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STRENGTH AND MICROSTRUCTURE OF ALKALI-ACTIVATED BLAST FURNACE SLAG PASTE

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Abstract

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The use of Alkali-activated cementitious materials has been increased to a great extent in the recent past. The focus of this research is to investigate the effects of Silicon dioxide (SiO₂) content on compressive strength and microstructure of alkali-activated blast furnace slag paste. The Ground granulated blast furnace slag (GGBS) is activated by sodium silicate and sodium hydroxide solution. SiO₂ content was varied from 1.6 % to 9.61 % of GGBS, keeping Na₂O content (8%) and Water to GGBS ratio (0.32) constant. It was observed that the compressive strength increases with the increase in SiO₂ content up to 6.4 % and then reduces. The results show that specimens cured in water at room temperature provides 28 day strength of maximum 44.50 MPa. It was also observed that the silica content has a significant influence on porosity and water absorption. The micro-structural changes were studied using scanning electron microscopy (SEM).

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1. INTRODUCTION

The manufacture of Alkali-activated blast furnace slag may be considered as an alternate binder to Ordinary Portland cement (OPC) which will be the need of the hour for the construction industry. Alkali-activated binders are receiving increasing attention because of their high strength, durability and low environmental impact [1]. Alkali-activated binder are made by mixing source materials which are rich in alumina and silica such as fly ash or ground granulated blast furnace slag (GGBS) with an alkaline activating solution [1-3]. The detailed chemistry of alkali activation is still a subject of discussion and depends both on the nature of the solid precursor [4] and the alkali activator [5, 6]. There are many factors such as chemical composition of source material as well as the amount of glassy phase and fineness [7, 8], type and concentration of alkaline activator which can influence the properties of final product.

The present study was conducted to investigate the effects of silicon dioxide (SiO_2) on the compressive strength, water absorption, apparent porosity and

microstructure of alkali-activated ground granulated blast furnace slag (AAGGBS) paste.

MATERIALS AND METHODS

Ground granulated blast furnace slag (GGBS)

GGBS used in this study was obtained from Tata Metaliks Ltd. Kharagpur, India. The chemical composition was obtained using XRF and is shown in Table 1. Slag used was having a density of 2900 kg/m^3 with particle size less than 45 microns with 95% glass and having semi crystalline components such as akermanite, gehlenite and quartz etc.

Alkaline activator

The Alkaline activator liquid was the combination of sodium hydroxide pellets and sodium silicate solution. Laboratory grade sodium hydroxide in pellet form (97 % purity with $\text{Na}_2\text{O} = 77.5 \%$ and 22.50 % water) was supplied by Merck India Ltd. and sodium silicate solution ($\text{Na}_2\text{O} = 8 \%$, $\text{SiO}_2 = 26.50\%$ and 65.50 % water) with silicate modulus ~ 3.3 and a bulk density of 1410 kg/m^3 was supplied by Loba Chemie Ltd. India, were used to achieve the desired composition of Alkali activated GGBS paste.

Table 1 Chemical composition of blast furnace slag by XRF.

Chemical composition	SiO ₂	CaO	Al ₂ O ₃	MgO	Fe ₂ O ₃	S	MnO	LOI ^a
Mass (%)	32.50	33.50	18.50	8.00	0.40	0.5	0.55	0.7

^aLoss on ignition

Preparation of Test specimens

The alkali activated GGBS paste was prepared by varying SiO₂ from 1.6% to 9.61% (by weight of GGBS) by keeping a percentage of Na₂O = 8. The compositional change in AAGGBS mix was obtained by adjusting the quantity of sodium hydroxide (NaOH), sodium silicate solution and water. The activator solution was prepared at least one day prior to casting of test specimens. The water / slag ratio was kept constant equal to 0.32. The chemical composition of AAGGBS mix and corresponding compressive strength of specimens are presented in Table 2.

For making AAGGBS paste specimens, the blast furnace slag and activating solution in desired proportion were first mixed together for five minutes in a Hobart Mixer to get a homogeneous paste. The fresh paste mix had a sticky nature with good workability. The workability was assessed

using mini flow table test as per ASTM C 1437-07 [9]. Flow diameter was found between 170 mm to 200 mm. The fresh mix was then transferred into 50 mm ×50 mm ×50 mm steel moulds and vibrated for two minutes on vibrating table to remove any entrapped air. The specimens were left at room temperature for 24 hours, then de-moulded and kept in water in fully immersed condition at room temperature until testing was done. The tests were conducted at the age of 3, 7 and 28 days.

Water absorption and Apparent Porosity

To determine the water absorption, three cube specimens from each series were oven dried at a temperature of 85⁰ C for 24 hours and its weight was determined (initial weight). The specimens were then immersed in water for 24 hours and its saturated surface dry weight was recorded

(final weight). Water absorption is reported as the percentage increase in weight.

Archimedes principle with water as immersion medium.

The apparent porosity was determined for 28 days old specimens according to

Table 2 Detail of mix composition of Alkali activated blast furnace slag paste (% of mass added with respect to the total mass of slag)

Mix ID	Mix Composition			Compressive strength (MPa)
	% Na ₂ O	% SiO ₂	Water / Slag	28 Days
AABFS8-1.6	8.0	1.6	0.32	20.30
AABFS8-3.2	8.0	3.2	0.32	26.40
AABFS8-4.8	8.0	4.8	0.32	36.60
AABFS8-6.4	8.0	6.4	0.32	44.50
AABFS8-8.0	8.0	8.0	0.32	42.20
AABFS8-9.61	8.0	9.61	0.32	39.50

Compressive strength

The alkali activated GGBFS paste specimens (50mm x 50mm x 50mm) were tested for compressive strength using 20 ton capacity digital compressive testing machine with a loading rate of 20 MPa/min. The compressive strength tests were conducted at the age of 3, 7 and 28 days. Three specimens of each series at each age were

crushed in a digital compression testing machine in accordance with ASTM C-109-02 [10] and the average strength of three specimens is reported as the compressive strength.

RESULTS AND DISCUSSION

Water absorption and apparent porosity

The relationship between SiO₂ content with water absorption and apparent porosity is presented in Fig.1. A decrease in apparent

porosity and water absorption was noticed for SiO₂ ranging from 1.6 % to 4.8 % and thereafter, sudden decrease of apparent porosity and water absorption at SiO₂ content of 6.4 %. AAGGBS specimen having lower SiO₂ from 1.6 % to 4.8 % shows higher water absorption that is indicating higher void content. For SiO₂ content of 6.4 % and 8 %, the water absorption was observed 6.06% and 9.37 % respectively, indicating the addition of soluble silicates makes more homogeneous and denser microstructure.

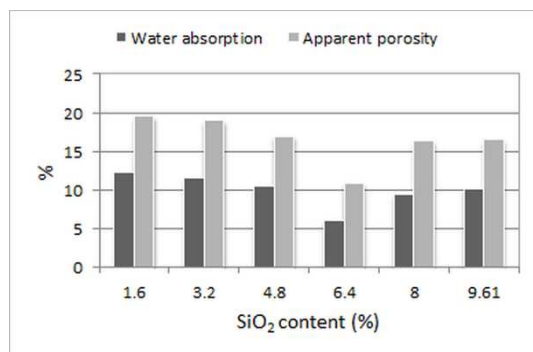


Figure 1 Effect of SiO₂ content on water absorption and apparent porosity.

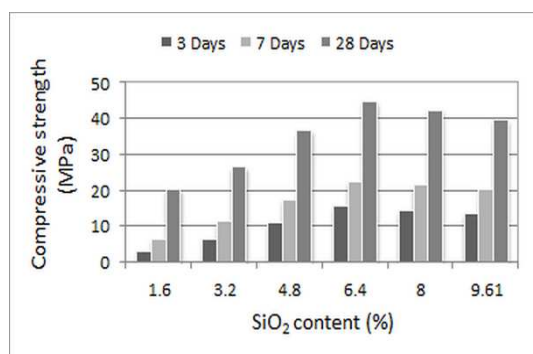


Figure 2 Effect of SiO₂ on compressive strength of AAGGBS paste.

Compressive strength

The SiO₂ content varied from 1.6 % to 9.61 % at constant alkali content of 8.0 %. Water to slag ratio by weight was kept constant at 0.32. The compressive strength of AAGGBS paste was determined at the age of 3, 7 and 28 days. In Fig. 2, it was observed that the compressive strength of the specimen increases with increase in SiO₂ content from 1.6 % to 1.8 %. The maximum compressive strength of 44.50 MPa was observed for SiO₂ content of 6.4 % and minimum compressive strength of 20.30 MPa was observed for SiO₂ of 1.6 % indicating the incomplete process of dissolution of the slag and adsorption of ions in solution on the surface of the slag. Increasing silicate ratio means increasing the concentration of anions of sodium silicate. The anion in sodium silicate reacts with Ca²⁺ dissolving from the surface of the slag grains and forms the primary C-S-H [11]. The C-S-H deposits among the slag grains and makes the paste set quickly and gives higher strength as indicated in the SEM image (Fig.3). The 7 days strength was found out to be 31.72 %, 42.44 %, 47.76 %, 50.48 %, 50.09 % and 51.03 % of 28 days strength of

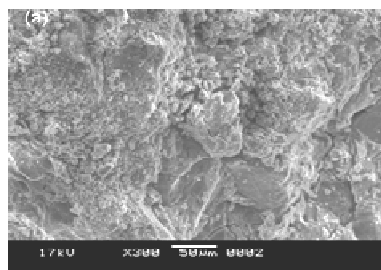
specimens having SiO₂ content of 1.6 %, 3.2 %, 4.8 %, 6.4%, 8 % respectively. The optimum value of SiO₂ content was found to be 6.4 % corresponding to the highest strength of 44.50 MPa, thereafter with an increase in silicate ratio, there is a slight reduction in strength corresponding to peak strength value, which indicates excess silicate contents hinders alkali activation of slag and structure formation.

Micro-structural Study by Scanning Electron Microscopy (SEM)

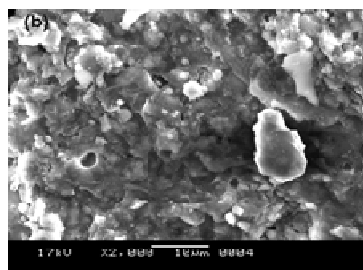
Scanning Electron Microscopy (SEM) was used to record micrographs using JEOL JSM 6360 scanning electron microscope.

Samples for scanning electron microscope (SEM) were carried out for untreated slag and for the alkali activated paste specimen with silicate content of 1.6 %, 6.4 % and 9.61 % are shown in Figure 3. SEM images show a highly amorphous microstructure with some crystalline phases. The matrix of

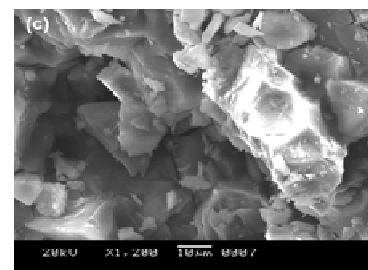
AABFS8-1.6 was not fairly uniform as shown in Fig. 3 a. with uniformly distributed wide cracks were also found on the surface of the specimens. Most of the slag grains had not been dissolved in alkaline solution hence resulted in low strength with high porosity and water absorption. The matrix of AABFS8-6.4 (Fig. 3 b) was quite different from others specimens as the microstructure was very dense with fewer unreacted slag grains and less micro cracks, most of the slag grains formed C-S-H gel hence responsible for higher strength. In the matrix of AABFS8-9.61, unreacted silica was found (Fig. 3 c). The number of micro cracks was reduced, but macro cracks were formed on the border of C-S-H and unreacted silica. Increasing too much sodium silicate is not beneficial as excess silica content caused macro cracks as shown in Figure 3 (c).



(a)



(b)



(c)

Figure 3 SEM micrograph of AAGGBS paste with different SiO₂ content (a) AABFS8-1.6, (b) AABFS8-6.4 and (c) AABFS8-9.61

CONCLUSION

The effect of the SiO₂ on the properties of Alkali activated blast furnace slag paste has been investigated. Based on experimental study, the following conclusions are drawn.

- a. Blast furnace slag paste composite activated by sodium silicate and sodium hydroxide solution, can be produced at normal temperature under water curing.
- b. The compressive strength is increased as SiO₂ content increases from 1.6 % to 6.4 %. Highest compressive strength at the age of 28 days was 44.50 MPa for a silicate content of 6.4 %.
- c. At a constant Na₂O dosage, increasing the SiO₂ content up to 6.4 % reduces the water absorption and porosity.
- d. The compressive strength of the paste can be controlled by judiciously choosing the SiO₂ dosage.

REFERENCES

1. Juenger MCG, Winnefeld F, Provis JL, Idekar J. Advances in alternative cementitious binders, *Cem Concr Res*, 2011; 41: 1232-43.
2. Chi M. and Huang R., Binding mechanism and properties of alkali-activated flyash/slag mortars, *Construction and Building Materials*, 2013; 40: 291-298.
3. Bernal SA, Provis JL, Rose V, Gutierrez RMd, Evolution of binder structure in sodium silicate-activated slag-metakaolin blends, *Cement Concr Compos*; 2011; 33: 46-54.
4. P. Duxson, J.L. Provis, Designing precursors for geopolymer cements, *J. Am. Ceram. Soc.*, 2008; 91 (12): 3864–3869.
5. J.L. Provis, Activating solution chemistry for geopolymers, in: J.L. Provis, J.S.J. van Deventer (Eds.), *Geopolymers: Structures, Processing, Properties and Industrial Applications*, Woodhead, Cambridge, UK, 2009; 50–71.
6. Qureshi M.N. and Ghosh Somnath, Effect of alkali content on strength and microstructure of GGBFS paste, *Global Journal of Researches in Engineering*, 2013; 13(1) (in press).
7. Krizan D, Zivanovic B, Effects of dosage and modulus of water glass on early hydration of alkali-slag cements, *Cement*

and Concrete Research, 2002; 32(8): 1181-1188.

8. Qureshi M.N. and Ghosh Somnath, Effect of Fineness on Engineering Properties of Alkali-activated GGBFS paste, International Journal of Applied Engineering Research, 2013; 8 (2), 131-146.

9. ASTM C1437-07, Standard test method for flow of hydraulic cement mortar, American Society for Testing and Materials, 2007.

10. ASTM C-109-02, Standard test method for compressive strength of hydraulic cement mortars [using 2-in or [50-mm] Cube Specimens]; , American Society for Testing and Materials, 2002.

11. Shi C, & Li Y. Investigation on some factors affecting the characteristics of alkali-phosphorus slag cement, Cement and Concrete Research, 1989; 19(4): 527-533

Author's biography



Mohd. Nadeem Qureshi, M.E. (Civil) is working as a senior lecturer in Civil Engineering Department, Government Polytechnic, Khamgaon. (M.S), India. He is presently pursuing Ph.D in the field of 'Alkali-activated Blast Furnace Slag Composite' at Jadavpur University, Kolkata - 7000 32 (India), under QIP Program. He did his Masters in Structural Engineering from M.S.University of Baroda in 1991. He has done diploma in Construction from George Brown College, Toronto (Canada) He has gold seal certification in steel construction from Ontario General Contractors Association (Canada). Mr. Qureshi has over 20 years of teaching and industrial experience at the national and international level. He has worked from 1991 to 1999 as Civil and Structural Engineer for Thinet International Co. Paris France and Issam Kabbani and partners Co. for their various projects in gulf countries.

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Dr. Ghosh has contributed significantly in the area of High performance concrete, Geopolymer composites and FEM analysis of concrete structures. . His contribution on 'Fly ash based Geopolymer composite' has added a new dimension in the area of non-conventional green binder material using waste and is acclaimed internationally.

Dr. Ghosh has demonstrated his skill by providing technical advice on a number of occasions and the same has been implemented very successfully in practice. Repair and restoration techniques adopted for the earthquake damaged structures of the Kandla special economic zone (SEZ) through his expertise deserve a special mention. Another noteworthy contribution is the restoration of Assembly building at Sikkim. His skill in computer aided analysis of structure has been demonstrated through the design of a Buddha statue of 52m tall, on the top of a hill at Namchi, Sikkim and a cricket stadium in Guwahati. His selection as the Country Head of a division in a multinational company in Nigeria speaks about his skill and expertise. During this period, Dr. Ghosh has successfully guided a good number of students for their Ph.D and Master's degree. He has acted as expert member on several occasions for CSIR, AICTE, UGC, IIT, NIT & other Universities. Dr. Ghosh has contributed immensely both in academics as well as in practice through his activities.

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