Development of Alkali Activated Solid and Hollow Geopolymer Masonry Blocks

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Abstract: Cement masonry units are not considered as sustainable since their production involves consumption of fuel, cement and natural resources and therefore it is essential to find alternatives. This paper reports on making of geopolymer solid & hollow blocks and masonry prisms using non conventional materials like fly ash, ground granulated blast furnace slag (GGBFS) and manufactured sand and curing at ambient temperature. They were tested for water absorption, initial rate of water absorption, dry density, dimensionality, compressive, flexural and bond-strength which were tested for bond strength with and without lateral confinement, modulus of elasticity, alternative drying & wetting and masonry efficiency. The properties of geopolymer blocks were found superior to traditional masonry blocks and the masonry efficiency was found to increase with decrease in thickness of cement mortar joints. There was marginal difference in strength between rendered and unrendered geopolymer masonry blocks. The percentage weight gain after 7 cycles was less than 6% and the percentage reduction in strength of geopolymer solid blocks and hollow blocks were 26% and 28% respectively. Since the properties of geopolymer blocks are comparatively better than the traditional masonry they can be strongly recommended for structural masonry.

Keywords: Fly ash, GGBFS, M-Sand, Masonry units and Strength.

Introduction

Masonry construction is one of the oldest methods of construction on the earth where masonry units are joined together with mortar to make structural masonry. The most popular masonry units are burnt bricks and concrete blocks. Conventional masonry blocks are not considered as sustainable due to consumption of cement, fossil fuels and top fertile soil. Cement is the primary ingredient in the manufacture of concrete blocks. Production of one tonne of cement liberates approximately same amount of carbon-di-oxide to the atmosphere and cement industries are responsible for 5% of total CO₂ emissions and subsequently responsible for 4% of manmade global warming [1]. Sarangapani et al, found that the modulus of burnt brick in the range of 5 to 10% of the modulus of 1: 6 cement mortars results to the masonry where mortar joints develop lateral tension while brick develops...
lateral tension[2-3]. The compression characteristics of solid brick-pure lime mortar masonry prisms exhibited 10 times more strength than the mortar [4]. It is reported that the modulus of elasticity of burnt bricks manufactured in India ranges from 330 MPa to 8900 MPa and the compressive strength ranges from 3 to 19 MPa [5].

There is some literature reported on use of non-traditional materials in making structural masonry. The binder used was geopolymer, one of the new alternative materials among others, where complete elimination of cement is achieved without compromising on the strength and other parameters. The term, Geopolymer was coined by Professor Joseph Davidovits for the family of high alkali binders formed in a reaction called as geopolymerization [16]. 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 which are environmental friendly since are made by use of industrial by-products and eliminate use of conventional cement. Vijaysankar et al, investigated that the compressive strength of ambient-cured fly ash based geopolymer blocks achieve good compressive strength of about 3.83N/mm² and percentage water absorption is less when M-Sand is used as compared to regular cement solid blocks [6-7]. Radhakrishna et al, have reported that, it is possible to manufacture geopolymer masonry units using class F fly ash which is abundantly available throughout the world. It is also reported that phenomenological models can be developed to re-proportion the materials [8-12]. Khater et al, investigated that use of nano clay materials leads to enhancement in geopolymer microstructures affecting compressive strength increase up to 1% and better mechanical properties [13-14]. Susan et al developed a good understanding of chemistry of activated binders when exposed to aggressive environments and the existing correlation with their microscopic properties [15]. Some of researchers concluded that the geopolymer concrete specimens cured at 60°C exhibited better compressive strength than those cured in room temperature. Increase in strength with age of ambient cured specimens was higher than those of heat cured specimens [17-18]. Researchers reported that compressive strength of geopolymer concrete increased with concentration of sodium hydroxide and molarity of alkaline fluid used and stated that higher the ratio of sodium silicate to sodium hydroxide, higher the compressive strength of flyash based geopolymer concrete [19-20]. 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 which can be geopolymer unit. This paper addresses the technology of making solid and hollow geopolymer units and prisms. The main objectives of the research are as follows: -

A. To evaluate properties of masonry units like water absorption & initial rate of water absorption, dry density, dimensionality test, compression strength, flexural strength, bond-strength with and without lateral confinement, stress-strain values and alternative drying and wetting method.

B. To determine properties of masonry prisms like compressive strength and masonry efficiency of masonry prisms.

Methodology

Following materials were used to prepare geopolymer masonry blocks: -

(i) Class F Fly ash and Ground granulated blast furnace slag (GGBFS).
(ii) Sodium hydroxide and Sodium silicate
(iii) Manufactured sand.
Recycled water.

Low calcium Class-F fly ash (Fly ash) and Ground granulated blast furnace slag (GGBFS) were used as binders in the research. The specific gravity of fly ash and GGBFS were found to be 2.40 and 2.90 respectively. Manufactured sand (M-sand) (zone II) having specific gravity of 2.61 was used as fine aggregate. The fineness modulus of M-sand was found to be 3.45. 8 molarity (8 M) alkaline solutions were prepared with sodium hydroxide to sodium silicate ratio of 1:1.5. The ratio of solution and binder was maintained at 0.2. Fly ash, GGBFS and M-sand were mixed thoroughly in dry condition. Alkaline solution was added to the dry mix to get fresh geopolymer mortar. The aggregate to binder mix ratio was 1:1 and percentage of fly ash to GGBFS was maintained at the ratio of 80:20. Block making compression machine was used to cast the geopolymer blocks. The percentage hollowness for the hollow blocks was 35% and details of solid and hollow geopolymer blocks are shown in Fig.1. The geopolymer blocks were cured in open air condition and the blocks were tested for water absorption, initial rate of water absorption, dry density, dimensionality, compression strength, flexural strength, and bond-strength with & without lateral confinement, modulus of elasticity, alternative drying and wetting test and masonry efficiency. Some of the geopolymer prisms were rendered with cement mortar.

Results and Discussion

Water absorption and density of blocks were determined as per IS 2185:2005 and are shown in Table 1. It was found that the water absorption of geopolymer solid blocks (GPSB) and geopolymer hollow blocks (GPHB) were 8.25% and 9.1% respectively, which are considerably less compared to the traditional cement blocks. The density of geopolymer blocks ranges from 1800 to 2000 kg/m$^3$ which is same as traditional units. Initial rate of absorption [IRA] of geopolymer blocks at 28 days was found to be less than 3% which indicates that the masonry mortar will have good water retentivity. These properties are much less than the values specified in IS 2185:2005 [8].

| Series ID | Water Absorption [%] | Initial Rate of water absorption IRA [Kg/m$^2$/min] | Average Dry Density [kg/m$^3$] |
|-----------|----------------------|-----------------------------------|-------------------------------|
| GPSB      | 8.25                 | 2.70                              | 1810                          |
| GPHB      | 9.1                  | 2.5                               | 1750                          |
| IS 2185:2005 | < 20                | < 5.0                             | 1800 to 2000                  |
The results of dimensionality test of masonry units are shown in Table 2. It was found that there is not much of variation in dimensions of the blocks and variation of the blocks are within the permissible limits [9].

Table 2. Dimensionality tests of Blocks

| ID'S  | Dimensio ns along | Size of the block (mm) | Dimensio ns (mm) | Average Dimensions (mm) | Variation in dimension (mm) | IS 1077:1992 |
|-------|-------------------|------------------------|------------------|-------------------------|-----------------------------|--------------|
| GPSB  | Length            | 230                    | 4615             | 230.75                  | +0.75                       | +5           |
|       | Breadth           | 150                    | 3012             | 150.60                  | +0.60                       | +3           |
|       | Height            | 85                     | 1724.4           | 86.24                   | +1.24                       | +3           |
| GPHB  | Length            | 304                    | 6103             | 305.15                  | +1.15                       | +5           |
|       | Breadth           | 150                    | 3015             | 150.75                  | +0.75                       | +3           |
|       | Height            | 110                    | 2221             | 111.05                  | +0.05                       | +3           |

Compressive strength of the masonry blocks was determined as per IS 2185:2008 and the variation of compressive strength of the geopolymer masonry units with age is shown in Fig. 2. It was noticed that the compressive strength of geopolymer masonry units at the age of 3 days is more than 5 MPa. This range of strength is sufficient to handle the masonry units for various purposes. The geopolymer masonry blocks also satisfy the requirement of IS 2185:2008 according to which the minimum compressive strength is 3.5 MPa. The strength of masonry units increases with age ranging from 5-25 MPa. It can be recommended to use these geopolymer blocks in-filled applications [10].
The flexural strength test on geopolymer blocks was conducted as per IS 4860:1968 as shown in Fig. 3. It was found that, flexural strength of the geopolymer solid blocks and hollow blocks are 1.55 and 1.79 MPa respectively, which are considerably higher compared to the traditional cement blocks due to good bonding between fluid binders and aggregates [12].

The test set up for shear bond strength test on geopolymer block is shown in Fig. 4. The results of the tests are shown in Table 3. These properties are considerably high due to the bonding between geopolymer masonry units and mortar compared to the traditional cement blocks. It was found that the shear bond strength was higher for the 1:2 mortar compared to 1:4 mortars as expected and also bond strength reduces for prisms without lateral confinement due to zero lateral load on prisms [2, 3].
Table 3. Bond Strength of Blocks

| ID’S | Mortar Ratio | Bond Strength with lateral confinement (MPa) | Bond Strength without lateral confinement (MPa) | Reduction in shear strength (%) |
|------|--------------|---------------------------------------------|------------------------------------------------|-------------------------------|
| GPSB | 1:2          | 0.3826                                      | 0.2976                                         | 28.57                         |
|      | 1:3          | 0.3061                                      | 0.2211                                         | 38.46                         |
|      | 1:4          | 0.1700                                      | 0.1275                                         | 33.33                         |
| GPHB | 1:2          | 0.4169                                      | 0.3411                                         | 22.22                         |
|      | 1:3          | 0.2653                                      | 0.2085                                         | 27.27                         |
|      | 1:4          | 0.1895                                      | 0.1327                                         | 42.86                         |

The variation of stress and strain for geopolymer blocks is indicated in Fig. 5. The modulus of elasticity of geopolymer masonry blocks was found to be 9394 MPa at the age of 28 days. This is superior compared to traditional burnt block units [5].

Figure 5. Normalized stress strain curve for the blocks.
The compressive strength was determined after completion of 7 cycles for alternative drying and wetting test. The typical variation in the weight of geopolymer solid blocks and hollow blocks are represented in Fig. 6 and 7.

It was found that percentage weight gain after 7 cycles for the geopolymer solid blocks and hollow blocks are 5.05% and 5.75% respectively and the percentage reduction in strength are 26.1% and 28.27% respectively. These properties are comparatively better than the traditional masonry [3].

**Figure 6.** Alternate wetting and drying test on geopolymer solid block

**Figure 7.** Alternate wetting and drying tests on geopolymer Hollow blocks

The masonry efficiency was determined for the rendered and unrendered geopolymer prisms and cement mortar joints, the test setup of which is shown in Fig. 8. The variations of the strength and efficiency for the rendered and unrendered geopolymer block prisms are shown in Figs. 9, 10, 11 and 12 respectively [3]. It is observed that the efficiency of masonry increases with decrease in thickness of cement mortar joint. Whereas the difference in masonry efficiency of rendered and unrendered
block prisms is nominal the modulus of elasticity increases with decrease in thickness of mortar joints.

It was observed that the vertical cracks developed from one third of the prism from left hand side and cracks increased up to 3 mm and also bottom most prisms were crushed to a considerable extent.

Fig 8. (a) Test Setup        Fig 8. (b) After Test
Figure 8. Stack Bonded Geopolymer block prisms

Figure 9. Rendered Geopolymer Solid Block Prisms.
Figure 10. Unrendered Geopolymer Solid Block Prisms.

Figure 11. Rendered Geopolymer Hollow Block Prisms.
The modulus of elasticity for the rendered and unrendered geopolymer solid blocks and hollow blocks prisms are shown in Table. 4. It was observed that the moduli of elasticity for the lesser joint thickness for rendered blocks are more compared to unrendered geopolymer block and it was noticed that there is not much difference between the rendered and unrendered geopolymer solid and hollow blocks. Since the solid and hollow geopolymer masonry blocks satisfy all the requirements, they can be recommended for structural masonry.

![Graph showing modulus of elasticity](image)

**Figure 12. Unrendered Geopolymer Hollow Block Prisms.**

| IDs   | Mortar joint thick (mm) | Modulus of elasticity of the Blocks (MPa) | Rendered | Unrendered |
|-------|-------------------------|----------------------------------------|----------|------------|
|       |                         |                                        |          |            |
| GPSB  | 7.5                     | 8999                                   | 8471     |            |
|       | 10                      | 7473                                   | 6313     |            |
|       | 12.5                    | 7037                                   | 5831     |            |
| GPHB  | 7.5                     | 8683                                   | 7942     |            |
|       | 10                      | 7811                                   | 7296     |            |
|       | 12.5                    | 7536                                   | 6682     |            |

**Table 4. Modulus of elasticity for rendered and unrendered geopolymer block prisms**

**Conclusions**

Following are the broad conclusions based on the limited study on geopolymer masonry blocks.

- The compressive strength of geopolymer hollow blocks at the age of 3 days was more than 5MPa. This facilitates the user to handle blocks without any difficulties.

- The water absorption, initial rate of water absorption, density, dimensionality modulus of elasticity of masonry units were found suitable for their use in field.

- Flexural bond strength of the geopolymer hollow blocks is more than that of solid blocks.
Masonry efficiency of geopolymer blocks increases with decrease in height/thickness ratios.

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