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Structural Behavior of Geopolymer Masonry

K. Venugopal[1] and Radhakrishna[2]

[1]Department of Civil Engineering, Jain University, Bengaluru – 560069, Karnataka, India; venugopalk82@yahoo.co.in
[2]Department of Civil Engineering, RV College of Engineering, Affiliated to Visvesvaraya Technological University, Bengaluru - 560059, Karnataka, India; radhakrishna@rvce.edu.in

Abstract

Background/Objectives: To determine the basic properties of masonry units, masonry efficiency for the different h/t ratios of the masonry prisms and wallets. **Methods/Statistical Analysis:** The geopolymer bricks were cured at ambient temperature. These bricks were tested for compression, Initial Rate of Absorption [IRA], density, water absorption, dimensionality and modulus of elasticity. They were also tested for alternative drying and wetting. The microstructure of the bricks was also analyzed. Geopolymer prisms were cast and tested using geopolymer mortar / cement mortar for the different thickness of joints. The Masonry wallets were constructed using geopolymer brick and conventional cement mortar. They were tested for axial and eccentric loading. **Findings:** The compressive strength of geopolymer brick attains more than 5MPa within 24 hours which influences the user to handle without any issues. It was found that the basic properties of geopolymer masonry brick well within the limits prescribed in the relevant codes. Geopolymer mortar can be used as mortar in building masonry structures as it exhibits better compressive strength and other properties than cement mortar. The performance of the axial and eccentrically loaded wallette was found to be superior compared to the conventional cement brick masonry. **Application/Improvements:** The geopolymer masonry bricks were used as structural masonry units due to better performance.

Keywords: Efficiency, Geopolymer Bricks, Masonry, Strength, Sustainable

1. Introduction

Masonry units are the main component of a masonry structure. They fill up the bulk of the space in the structure. They play a major role in the compressive strength of masonry and in resisting the structural loads[1]. The popular masonry units are burnt clay bricks, hollow and solid concrete blocks, stabilized mud blocks etc. They are selected based on the consideration of required compressive strength, accessibility, cost and ease of construction[2-5]. Cement is the chief ingredient for manufacturing concrete blocks. Production of one tonne of cement liberates approximately same amount of carbon-di-oxide to the atmosphere. Cement industries are responsible for 5% of the total CO_2 emissions and are subsequently responsible for 4% of the manmade global warming[6,7]. Due to increase of green house gas emissions, the consumption of cement needs to be reduced. Geopolymer technology is one in which conventional cement can be replaced by products such as fly ash and Ground Granulated Blast-Furnace Slag (GGBFS). Geopolymer is the term coined by professor Joseph Davidovits for the family of high alkali (K-Ca)-poly-(Sialate-siloxo) binders formed in a reaction called as geopolymerization resulting in 3 dimensional zeolitic frameworks[8]. Geopolymers are the family of binders formed 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 the use of conventional cement.

Radhakrishna et al have reported that, it is also possible to manufacture geopolymer masonry units using class F fly ash by open curing[9-13]. It is reported that the extent of alkali silica reaction in flyash based geopolymers is relatively less than that of conventional concrete[14].

Other researchers have studied the optimum dosage of flyash and concluded that the bricks attained the highest

**Author for correspondence*

compressive strength when 20% of clay was replaced by flyash[15-18]. It is reported that the bricks were porous, light weight, had low thermal conductivity and satisfactory compressive strength[19]. The masonry prisms exhibited 10 times more strength than the mortar[20-22].

Though there is considerable research reported on brick and block masonry, the production of these masonry units is not sustainable. Hence there is a need to develop alternative masonry units, one of which can be geopolymer unit. This paper addresses the technology of making geopolymer units, prisms and wallets and their structural behavior.

2. Methodology

The following materials were used to prepare geopolymer masonry bricks:

- Class F Fly ash and GGBFS.
- Manufactured sand of zone II having specific gravity of 2.55.
- Recycled water.
- Commercially available Sodium hydroxide and Sodium silicate.

Low calcium Class-F fly ash and GGBFS were used as binders. The specific gravity of fly ash and ground granulated blast furnace slag were 2.40 and 2.90 respectively. Eight molarity alkaline solutions was prepared having 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 manufactured 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. The percentage of fly ash to GGBFS was 80:20. Brick making compression machine was used to cast the geopolymer bricks. The geopolymer bricks were cured in ambient temperature. These bricks were tested for compression, Initial Rate of Absorption (IRA), density, water absorption, dimensionality and modulus of elasticity. They were also tested for alternative drying and wetting. The microstructure of the bricks was also analyzed.

GeoPolymer Prisms (GPP) was cast and tested using geopolymer mortar/cement mortar for the different thickness of joints. The IDs indicated in Table 1. Masonry wallets were constructed using geopolymer brick and conventional cement mortar. They were tested for axial and eccentric loading. Properties of recycled water are shown in Table 2 and were tested for different parameters.

3. Results and Discussion

The results of water absorption test and density of the bricks are shown in Table 3. It was found that the water absorption of the masonry units was 8.25% which is considerably less compared to the conventional bricks[17]. The density of the masonry was in the range of 1800 to 2000 kg/m^3 which are at par with the traditional masonry

Table 1. Designation of the brick prisms

Sl no	Brick ID	Type of Mortar	Thickness of Mortar joint in mm
1	GPP-12.5GPM	Geopolymer	12.5
2	GPP-10GPM	Geopolymer	10.0
3	GPP-7.5GPM	Geopolymer	7.5
4	GPP-12.5CM	Cement	12.5
5	GPP-10CM	Cement	10.0
6	GPP-7.5CM	Cement	7.5

Table 2. Properties of recycled water

Colour	Odour	pH	Chlorine in mg/l	Total suspended solids in mg/l	BOD in mg/l	COD in mg/l
Colour less	Odour less	7.67	0.13	20	27	68

Table 3. Water absorption and dry density tests for bricks

Series	Water Absorption (%)	Initial Rate of water absorption IRA (Kg/m^2/min)	Average Dry Density (kg/m^3)
Geopolymer Brick	8.5	3.0	1800
IS 2185:2005	< 20	< 5.0	1800 to 2000

units. IRA of geopolymer bricks at 28 days was found to be less than 5% which indicates that the masonry mortar will have good water retentivity[17]. These properties are much less than the value specified in IS 2185: 2005.

The dimensionality test of the masonry units was conducted as per IS 1077:1992. The test results are shown in Table 4. It was found that the variations (dimensions) of the bricks are within the permissible of codal provisions.

The variation of the compressive strength of the masonry units with age is shown in Figure 1. It was observed that the compressive strength of the masonry units at the age of 24 hours is more than 5 MPa. This order of strength would be sufficient to handle the masonry units for various purposes. Also, the minimum compressive strength for a brick is 3.5MPa at the time of using them in masonry construction[17]. The strength increases with age ranging from 5-22 MPa for the masonry units. This high strength of masonry units can be recommended for high raised buildings by avoiding framed structures.

The variation of stress and strain for geopolymer brick is indicated in Figure 2. The modulus of elasticity of geopolymer masonry brick was found to be 9394 MPa at the age of 28 days. This is superior compared to traditional burnt brick[17].

Scanning Electron Microscope image of 8M NaOH brick is as shown in Figure 3 at the age of 28 days. Microstructure shows the presence of some unreacted flyash particles and aluminosilicate gel phases. The unreacted flyash particles were of size less than 2 µm. Low molarity of alkaline solution may not have been influenced by all the fly ash available. There is a possibility of activating these particles at higher molarity and develop higher strength.

The compressive strength was evaluated after completion of 7 cycles of alternative drying and wetting test. The typical variation in the weight of geopolymer brick are represented in Figure 4. It was found that per-

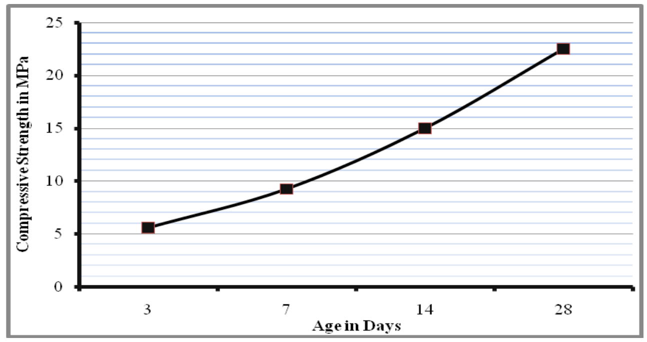


Figure 1. Compressive strength of Geopolymer bricks with age.

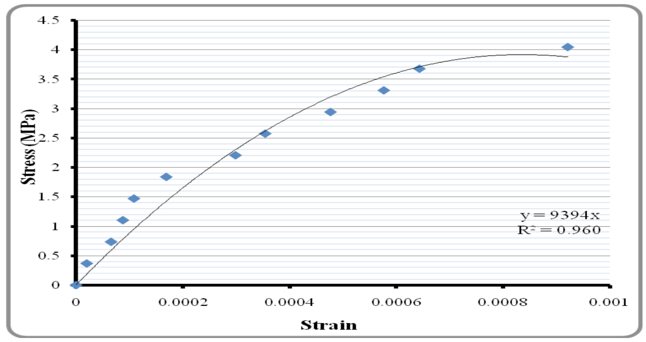


Figure 2. Normalized stress strain curve for brick.

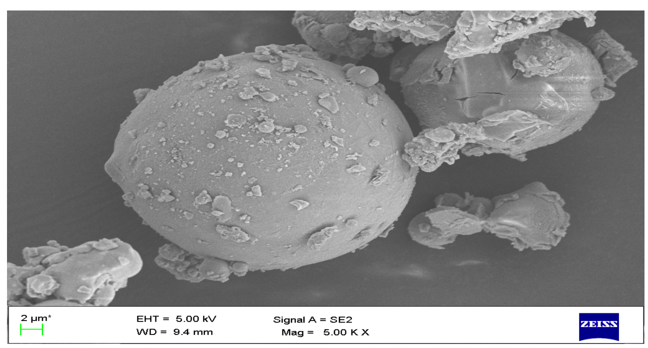


Figure 3. Scanning electron microscope image of 8 M NaOH brick.

Table 4. Dimensionality tests of bricks

Number of block in each type: 20 no's						
Type of block	Over all dimensions measured along	Size of the Brick (mm)	Dimensions (mm)	Average Dimensions (mm)	Variation in dimension (mm)	Codal Provision IS 1077:1992
Geopolymer Brick	Length (L)	225	4557	227.85	+2.85	+5
	Breadth (W)	107	2155	107.75	+0.75	+3
	Height (H)	75	1510	75.50	+0.50	+3

centage weight gain after 7 cycles was 5.20% and the percentage of reduction in strength of geopolymer brick was 26.66%. These properties are comparatively better than the traditional masonry units[17].

The test setup for the geopolymer masonry prisms are shown in Figure 5. The variation of compressive strength and masonry efficiency for geopolymer prisms with geopolymer mortar and geopolymer prism and cement mortar is shown in Figure 6 and 7 respectively. It was observed that the masonry efficiency and strength were increased with the increase in mortar thickness

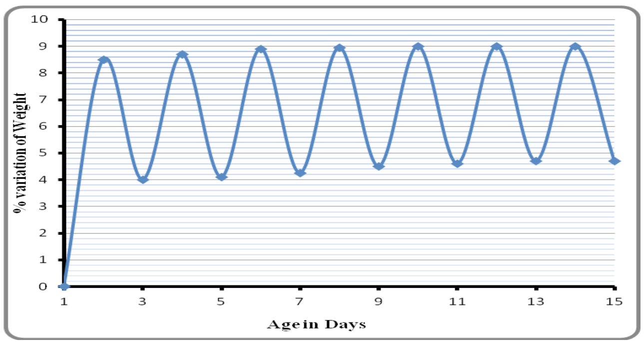


Figure 4. Alternate wetting and drying test on geopolymer brick.

(a) (b)

Figure 5. Stack bonded geopolymer brick prisms. (**a**) Test setup. (**b**) Cracking pattern.

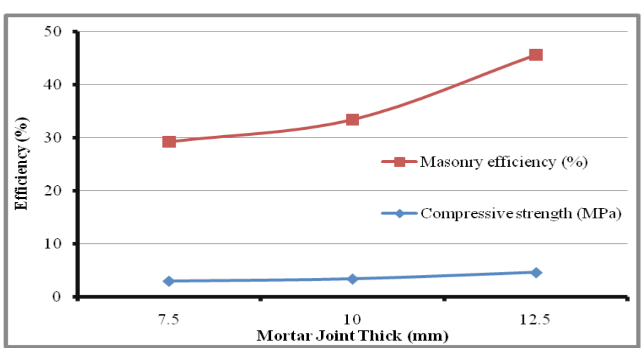


Figure 6. Geopolymer prisms with geopolymer mortar joints.

in geopolymer prisms with geopolymer mortar joints. Whereas, the efficiency and strength increased as the mortar thickness reduces for prisms with cement mortar. The vertical cracks were developed from top of a brick and it propagates till the bottom of the brick in the prism. It also noticed that bottom most brick was crushed to considerable extent.

The normalized stress strain curves for the geopolymer masonry prism with geopolymer mortar are shown in Figures 8(a), (b), (c) and the geopolymer prisms with cement mortar joints are shown in Figures 9(a), (b), (c) respectively[18]. It was observed that the young's modulus increased with the increase in mortar thickness in geo-

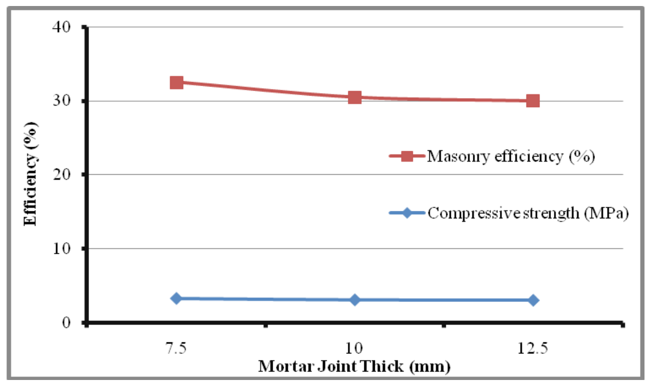
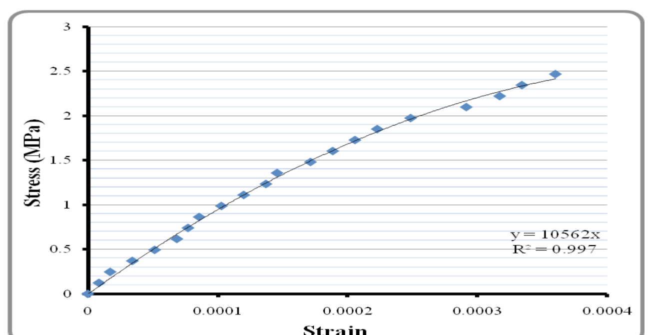
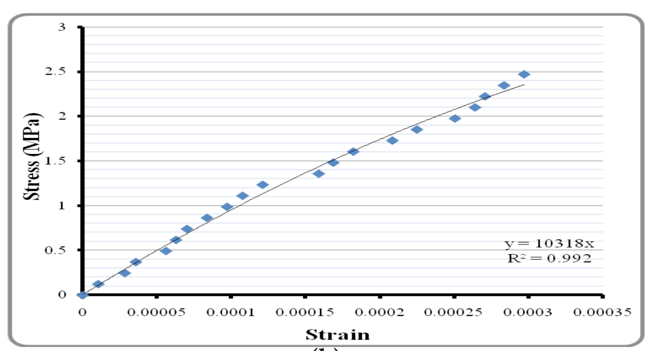


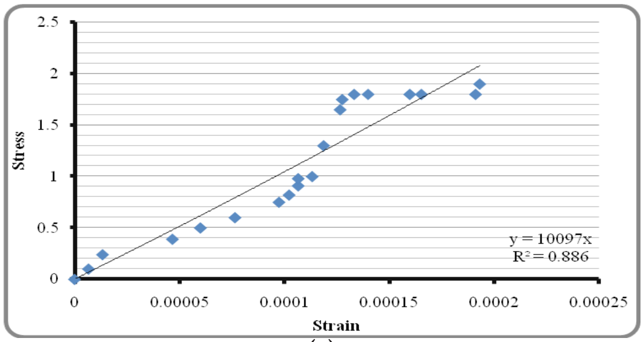
Figure 7. Geopolymer prisms with cement mortar joints.



(a)

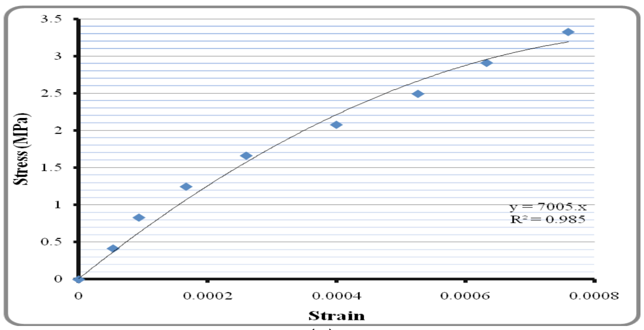


(b)

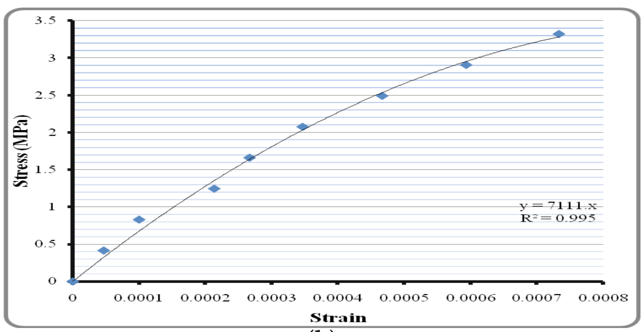


(c)

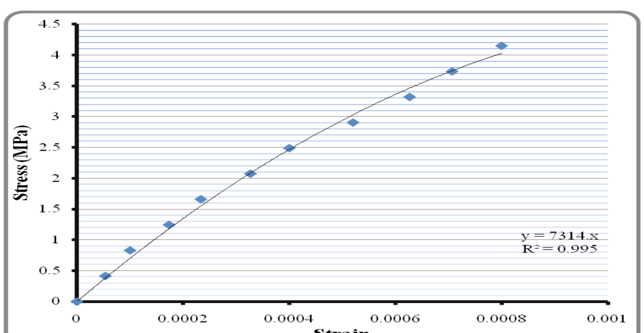
Figure 8. (**a**) Normalized stress-strain curve for GPP-12.5-GPM. (**b**) Normalized stress-strain curve for GPP-10-GPM. (**c**) Normalized stress-strain curve for GPP-7.5-GPM.



(a)



(b)



(c)

Figure 9. (**a**) Normalized stress-strain curve for GPP-12.5-CM. (**b**) Normalized stress-strain curve for GPP-10-CM. (**c**) Normalized stress-strain curve for GPP-7.5-CM.

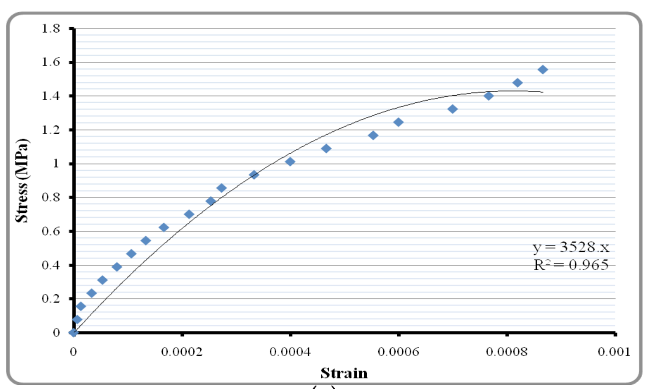
polymer prisms with geopolymer mortar joints. Whereas the young's modulus increased as the mortar thickness reduces for prisms with cement mortar.

The test setup of testing geopolymer masonry wallets for axial compressive strength is shown in Figure 10. It is observed that the average compressive strength of the axially loaded and eccentrically loaded wallets was 1.99 and 1.66 MPa respectively. It is comparatively higher to the conventional brick wallets of same geometry[18]. The vertical cracks were developed from top of a wallette and propagated till one third of the height from top of the wallette as shown in Figure 10 (b). This behaviour is in line with any masonry wallet.

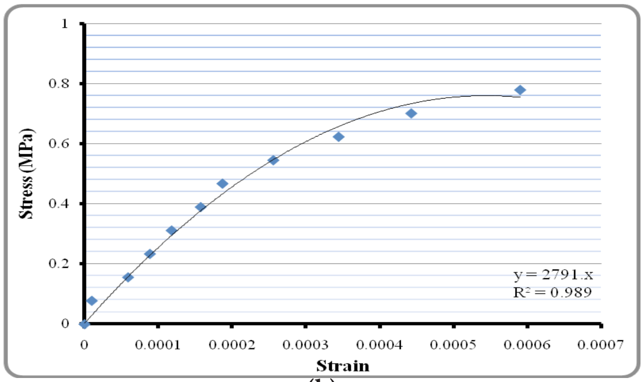
The normalized stress strain curve for the geopolymer masonry walletes with cement mortar are shown in Figure 11 (a) and (b), the modulus of elasticity for the axially loaded and eccentrically loaded walletes was found to be 3528 and 2791 MPa respectively.

(a) (b)

Figure 10. Ladder arrangement for wallete testing. (**a**) Test setup. (**b**) Cracking pattern.



(a)



(b)

Figure 11. (**a**) Normalized stress-strain curve for axially loaded wallete. (**b**) Normalized stress-strain curve for eccentrically loaded wallete.

4. Conclusions

- The compressive strength of geopolymer brick attains more than 5 MPa within 24 hours which influences the user to handle without any issues.
- The water absorption, initial rate of water absorption, dimensionality, alternative drying and wetting method and modulus of elastic of the units were well within the limits prescribed in the relevant codal provision.
- Geopolymer mortar can be used as mortar in building masonry structures as it exhibits better compressive strength than cement mortar. Its compressive strength was higher than that specified in IS 2250-1981.
- The use of geopolymer bricks and cements mortar joints have a great influence in the preparation of masonry units.
- The performance of the axial and eccentrically loaded wallette was found to be superior compared to the conventional cement brick masonry. They satisfy the requirements of IS 2185:2008 (part 4).

5. Acknowledgement

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