Ambient Cured Alkali Activated Flyash Masonry Units

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Abstract: Geopolymers belong to a category of non-conventional and non-Portland cement based cementitious binders which are produced using industrial by products like fly ash and ground granulated blast furnace slag (GGBFS). This paper reports on the development of geopolymer mortars for production of masonry units. The geopolymer mortars were prepared by mixing various by products with manufactured sand and a liquid mixture of sodium silicate and sodium hydroxide solutions. After curing at ambient conditions, the masonry units were tested for strength properties such as water absorption, initial rate of absorption, compression, shear-bond, and stress-strain behaviour etc. It was observed that the flexural strength of the blocks is more than 2 MPa and shear bond strength is more than 0.4MPa. It was found that the properties of geopolymer blocks were superior to the traditional masonry units. Hence they can be recommended for structural masonry.

Key words: Fly ash, GGBFS, M-Sand, Masonry units, Strength.

1. Introduction

The history of masonry construction is regarded as the beginning of civil engineering. Masonry is one of the oldest methods of construction built for provide aesthetics and durability. Masonry is building of structures with individual units called masonry units well bonded by mortar between units. In the 19th century, Park Guell in Barcelona, a famous monument was built using reinforced masonry designed by Spanish architect Antoni Gaudi [1]. In the present construction, masonry is being widely used in the construction of residential buildings, commercial buildings and public buildings. Masonry structure performs variety of functions like, supporting loads, dividing and subdividing the space, providing aesthetic appearance, thermal and acoustic insulations etc. The traditional types of masonry units are burnt clay bricks, hollow blocks, solid blocks and stabilized mud blocks. These masonry units are adopted based on requirements like, compressive strength, accessibility, cost and ease of construction [2]. In India, there are about 1lakh brick manufacturing industries which produce 140 billion bricks per year and consume around 400 million tonnes of top fertile soil. Nearly 25 million tonnes of coal and fossil fuel are required for burning of bricks that are energy intensive materials [3]. Brick industries are releasing 28% of sulphur oxide one of the major air pollutants to the atmosphere annually. Cement being main ingredient in the manufacture of cement concrete blocks produces
considerable amount of carbon dioxide contributing to nearly 7% of world’s CO₂ emission leading to
global warming [4].

Geopolymer is the term coined by Professor Joseph Davidovits for family of high alkali binders
formed in a reaction called as geopolymerization [5]. Geopolymers are the family of binders formed
by using alkaline solutions and alumino silicates like fly ash, Ground granulated blast furnace slag
(GGBFS) resulting in three dimensional aluminosilicate polymeric gel. Geopolymers are
environmental friendly as they make use of industrial by-products and eliminate use of conventional
cement. Many researchers have reported that, utilization of refractory concrete can be made using
quartz sand, alumina powder, zeolites and rice husk using geopolymer [6-7]. Use of fly ash and
GGBFS in concrete can result in achieving considerable compressive, split tensile and bond strength
[8-14]. Different geopolymer composites can be made using geopolymers and phenomenological
models can be developed to re-proportion them [15-20]. Compressive and tensile strength of
geopolymer concrete can be increased to 5-10% by replacement of fine aggregates with paper sludge
in fresh concrete [21-22]. Use of solid brick-pure lime mortar masonry prisms will exhibit 10 times
more strength than the mortar [23]. It was found that the effect of freeze-thaw cycles on masonry does
not affect up to 150 cycles but after 150 cycles the bricks and mortar were damaged [24]. Study on
properties of ready mix earth plastering mortar satisfied the German codal provisions and can be used
as rehabilitation plaster for existing masonry structures [25-27]. Though there is considerable research
reported on brick and block masonry, the production of these masonry units are not sustainable.
Hence there is need to develop alternative masonry units, one of these can be geopolymer masonry
blocks. This paper addresses the technology of making geopolymer masonry blocks and their
properties.

Even though the research on geopolymer concrete is extensively reported the development of
geopolymer masonry blocks is relatively a new concept. In case of geopolymer concrete, use of
alkaline salts is considerably high therefore may not be economically feasible all the times. The
amount of alkaline salts can be considerably reduced in making geopolymer masonry blocks.
Determination of strength and durability of these blocks will boost the confidence level of field
engineer and thus present study will be helpful to construction industry.

2. Methodology

The following materials were used to prepare geopolymer masonry blocks: -

(i) Class F Fly ash and GGBFS.
(ii) Manufactured sand (M-sand).
(iii) Sodium hydroxide and Sodium silicate.
(iv) Recycled water.

In the experiment, Low calcium Class-F fly ash and GGBFS were used as binders. The specific
gravity of fly ash and GGBFS were 2.40 and 2.90 respectively. M-sand was used as fine aggregates.
The specific gravity of M-sand was 2.61. The fineness modulus of M-sand (zone-II) was 3.45. The
details of mix proportions are shown in Table 1.

The fly ash, GGBFS and M-sand were first mixed thoroughly in dry condition and then alkali solution
was added to prepare fresh mortar. The molarity of Sodium Hydroxide used was 8M. The geopolymer
masonry blocks were prepared by compressing the required amount of mortar and cured in open air
without any special treatment. The masonry units were tested for water absorption, initial rate of water
absorption, density, flexural strength, shear bond strength. The compressive strengths were
determined along with modulus of elasticity.
Table 1. Details of Mix Proportions with Series designation of the blocks

| Series Designation | Mortar Proportion [Binder : M-Sand] | Alkaline Proportion [Hydroxide : Silicate] | Fluid-Binder Ratio [F/B] |
|--------------------|--------------------------------------|--------------------------------------------|--------------------------|
| GPB-1              | 1 : 1                                 | 1:0                                        | 0.20                     |
| GPB-2              | 1 : 1                                 | 1:0.5                                      | 0.20                     |
| GPB-3              | 1 : 1                                 | 1:1                                        | 0.20                     |
| GPB-4              | 1 : 1                                 | 1:1.5                                      | 0.20                     |
| GPB-5              | 1 : 1                                 | 1:2                                        | 0.20                     |
| GPB-6              | 1 : 1                                 | 1:2.5                                      | 0.20                     |

3. Results and Discussion

The water absorption and density tests of geopolymer masonry blocks were conducted as per IS 1077-1992 and are tabulated in Table 2. According to codal provision the water absorption of masonry blocks should be less than 20% and densities should not be more than 2.0 gm/cc. It was found that the water absorption of geopolymer masonry blocks ranges from 9.0 to 10.5% which is considerably low as compared to the traditional masonry blocks. The density of geopolymer masonry blocks ranges from 1.78 to 1.89 g/cc which are at par with the traditional masonry blocks.

Table 2. Water absorption and dry density tests for geopolymer masonry blocks

| Series Id. | Water Absorption [%] | Average Dry Density [gm/cc] |
|------------|----------------------|----------------------------|
| GPB-1      | 10.5                 | 1.78                       |
| GPB-2      | 10.1                 | 1.81                       |
| GPB-3      | 9.8                  | 1.825                      |
| GPB-4      | 9.6                  | 1.85                       |
| GPB-5      | 9                    | 1.89                       |
| GPB-6      | 8.5                  | 1.91                       |

Initial Rate of Absorption [IRA] of geopolymer blocks at 28 days is shown in Table 3 for various phases of immersion. IRA was found to be less than 5% of phases of immersions for the different series, which indicates that the masonry mortar will have good water retentivity [26].

Table 3. Initial Rate of Absorption [IRA] of geopolymer blocks at 28 days

| Series Id. | Face Immersed | IRA [kg/m²/min] | Avg. IRA [kg/m²/min] |
|------------|---------------|-----------------|----------------------|
| GPB-1      | 230mm x 150mm | 4.9             | 4.83                 |
The variation of compressive strength of the geopolymer masonry blocks with age is indicated in Figure 1. It can be observed that the compressive strength of the geopolymer masonry blocks at the age of 3 days is more than 3 MPa, which is quite interesting when compared to the conventional masonry blocks. It is sufficient to handle the geopolymer masonry blocks for various purposes and increased production at site. The minimum compressive strength of geopolymer masonry blocks at 28 days is 3.5MPa as per IS 1077-1992. The strength of the geopolymer masonry blocks increased with increase in sodium silicate ratio. The compressive strength varies ranging from 5-23 MPa for the masonry units [26].
Scanning Electron Microscope (SEM) image of geopolymer masonry blocks is shown in Figure 2. Microstructure of the image shows the presence of unreacted flyash particles and aluminosilicate gel phases and the unreacted fly ash particles were of size less than 2µm. It appears that the low molarity of alkaline solution may not have influenced by all the available fly ash. There is a possibility of activating these particles at higher molarity and develop higher strength.

![Figure 2](image1.png)

**Figure 2.** Scanning Electron Microscope Image of geopolymer masonry blocks

Figure 3 shows the X-Ray Diffraction (XRD) results of the geopolymer masonry block. The Material composition of geopolymer masonry block is shown in Table 4.

![Figure 3](image2.png)

**Figure 3.** X-Ray Diffraction Results of Block
The flexural strength test was carried out as per IS 4860:1968 and the minimum flexural strength of compressed geopolymer masonry block at 28 days was 10% of the compressive strength and is shown in Table 5. It was also found that flexural strength was more than 2 MPa and shear bond strength more than 0.4 MPa which are considerably more due to bonding between fluid, binders and aggregates as compared to the traditional cement blocks [26].

![Image](https://via.placeholder.com/150)

**Figure 4.** Normalized Stress-Strain curve for the blocks
4. Conclusions

Based on the limited study of geopolymer masonry blocks, the following broad conclusions can be made:

- Basic properties of geopolymer masonry blocks indicate their suitability for use in structural masonry.
- The flexural strength, shear bond strength of geopolymer masonry blocks is higher compared to regular cement blocks.

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References

[1] Anita Fódi and István Bódi, Basics of reinforced masonry, Concrete structures, 3(1), pp 69-77 (2011).
[2] Robert G. Drysdale and Ahmad A. Hamid, “Masonry structures behaviour and design”, Third edition, McMaster University, Hamilton, Ontario (2008).
[3] Deepasree M Vijay., Poornima A Menon., Fathima Shahanas., “Environmental pollution from brick making operations and their effect on workers”, Biomarkers, 4(3), pp 162-166 (2001).
[4] “Climate change and the cement industry” GCL’s Cement Trends-2002, GCL-Environmental special issue, Conference and forum, London, Monday 27 May (2002).
[5] Joseph Davidovits, “Properties of geopolymer cements”, Proceedings of Kiev state technical university Conference, Ukraine, pp 131-149 (1994).
[6] Andri Kusbiantoro, Muhd Fadhil Nuruddin b, Nasir Shafiq b and Sobia Anwar Qazi, “The effect of microwave incinerated rice husk ash on the compressive and bond strength of fly ash based geopolymer concrete”, Construction and Building Materials. 36, pp 695–703. (2012).
[7] Rajamane N. P., Nataraja M. C. and Lakshmanan N., “Applicability of Acceptance Criteria of IS: 456-2000 to GGBS based Self Curing Geopolymer Concrete”, Proceedings of International Conference, “Advances in Materials and Structures”, ICI-AMAS, Puducherry, India. pp. 370-378. (2011).
[8] Rajamane N. P., Nataraja M. C., Lakshmanan N. and Dattatreya J. K., “Pull-Out Tests for Strengths of Geopolymer Concretes”, Proceedings of International Conference, “Advances in Materials and Structures”, ICI-AMAS, Puducherry, India. pp. 350-358. (2011).
[9] Venugopal K, Radhakrishna Properties and Application of Geopolymer Masonry Units SSRG International Journal of Civil Engineering (SSRG-IJCE) –EFES, ISSN: 2348 –8352, pp 117-119, April (2015).
[10] K. Vijai, R. Kumutha and B. G. Vishnuram, “Experimental Investigation on Mechanical Properties of Geopolymer Concrete Composites”, Asian Journal of Civil Engineering (Building and Housing), Vol. 13, No. 1, pp. 89-96 (2012).
[11] Prabir K. Sarker, Rashedul Haque and Karamchand V. Ramgolam, “Fracture behaviour of heat cured fly ash based geopolymer concrete”, Materials and Design, 44, pp. 580–586 (2013).
[12] Benny Joseph and George Mathew, “Influence of aggregate content on the behaviour of fly ash based geopolymer concrete”, Scientia Iranica Transactions A: Civil Engineering, doi:10.1016/j.scient.2012.07.006. (2012).
[13] Saeed Ahmari, Xin Ren, Vahab Toufigh and Lianyang Zhang, “Production of geopolymeric binder from blended waste concrete powder and fly ash”, Construction and Building Materials, 35 pp. 718–729. (2012).
[14] Ali Nazari, “Compressive strength of geopolymers produced by ordinary Portland cement: Application of genetic programming for design”, Materials and Design, 43, pp. 356–366 (2013).

[15] Radhakrishna, Shashishankar A., Udayashankar.B.C and Renuka Devi. M.V., “Compressive Strength Assessment of Geopolymer Composites by a Phenomenological Model”, Journal of Reinforced Plastics and Composites, 4 Vol. 29, No. 6, pp 840-852 (2010).

[16] Radhakrishna, “A Phenomenological Model To Re-Proportion Geopolymer Compressed Blocks”, Concrete Technology Today, vol 7, No. 3 pp.46-48 (2008).

[17] Radhakrishna, Renuka Devi. M.V. and Udayashankar.B.C. “Use of fly ash in Construction Industry for sustainable development” Journal of Environmental Research and Development, volume 03, pp1211-1221 (2009).

[18] Radhakrishna, Shashishankar A. and Udayashankar.B.C “Analysis and Assessment of Strength Development in Class F Fly Ash Based Compressed Geopolymer Blocks” Indian Concrete Journal, Vol 82, No.8.pp.31-37 (2008).

[19] Radhakrishna, Shashishankar A. and Udayashankar. B. C., Phenomenological Models to Proportion Phenomenological Model To Re-Proportion geopolymer Compressed Blocks. 3rd Conference on Our World in Concrete & Structures, Singapore, 25 – 27 August (2008).

[20] Radhakrishna, Manjunath GS., C Giridhar and Mahesh Jadav “Strength Development in Geopolymer pastes and Mortars”, International Journal of Earth Sciences, ISSN 0974-5904, Volume 04, No 06 SPL, pp. 830-834 (2011).

[21] Abdullah shahbaz khan, Ram panth, Gagan Krishna R.R, Suresh G. Patil “Structural Performance of Concrete by Partial Replacement of Cement with Hypo Sludge” International Journal of Emerging Technologies and Engineering (IJETE) ISSN 2348–8050 Volume 1 Issue 7 August (2014).

[22] Andrew M Dunster “Characterization of Mineral wastes, Resources and Processing Technologies-Integrated Waste management for the production of construction material- Case study on Paper Sludge ash in portland cement manufacture, WRT 177 / WR0115, October- (2007).

[23] Anastasios Drougkas, Pere Roka, Clement Molins, “Compressive strength and elasticity of pure lime Mortar masonry”, Journal of materials and structures, Vol-49, issue-3, pp 983-999, march (2016).

[24] Mojmir Urankjek and violeta Bokan-Bosiljekov, “Influence of freeze-thaw cycles on mechanical properties of Historical brick masonry”, Journal of construction and building materials 84, pp 416-428, (2015).

[25] Paulina Faria, Tânia Santos, Jean-Emmanuel Aubert, “Experimental characterization of an earth eco-efficient plastering mortar”, Journal of materials in civil engineering, ISSN (online): 1943-5533, pp-116-120, Volume 28, Issue 1 January (2016).

[26] G. Sarangapani, B. V. Venkatarama Reddy and K. S. Jagadish “Structural characteristics of bricks, mortars and masonry” Journal of Structural Engineering. No.29-11, pp. 101-107, July-September (2002).

[27] G. Sarangapani, B. V. Venkatarama Reddy and K. S. Jagadish “Brick-Mortar Bond and Masonry Compressive Strength” Journal of Materials in Civil Engineering. Vol. 17, No. 2, pp. 229–237, April (2005).