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Sustainable Units for Structural Masonry

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Abstract

Background/Objectives: To determine the basic properties of masonry units, modulus of elasticity and to evaluate the masonry efficiency for the different h/t ratios of the masonry prisms and wallets. **Methods/Statistical analysis:** The geopolymer blocks were cured in open air temperature. These 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 and modulus of elasticity. Rendered and unrendered geopolymer solid block and hollow prisms were cast and tested using cement mortar for the different h/t ratios and wallets were tested for compression. **Findings:** It was found that the basic properties of geopolymer masonry units were well within the limits prescribed the relevant codes of practice. Flexural strength and bond strength of geopolymer blocks prisms was more due to the good bonding between the blocks and the mortar joints. The masonry efficiency is increases with decrease in h/t ratios. There will be no much difference between rendered and unrendered masonry efficiency block prisms. The performance of the axial and eccentrically loaded wallette was found to be superior compared to the conventional cement block masonry. They satisfy the requirements of IS 2185:2008 (part 4). **Application/Improvements:** These geopolymer masonry units were used as structural masonry units due to the good compressive strength and performance.

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

1. Introduction

The history of masonry construction is regarded as the beginning of civil engineering. Masonry is one of the oldest methods of construction which has been built for the aesthetics and durability. Masonry is building structure with individual units called as masonry units; it is well bonded by mortar between units. In the 19th century, Park Guell in Barcelona, a famous monument was built using reinforced masonry structure [1-4].

The use of geopolymer composites can be made using geopolymers and phenomenological models can be developed to re-proportion [5-11]. Some of other researcher stated that the masonry mortar is used to bond the masonry units together. In India, there are about 1lakh brick manufacturing industries producing 140 billion bricks per year. It consumes around 400 million tonnes of top fertile soil. Also nearly 25 million tonnes coal and fossil fuel is required for burning of bricks and it is energy intensive material [12-13].

Brick industries are releasing annually 28% of sulphur oxide to the atmosphere which is one of the major air pollutants. Sarangapani et al explained the influence of bond strength on masonry compressive strength through an experimental program using local bricks and mortars. Masonry prism compressive strength has been determined when the brick-mortar bond strength is varied over a wide range without altering the strength and deformation characteristics of the brick and mortar. Brick-mortar bond strength has been determined through flexure bond strength and shear bond strength tests. A relationship between the masonry prism compressive strength and bond strength has been obtained. The results clearly indicate that an increase in bond strength, while keeping the

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mortar strength constant, leads to an increase in the compressive strength of masonry [14-15].

They concluded that the compressive strength of masonry decreases with the increase in joint thickness. They obtained the masonry efficiency of 41% [16]. They concluded that the compressive strength decreases with the increase in eccentricity. For the eccentricity of e/d=1/6, the compressive strength was 66% and 62% of axially loaded prism respectively for stack bonded and English bonded prisms. They reported that the English bonded prism had less compressive strength than the stack bonded prism [17]. Cement which is the main ingredient in the manufacture of cement concrete blocks produces considerable amount of carbon dioxide. It contributes nearly 7% of world's emission which leads into global warming [18].

Geopolymer is the term coined by Professor Joseph Davidovits for the family of high alkali binders formed in a reaction called as geopolymerization [19]. 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 the use of conventional cement.

Table 1. Water absorption and dry density tests for blocks

Series ID	Water Absorption [%]	Initial Rate of water absorption IRA [Kg/m2/min]	Average Dry Density [kg/m3]
GPSB	8.25	2.70	1810
GPHB	9.1	2.5	1750
IS 2185:2005	< 20	< 5.0	1800 to 2000

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 properties of geopolymer units.

2. Methodology

The following materials were used to prepare geopolymer masonry blocks:

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

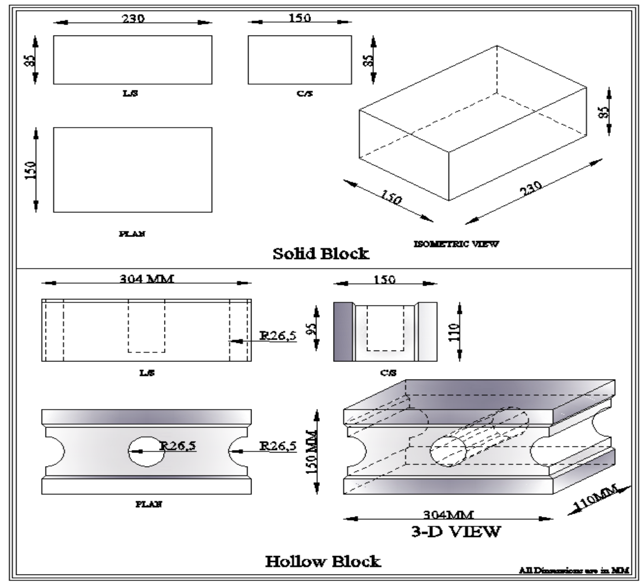


Figure 1. Line diagram of solid and hollow block

Low calcium Class-F fly ash and ground granulated blast furnace slag (GGBFS) were used as binders. The specific gravity of fly ash and ground granulated blast furnace slag were 2.40 and 2.90 respectively. Manufactured sand of zone II having specific gravity of 2.61 was used fine aggregates. The fineness modulus of manufactured sand was found to be 3.45. The aggregate to binder mix ratio was 1:1. The percentage of fly ash to GGBFS was 80:20. 8 molarity alkaline solutions were 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. Block making compression machine was used to cast the geopolymer blocks. The geopolymer blocks were cured in open air temperature. These 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 and modulus of elasticity.

Rendered and unrendered geopolymer solid block and hollow prisms were cast and tested using cement

Table 2. Dimensionality tests of Blocks.

Number of block in each type : 20 no's						
ID'S	Dimensions along	Size of the block (mm)	Dimensions (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

mortar for the different h/t ratios and wallets were tested for compression.

3. Results and Discussion

The results of water absorption and density of the blocks test was done as per IS 2185:2005 and are tabulated in Table 1. It was found that the water absorption of the geopolymer solid blocks (GPSB) and geopolymer hollow blocks (GPHB) are 8.25 and 9.1% respectively, which are considerably less compared to the traditional cement blocks. The density of the cement blocks ranges from 1800 to 2000 kg/m^3, these geopolymer masonry blocks are par with the 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 value specified in IS 2185:2005. The line diagram of the solid block and hollow block are shown in Fig. 1.

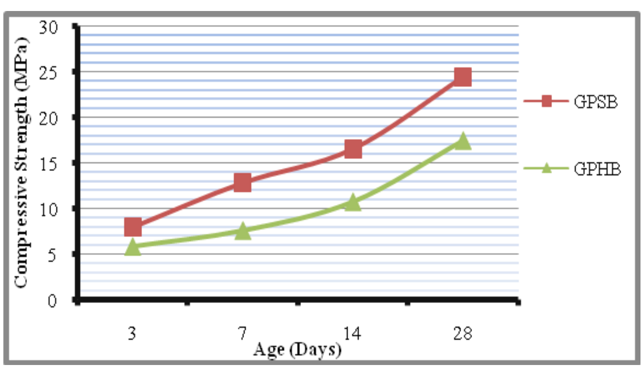


Fig 2. Development of compressive strength blocks with age

The dimensionality test of the masonry units was done as per IS 1077:1992 and results are shown in Table 2. It was found there is no much variation or dimensions of the blocks and variation of the blocks are within the limits of codal provision.

Compressive strength test was done according to IS 2185:2008, the variation of compressive strength of the geopolymer masonry units with age is shown in Fig. 2. It was observed that the compressive strength of the geopolymer masonry units at the age of 24 hours is more than 5 MPa, this significance of strength would be sufficient to handle the masonry units for various purposes. As per IS 2185:2008, the minimum compressive strength of the blocks is 3.5 MPa. The strength of masonry units increases with age ranging from 5-25 MPa. It is quite interesting to influence the usage of the geopolymer blocks in practical applications of industry.

(a) Test Setup (b) Failure pattern

Figure 3 : Flexural strength test

The flexural strength test was done as per IS 4860:1968 shown in Fig. 3. It was found that flexural strength of the geopolymer solid block and hollow blocks are 1.55 and 1.79 MPa respectively, which are considerably more due to bonding between fluid binders and aggregates compared to the traditional cement blocks.

(a) Test Setup (b) Failure Pattern

Figure 4 : Triplet Bond strength test setup

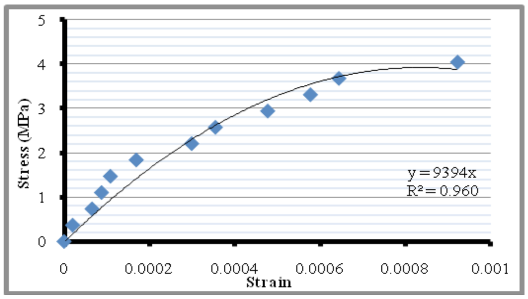
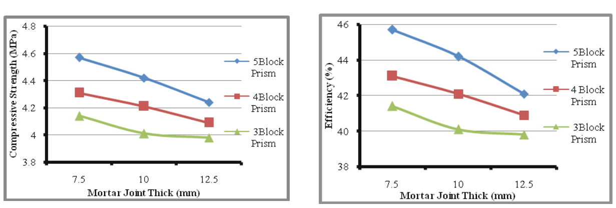


Figure 5. Normalized stress strain curve for the blocks.

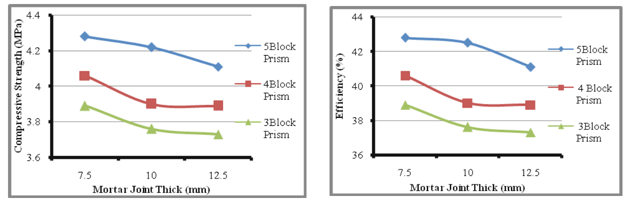
(a) Test Setup (b) Cracking pattern

Figure 6. Stack Bonded Geopolymer block prisms



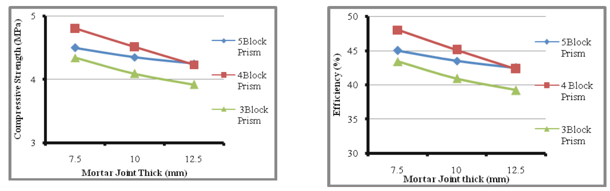
(a) Compressive Strength (b) Masonry Efficiency

Figure 7. Rendered geopolymer solid block prisms with different h/t ratios



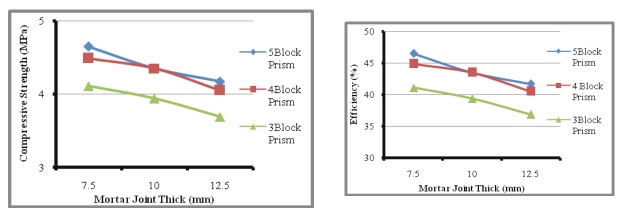
(a) Compressive Strength (b) Masonry Efficiency

Figure 8. Unrendered geopolymer solid block prisms with different h/t ratios



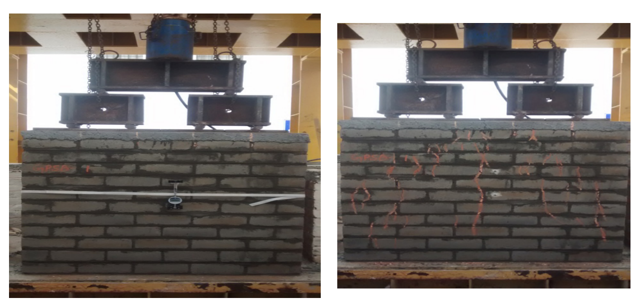
(a) Compressive Strength (b) Masonry Efficiency

Figure 9. Rendered geopolymer Hollow block prisms with different h/t ratios



(a) Compressive Strength (b) Masonry Efficiency

Figure 10. Unrendered geopolymer Hollow block prisms with different h/t ratios



(a) Test Setup Cracking pattern

Figure 11. Ladder Arrangement for Wallete Testing

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 (%age)
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

Table 4. Modulus elasticity for the rendered and unrendered block

Sl no	Mortar Joint thickness (mm)	Modulus of elasticity for the Geopolymer Solid Block (MPa)			Modulus of elasticity for the Geopolymer Hollow Block (MPa)		
		h/t ratio	Rendered	Unrendered	h/t ratio	Rendered	Unrendered
01	7.5	3.03	8999	8471	3.86	8683	7942
02	10	3.10	7473	6313	3.93	7811	7296
03	12.5	3.17	7037	5831	4.0	7536	6682
04	7.5	2.41	8729	8290	3.08	9108	8376
05	10	2.46	7892	7483	3.13	7956	7656
06	12.5	2.51	7567	7203	3.18	8009	7838
07	7.5	1.8	8500	8149	2.30	10045	9612
08	10	1.83	8053	7803	2.33	9299	8716
09	12.5	1.86	8005	7507	2.36	8677	8345

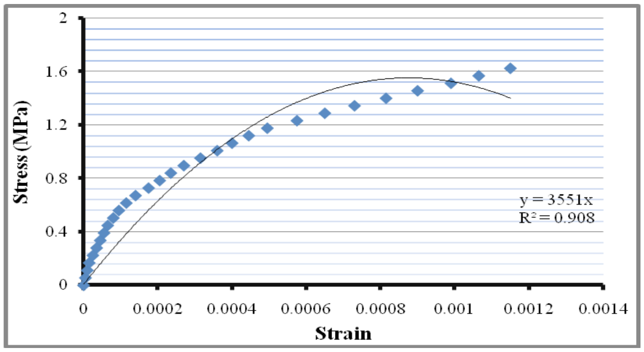


Figure 12. (a) Normalized Stress-Strain Curve for axially loaded Wallete

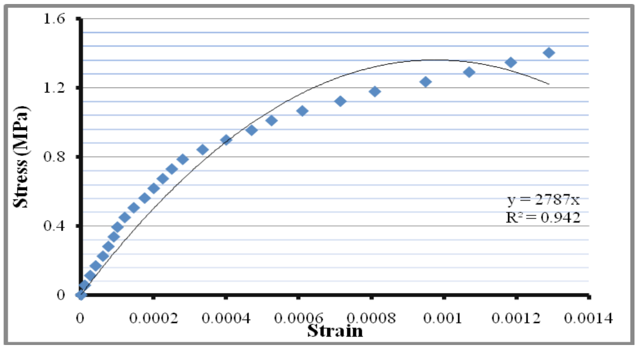


Figure 12. (b) Normalized Stress-Strain Curve for Eccentrically loaded Wallete

(a) Test Setup (b) Cracking pattern

Figure 13. Ladder Arrangement for Wallete Testing

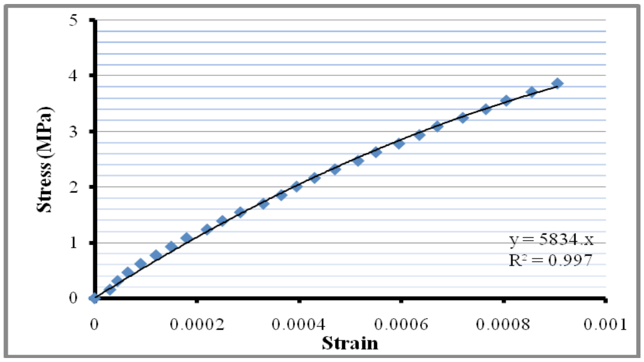


Figure 14. (a) Normalized Stress-Strain Curve for axially loaded Wallete

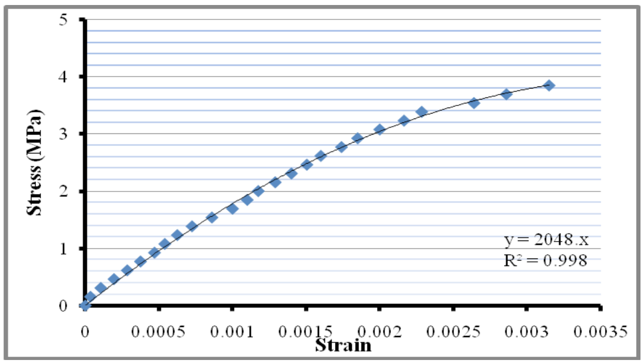


Figure 14. (b) Normalized Stress-Strain Curve for Eccentrically loaded Wallete

Shear bond strength test is shown in Figure 4 and these properties are shown in Table 3. It was found that the shear bond strength is increased with the 1:2 mortar ratios when compare to 1:4 mortar joints, these properties are considerably high due to the bonding between masonry units and mortar joints compared to the traditional cement blocks.

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

The masonry efficiency was done for the rendered and unrendered geopolymer prisms and cement mortar joints and the test setup as shown in Fig. 6. The variations of the strength and efficiency of rendered and unrendered geopolymer block prisms are shown in Fig. 7, 8, 9 and 10 respectively. It was observed that in geopolymer block and cement mortar prisms efficiency is increases with lower in cement mortar joint thickness. Whereas efficiency not much difference between the rendered and unrendered block prisms.

It was also observed that the vertical cracks were developed from top of a block and it propagates till the bottom of the prism, also it was observed that bottom most blocks was crushed to considerable extent.

The modulus of elasticity for the rendered and unrendered of the geopolymer solid blocks and hollow blocks with different h/t ratios are shown in Table. 4. It was observed that modulus of elasticity is increases in lower cement mortar joints.

The test setup of geopolymer solid block masonry wallets are shown in Fig. 11. It is observed that the average compressive strength of the axially loaded and eccentrically loaded wallets was 2.07 and 1.87 MPa respectively. It is comparatively higher to the conventional block wallets of same geometry [18]. It was observed that vertical cracks were developed from top of a wallette and propagated till three fourth of the height from top of the wallette as shown in Fig. 11(b). This behaviour is in line with any masonry wallet.

The normalized stress strain curve for the geopolymer solid block masonry walletes with cement mortar joints are shown in Fig. 12 (a) & (b), the modulus of elasticity for the axially loaded and eccentrically loaded walletes was found to be 3551 and 2787 MPa respectively.

The test setup of geopolymer Hollow block masonry wallets are shown in Fig. 13. It is observed that the average compressive strength of the axially loaded and eccentrically loaded wallets was 2.31 and 1.95 MPa respectively. It is comparatively higher to the conventional block wallets of same geometry [18]. The vertical cracks were developed from top of a wallette and propagated till two third of the height from top of the wallette and also spalling of materials taken place in mortar joints due to the crushing of materials as shown in Fig. 13 (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 Fig. 14 (a) & (b), the modulus of elasticity for the axially loaded and eccentrically loaded walletes was found to be 3551 and 2787 MPa respectively.

4. Conclusions

- The compressive strength of geopolymer blocks at the age of 3days was more than 5MPa, which makes the user to handle without any issues.
- The water absorption, initial rate of water absorption, dimensionality and modulus of elastic of

the units were well within the limits prescribed the relevant codes of practice.

- Flexural strength and bond strength of geopolymer blocks prisms was more due to the good bonding between the blocks and the mortar joints.
- The masonry efficiency of the block prisms increases with decrease in h/t ratios. There will be no much difference between rendered and unrendered masonry efficiency block prisms.
- The modulus of elasticity increases in decrease in the cement mortar joints.
- The use of geopolymer blocks 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 block masonry. They satisfy the requirements of IS 2185:2008 (part 4)
- It is possible to prepare geopolymer blocks by replacing all the traditional ingredients including the water.

5. Acknowledgment

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6. References

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