Performance Study on Compressed Blocks Using Alkali Activated Alumino Silicate Binders

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Abstract: Ordinary Portland Cement (OPC) has become an important material in the production of concrete/mortar which act as its binder to bind all the constituents together. However, the utilization of cement causes pollution to the environment and depletion of raw material (limestone). The manufacturing of OPC requires the burning of large quantities of fuel and decomposition of limestone, resulting in significant emissions of carbon dioxide. The production of one ton of cement emits approximately one ton of carbon dioxide to the atmosphere. This paper envisages that geopolymer technology will be able to support the efforts necessary for the development of concrete materials without using cement. This paper presents the engineering properties of geopolymer compressed block/bricks manufactured using industrial byproducts such as fly ash and GGBS as binder, activated by sodium based alkaline reactor without any use of cement. Tests are carried out on 225x100x75mm geopolymer blocks to study their performance. The results revealed that as content of GGBS as well as molarity of sodium hydroxide solution are increased, the compressive strength of geopolymer block increases. Tests are conducted to study amount of water absorption and compared with clay and cement bricks.

Keywords: Geopolymer blocks, Sodium Hydroxide, Sodium Silicate.

1 INTRODUCTION

General

Climate change due to global warming has become a major concern. Global warming is caused by the emission of greenhouse gases, such as carbon dioxide (CO_2), to the atmosphere by human activities. Among the multiple greenhouse gases, CO_2 contributes to approximately 65% of global warming. The cement industry contributes a large volume of CO_2 to the atmosphere. Cement production is highly energy-intensive, after steel and aluminium. The usage of cement can be reduced by using the other possible cementing materials without compromising the strength and durability.

In order to address this issue, it is essential that other forms of binders be developed. At present, efforts have been made to promote the use of pozzolans to replace Portland cement. One possible alternative is the use of another form of cementitious material, rich in silicon and aluminium. Davidovits (1994, 1988) [1, 2] proposed that an alkaline liquid could be used to react with the silicon (Si) and the aluminium (Al) in a source material of geological origin or in byproduct materials. The most common industrial by-products used as binder or source materials are fly ash (FA), ground granulated blast furnace slag (GGBS), Rice husk, metakaolin, silica fume etc. The alkali activation of waste materials (especially those coming from industrial and mining activities) has become an important area of research in many laboratories because it is possible to use these materials to synthesize inexpensive and ecologically sound cement like construction materials. Fly ash and GGBS are used as partial replacements for cement in concrete manufacturing and are used in soil stabilization for road construction. The use of fly ash is increasing every year. The abundant availability of fly ash worldwide creates opportunity to utilise this by-product of burning coal, as a substitute for OPC to manufacture concrete. When used as a partial replacement of OPC, in the presence of water and in ambient temperature, fly ash reacts with the calcium hydroxide during the hydration process of OPC to form the calcium silicate hydrate (C-S-H) gel. GGBS has many similar characteristics to Portland cement. When it is blended with Portland cement, further recognized cementitious materials such as Portland-slag cement and blast furnace cement are produced. GGBS has been used at between 25 and 50% replacement of the Portland cement with or without the addition of lime. Recent research has shown that it is possible to use 100% fly ash or slag or combination of fly ash and GGBS as the binder by activating them with an alkali component such as caustic alkalis, silicate salts, and non silicate salts of weak acids (Bakharev et.al)[3]. The recent studies on the total replacement of cement to produce ‘No Cement Concrete’ by alkali activation of fly ash and GGBS are very encouraging from the point of development of sustainable alternative construction materials.

2 MATERIALS CHARACTERIZATION

An overview of materials and their characteristics used for manufacture of geopolymer based compressed blocks for ascertaining their suitability for using in construction practices is dealt. Although geopolymer compressed blocks can be produced by various source materials, in the present investigation, fly ash and GGBS are used as source materials. Other materials used for the synthesis of geopolymer compressed blocks are alkaline solutions (sodium hydroxide and sodium silicate) as activator and quarry dust as fine aggregates.

2.1 Fly Ash

Fly ash is one of the residues generated in combustion of coal in thermal power plants, and comprises the fine particles that rise with the flue gases. Ash which does not rise is termed bottom ash. In an industrial context, fly ash usually refers to ash produced during combustion of coal. Depending upon the source and makeup of the coal being burned, the components of fly ash vary considerably, but all fly ash includes substantial amounts of silicon dioxide (SiO_2) (both amorphous and crystalline) and aluminum tri-oxide (Al_2O_3), both being endemic ingredients in many coal-bearing rock strata.

ASTM C 618 (1993) [10] categorizes fly ash into the following two categories.

Class F: Fly ash normally produced from burning anthracite or bituminous coal falls in this category. This class of fly ash exhibits pozzolanic property but rarely, if any, self hardening property. It is pozzolanic in nature, and contains less than 20% lime (CaO).

Class C: Fly ash normally produced from lignite or sub-bituminous coal is included in this category. This class of fly ash has both pozzolanic and varying degree of self-cementitious properties. (Most Class C fly ashes contain more than 15% CaO. But some Class C fly ashes may contain as little as 10% CaO).

Flyash

The Physical and Chemical properties of fly ash are given in tables 1 & 2.

Table 1.Physical Properties of Fly Ash

Sp. Gravity	Fineness m^2/kg	LOI (%)
2.4	1134.1	0.9

Table 2.Chemical composition of fly Ash

Al_2O_3 %	Fe_2O_3 %	SiO_2 %	MgO %	SO_3 %	Na_2O %	Chlorides%	CaO %
31.23	1.5	61.12	0.75	0.53	1.35	0.06	3.2

2.2Ground Granulated Blast-Furnace Slag (GGBS)

Ground Granulated Blast Furnace Slag (GGBS) is a by-product of the manufacturing of iron in a blast furnace where iron ore, limestone and coke are heated up to 1500^0C.When these materials melt in the blast furnace, two products are produced – molten iron, and molten slag. The molten slag comprises mostly silicates and calcium oxide from the original iron ore, combined with some oxides from the limestone. The process of granulating the slag involves cooling the molten slag through high-pressure water jets. The rapid cooling prevents the formation of larger crystals, and the resulting granular material comprises some 95% non-crystalline calcium-alumino silicates. The granulated slag is further processed by drying and then ground to a very fine powder, which is GGBS (ground granulated blast furnace slag).

The Physical and Chemical properties of GGBS are given in tables 3 & 4.

Table 3.Physical Properties of GGBS

Physical form	Bulk density (kg/m3)	Specific gravity	Specific surface (m^2/kg)	LOI (%)
Off white powder	1200	2.9	416	0.19

Table 4.Chemical Properties of GGBS (in %)

Glass	SiO_2+ CaO +MgO	MgO	Sulphide sulphur	Sulphite content	Chlorides	MnO
90	76	8.46	0.54	0.23	0.01	0.05

2.3 Alkaline Liquid

A combination of sodium silicate solution and sodium hydroxide solution is used as alkali activator. The sodium silicate solution (Sp gravity = 1.385, Na_2O = 8.35%, SiO_2 =28.12%, and Na_2O: SiO_2 = 1:3.36) was purchased from local supplier in bulk. The sodium hydroxide (NaOH) in flakes form with 97% - 98% purity was purchased from Jai Amba Chemicals, Belgaum. The NaOH solids were dissolved in water to make the solution. Sodium-based solutions were chosen because they were cheaper than Potassium-based solutions.

2.3.1 Preparation of Liquid

The mass of NaOH solids in a solution varies depending on the concentration of the solution. The sodium hydroxide (NaOH) solution was prepared by dissolving the flakes in water. The concentration (measured in terms of molarity) of sodium hydroxide solution is kept as 8M and 12M for laboratory trails. NaOH solution with a concentration of 8M consists of 8x40 = 320 grams of NaOH solids (in flake form) per litre of the solution, where 40 is the molecular weight of NaOH; similarly for 12M. It is recommended that alkaline liquid is prepared my mixing sodium silicate and sodium hydroxide solution together at least 24 hours prior to use. Sodium hydroxide to sodium silicate solution ratio for mortar, 1:2 is used in the study.

2.4 Test on Fine Aggregate (Quarry Dust)

Sieve analysis of fine aggregates was carried out and fineness modulus of 3.33 was obtained. Physical properties of quarry dust are as given in table no 5.

Table 5.Physical Properties of Quarry Dust.

Sl. No	Description	Result
1	Specific gravity	**2.375**
2	Bulk Density (loose condition)	**1544.4 Kg/m^3**
3	Bulk Density Rodded condition)	**1755.55 Kg/m^3**

3 PRILIMINARY INVESTIGATION

3.1 Specimen Preparation

For the preliminary work, it was decided to observe the following standard process of mixing.

• Mix sodium hydroxide solution and sodium silicate solution together at least one day prior to adding the liquid to the dry materials.

• Mix all dry materials manually in a tray for about three minutes. Add the liquid component of the mixture at the end of dry mixing, and continue the wet mixing for another four minutes.

First the binder components i.e. Fly ash and GGBS are dry mixed in predetermined proportion and then quarry dust passing through 4.75 mm and retained on 75 micron sieve is added to get mortar proportion of 1:2.Then the activator solution of specified fluid binder ratio is added and mixed to get a uniform mix. The mortar is filled into 70.6 mm cubes and compressed using locally prepared wooden plank of 70.4 mm size to partially simulate the hydraulic compaction that will be used for casting bricks at the casting yard. The specimens were de-moulded after 3-4 hours of drying in ambient conditions after casting. The de-moulded specimens were kept in room temperature without any special curing regime (only cured in open air in the lab at room temp.) until tested without any curing. For each set of parameter, 9 cubes were cast, three each for determining 1 day, 3 days, and 7 days strengths. In all, 102 cubes were cast as laboratory trail for final casting of specimen.

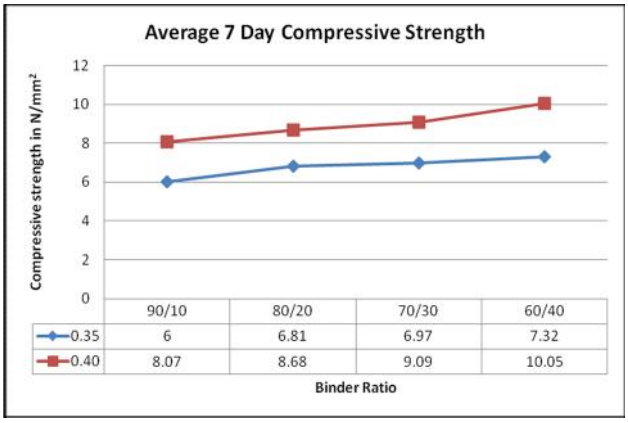
3.2. Parameters considered for geopolymer mortar for laboratory trials:

- Mortar proportion (Binder: Fine aggregate): 1:2
- Binder Proportion (FA: GGBS): 60:40, 70:30, 80:20 and 90:10
- Molarity (M) of NaOH in the activated solution: 12M and 8M
- Fluid-to- Binder Ratio (F/B): 0.35 and 0.40 and
- Sodium Hydroxide to Sodium Silicate ratio: 1:2

3.3 Results of compressive strength test on mortar with various binder ratio for 12M NaOH solution

The ambient cured specimens are tested at the end of 1day, 3 days and 7 days for uniaxail compressive strength. The results are indicated in fig1.

Fig.1 Variation of compressive strength v/s age for different fluid binder ratio.



It is observed that

- Strength increases with the increase in GGBS content.
- Strength also increases with age.
- For all of the combinations, the strength does not change appreciably between 20% and 40% GGBS.
- Strength obtained by using 30% GGBS is much higher when compared to conventional blocks.
- The expected compressive strength at 7 days is in range of 7 N/mm^2.
- The binder composition between 80/20 and 60/40 provide strength with variation of 3 to 4.5%. There is not much variation in strength in this band of binder proportion.
- Thus, for economizing, 70/30 binder proportion may be considered for further investigation.

Strength increases with increase in fluid binder ratio from 0.35 to 0.40. This may be due to the availability of more salts for polymerization. However, literature reveals that strength decreases with increase in fluid binder ratio. This could be true beyond certain ratio. This requires further investigation. Here again it is seen that strength variation with binder proportion between 80/20 to 60/40 is not significant. Therefore it is logically justified to take FA/GGBS as 70/30 for further trials.

As the compressive strength of mortar specimens with FA/GGBS of 70/30 with fluid binder ratios 0.35 and 0.40 was between 7-9 N/mm^2 it was decided to try reducing the molarity of sodium hydroxide to 8 Molar to further reduce cost and handling problem of high molar solution. Maintaining fluid binder ratio 0.35 and 0.40, cubes were cast and tested for 1,3,7,14,28 days. Table 5.3 and 5.4 gives the strength of specimens with fluid binder ratio 0.35 and 0.40 respectively with 8M NaOH solution. In this case, compaction effort was substantially increased.

Table 6. Compressive Strength for fluid binder ratio 0.35 (8 Molar Solution)

Binder Ratio	1 Day (N/mm^2)	3Days (N/mm^2)	7 Days (N/mm^2)	14 Days (N/mm^2)	28 Days (N/mm^2)
70/30	10.08	11.46	12.82	15.34	17.95
	10.08	11.12	14.58	16.14	18.43
	-	-	14.00	17.92	18.98
Average	**10.08**	**11.29**	**13.80**	**16.47**	**18.45**

Table 7.Compressive Strength for fluid binder ratio 0.40

Binder Ratio	1 Day (N/mm^2)	3Days (N/mm^2)	7 Days (N/mm^2)	14 Days (N/mm^2)	28 Days (N/mm^2)
70/30	7.26	13.12	19.6	23.24	24.77
	5.38	11.2	18.88	22.26	23.24
	-	-	17.94	25.1	26.57
Average	**6.32**	**12.16**	**18.8**	**23.53**	**24.86**

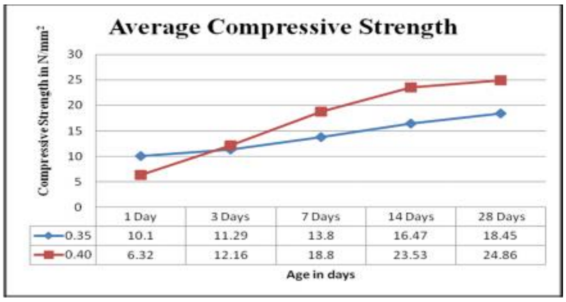


Fig .2 Variation of compressive strength v/s age for different fluid binder ratio.

Concluding Remarks.

Strengths obtained by using fluid binder ratio 0.35 were very high compared to normal cement bricks. Since pan mixer is used for mixing and hydraulic press is used for compaction in manufacturing compressed bricks, it could be possible to further reduce fluid binder ratio to 0.30 or even less for mortar proportion of 1:2, binder proportion of 70:30 and molarity of 8M **.**

4 FINAL CASTING

4.1 Specimen Preparation

First the binder components i.e. Fly ash and GGBS were dry mixed in 70/30 proportion and then quarry dust passing through 4.75mm and retained on 75 micron sieve was added to get mortar proportion of 1:2.Then the activator solution of 0.30 fluid binder ratio is added and mixed in pan mixer to get a uniform mix. The mortar is filled into 225x100x75 mm moulds and compressed using hydraulic press machine having provision to demould the specimen immediately by ejecting mechanism. The specimens were de-moulded and kept in room temperature without any special curing regime (only cured in open air in the casting yard at room temp.) until tested.

4.2 Various Tests conducted

4.2.1 Compressive Strength:

Compressive strength is an essential property which depends on curing time and curing temperature along with other parameters. In present study, the specimens were ambiently cured without any special curing regime. The specimen was placed with flat face horizontal and sand filled face, facing upwards between plates of the testing machine and load was applied till failure and maximum load at failure was noted. The bricks were tested for compressive strength for 1, 3, 7, 14 and 28 days and strength obtained are given in table.

Table 8. Compressive Strength of geopolymer blocks in (N/mm^2)

Specimen No.	1 Day	3Days	7 Days	14 Days	28 Days
1	13.48	22.39	32.17	26.52	33.70
2	18.91	20.87	28.91	30.65	30.87
3	14.35	26.52	20.22	30.65	30.87
4	16.30	23.26	28.26	30.65	32.39
5	16.96	22.61	23.48	30.44	32.61
Average	**16.00**	**23.13**	**26.61**	**29.78**	**32.09**

Discussions

In this section, strength development of ambient cured geopolymer compressed block is discussed with reference to the factors considered at the selected levels. Experimental results are presented in the form of graphs facilitating the discussions.

Fig. 3 Variation of Average compressive strength v/s age in days

Fig. 3 gives graphical representation of development of strength with age of blocks. Five blocks at each age were tested for compressive strength. From the average results of 5 blocks it is observed that strength of compressed blocks increases with age. 1 day strength of geopolymer block obtained was higher than the strength obtained by normal blocks (12-15 N/mm^2) at the end of 28 days. It is observed that the increase in strength of geopolymer compressed blocks is slower after 14 days of age. Compressive strength of 32MPa was obtained at the end of 28 days which was much greater than the normal cement blocks.

4.2.2 Weight Loss: After the blocks were casted in hydraulic press they were tested for the change in weight with age. 5 specimens were weighed every day until there was no further change in weight. Table below gives the change in weight with the age of blocks.

Table 9. Change of weight of geopolymer blocks (kg) with age (days)

Days	Specimen No.				
	1	2	3	4	5
1	3.38	3.42	3.40	3.84	3.54
2	3.28	3.34	3.35	3.76	3.48
3	3.26	3.28	3.30	3.70	3.42
4	3.23	3.27	3.27	3.68	3.39
5	3.20	3.26	3.25	3.66	3.38
6	3.20	3.25	3.25	3.65	3.38
% Change	**5.32**	**4.97**	**4.41**	**4.95**	**4.52**

With respect to 1st day weight it is observed that there is marginal loss of weight for initial 5 days after casting. Later it was found that the weight remained almost constant with age. The average change in weight was observed to be nearly 4-5%, when compared with the weight at 1 day age.

4.2.3 Instantaneous Water Absorption: As soon as the mortar is put on a brick during masonry work, the brick starts to absorb water out of the mortar. The microscopic pores in the brick soak up the water, which carries with it some of the partly-dissolved binder in the mortar. It is the setting of this cementitious material within the brick pores that provides most of the bond between the brick and the mortar, and thus gives the wall its strength. To get the best bond, it is important to match the "suction" of the brick to the water-retaining properties of the mortar. If the initial rate of absorption of the brick is too high for the mortar that is being used, the mortar may dry out too quickly and stiffen before the next course can be laid. If it is too low, not enough cementitious material is drawn up into the brick pores. In either case, the bond strength will suffer. The initial rate of absorption test measures the amount of water a dry brick can soak up during the first minute of contact with water. Blocks were immersed in water in different positions in order to study initial rate of absorption. The level of water was maintained at a height of 25mm from base and duration of immersion was maintained 1 minute (60 secs).

Table 10. Average Instantaneous Water Absorption

Brick Position	Average water absorption (kg/m^2/min)		
	Geopolymer compressed blocks	Clay bricks	Cement bricks
225x100mm	6.37	6.22	1.48
225x75mm	5.14	3.95	0.74
100x75mm	3.11	3.55	0.29

4.2.4 Water Absorption: Water absorption is a key factor affecting the durability of brick. The less water infiltrates into brick, the more durable the brick and resistant to the natural environment are expected. Thus, the internal structure of the brick must be intensive. The bricks were immersed completely in clean water at a temperature of 27+2°C for 24 hours. The specimen were removed after 24 hours and wiped out, for any traces of water with damp cloth and weighed.

Table 11. Water Absorption Test Results of geopolymer compressed blocks.

Dry Weight in kgs	Saturated Weight in kgs	Water Absorption %
3.41	3.73	9.38
3.66	3.92	7.10
3.27	3.59	9.72
Average % increase in weight		**8.74**

The water absorption requirement when tested in accordance with the procedure laid down in IS: 3495 (Part 2)-1976 [30] for 24 h immersion shall not exceed 15 percent for burnt bricks. The water absorption obtained for compressed blocks is around 9% which is well within limits. From the results it is observed that water absorption for geopolymer compressed blocks is well within the standards.

5. CONCLUSIONS

- Ambient cured fly ash based compressed geo-polymer bricks develop strength much more than that is required at the age of 7 days. Nearly 80% - 90% of strength is attained at the age of 28 days.
- Within the frame work of this study, it is observed that strength of ambient cured geo-polymer bricks increases with increase in GGBS content and molarity of alkaline solution to certain extent.

- Unit weight of geopolymer compressed bricks is less when compared to cement bricks; however, it is slightly more than that of burnt bricks.
- Water absorption for geo-polymer compressed blocks is found to be around 8% which is comparable to burnt clay bricks and it complies with IS standards laid down for 1st class bricks.
- The compressive strength of masonry prisms is found to decrease with increase in height to width ratio.
- Young's Modulus of brick prism is found to be much lesser than that of individual brick.
- It is possible to produce compressed bricks/blocks without any OPC, but using industrial by-products such as fly ash and GGBS as binder materials and quarry dust as fine aggregate instead of natural sand adopting Geopolymer Technology.
- The technology ensures lesser energy consumption, drastically reduced emission of green house gases and conservation of precious natural resources leading to environmentally friendly, eco-compatible and sustainable development of the construction industry.

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