is better than OPC when exposed to an aggressive environment.

VI. REFERENCES

[1] J. Davidovits, "Geopolymer, Man-made Rock Geosynthesis and the Resulting Devolopmentof Very Early High Strength Cement," Journal of Materials Education, 16 [2-3] 91-137(1994).

[2] Celia García Arenas, Madelyn Marrero, Carlos Leiva, Jaime SolísGuzmán,andLuis F. Vilches Arenas, "High fire resistance in blocks containing coal combustion fly ashes and bottom Ash. Waste Management, vol. 31, no. 8 pp. 1783- 1788, 2011.

[3] C. Arenas, C.Leiva, LF. Vilches, H.Cifuentes, "Use of co-combustion bottom ash to design an acoustic absorbing material for highway noise barriers", Waste Management, vol.33, no.11, pp.2316-2321, Nov 2013.

[4] Djwantoro Hardjito and Shaw Shen "Fly ash-based geopolymer mortar incorporating bottom ash", Modern Applied Science, vol.4, no.1, pp4452, 2010.

[5] H. Xua, Q. Lia, L. Shena, W. Wanga, and J. Zhai, "Synthesis of thermostable geopolymer from circulating fluidized bed combustion (CFBC) bottom ashes", Journal of Hazardous Materials, vol.175, no.(1/3), pp.198–204, 2010.

[6] Mohd Syahrul Hisyam Mohd Sani, Fadhluhartini Muftah, and Zulkifli Muda "The properties of special concrete using washed bottom ash (WBA) as Partial sand replacement", International Journal of Sustainable Construction Engineering & Technology, vol. 1, no.2., pp.65-76, 2010.

[7] M.J. Shannag, and A. Yeginobali, "Properties of pastes, mortars and concretes containing natural pozzolan", Cement and Concrete Research,vol.25, pp.647–657, 1995.

[8] Vanchai sata, Sathonsaowaphak, and Prinya Chindaprasirt, "Resistance of lignite bottom ash geopolymer mortar to sulfate and sulfuric acid attack", Cement and Concrete Composites, vol 34, no. 5, pp.700-708, 2012.

[9] Ilker Bekir Topcu, and Mehmut Ugur Toprak, "Properties of geopolymer from circulating fluidized bed combustion coal bottom ash", Materials Science and Engineering, vol.A528, pp.1472-1477, 2011.

[10] Si-Hwan Kim, Gum-Sung Ryu, Kyung-Taek Koh, and Jang-Hwa Lee, "Flowability and strength development characteristics of bottom ash based geopolymer", World Academy of Science, Engineering and Technology, vol. 70, pp. 53-59, 2012.

[11] Kornkanok Boonserm, Vanchai Sata, Kedsarin Pimraksa, and Prinya Chindaprasirt, "Improved geopolymerization of bottom ash by incorporating fly ash and using waste gypsum as additive'', Cement and Concrete Composites vol.34, no.7, pp.819–824, April 2012.

[12] Bennet Jose. Mathew, M.Sudhakar, and C.Natarajan, "Strength economic and sustainability characteristics of coal ash – GGBS based geopolymer concrete'', International Journal of Computational Engineering, Research, Vol. 3, no.1, pp.207-212, 2013.

[13] Deependra Kumar Sinha, A.Kumar, and S.Kumar. Reduction of pollution by using Fly ash, bottom ash and granulated blast furnace slag in geopolymer building materials'', Scholars Journal of Engineering and Technology, vol.1, no.3, pp.177-182, 2013.

[14] C.K.Yip, G.C. Lukey, and J.S.J. van Deventer "The co-existance of geopolymeris gel and calcium silicate hydrate at the early stage alkaline activation", Cement and Concrete Research, vol.35, no.9, pp.1688–1697, 2005.

[15] H. Xu, J.S.J. Van Deventer, "The geopolymerisation of alumino-silicate minerals", International Journal of Mineral. Processing, vol.59, no. pp. 247–266, 2000.

[16] Sanjay kumar, Rakesh kumar, and Mehrotra, "Influence of granulated blast furnace slag on the reaction,structure and properties of fly ash based geopolymer" , *Journal of Mater Science* 45:607–615, 2010.

[17] Keun hyeok yan, Jin-Kyu Song, Ashraf F. Ashour, Eun-Taik Lee' "Properties of cementless mortars activated by sodium silicate", *Construction and Building Materials*, vol. 22, no.9, pp.1981–1989, 2008,

[18] S.D. Wang, and K.L.Scrivener, "Hydration products of alkali-activated slag cement", *Cement and Concrete Research, vol.* 25, no.3, pp.561–571, 1995.

[19] K.C.Goreta,Nan Chen, F.Gutierrez-Mora, J.L.Routbort, G.C. Luckey, and J.S.J.Van Deventer, "Solid-partcle erosion of a geopolymer containing fly ash and blast furnace slag", *Wear*, vol.256, no.70-8, pp.714–719, April 2004.

[20] Susan A. Bernal, "Effect of binder content on the performance of alkaliactivated slag concretes", *Cement and Concrete Research*, vol.41.pp.1–8, 2011.

[21] ASTM C 33 Aggregates are classified (fine or course) Annual Book of ASTM Standards: Concrete and Aggregates. 04.02 philadelphia: American Society for Testing and Materials.

[22] Hardjito, D, Wallah SE, Sumajouw, Rangan BV. *Properties of Geopolymer concrete with Fly ash source material: effect of mixture composition*. In: Seventh CANMET/ACI international conference on recent advances in concrete technology, Las Vegas, USA; 2002.

[23] McCaffrey, R. (2002). *Climate Change and the Cement Industry*, Global Cement and Lime Magazine (Environmental Special Issue), 15-19.

[24] Mehta, P. K. (2001). *Reducing the Environmental Impact of Concrete.* ACI Concrete International 23(10): 61-66.

[25] BS 812: Part 102: (1984): Methods for sampling Testing Aggregates.

[26] BS 1881: Part 102: (1983) Method of normal curing of test specimens (20o C method).

[27] BS 1881-Part5:(1970). Methods of Testing concrete .

[28] BS: 1881 Part 208: (1996) Methods of Testing concrete.

.