Behavior of Stabilized Geopolymer Mud Blocks Masonry Prisms under Compressive Strength

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***Abstract*—Stabilized Geopolymer Mud Blocks were created through the compression of a mixture comprising mud as aggregate and fly ash as binder, combined with an alkaline solution containing sodium silicate and sodium hydroxide in a block making apparatus. These blocks underwent curing at room temperature and were subjected to various tests including water absorption, initial rate of absorption, dimensions, density, and compressive strength at different stages of maturity. Mortar serves as the adhesive binding two masonry units together, enabling them to function as a unified entity within a structure. This study investigates the performance of stabilized geopolymer mud block masonry, analyzing its strength with different types of mortar such as cement mortar, cement-soil mortar, and fly ash-based geopolymer mortar across various stages of development. Geopolymer mortar, boasting commendable compressive strength, demonstrates promising characteristics compared to conventional cement mortar and cement-soil mortar, thus proving its suitability in masonry construction. Moreover, the stabilized geopolymer mud block exhibited significant strength, rendering it suitable for load-bearing masonry structures, while complying with the essential properties outlined in relevant IS codes. Enhanced load-carrying capacity and crack resistance were observed during testing of the masonry prisms. This research underscores the efficiency of stabilized geopolymer block masonry as an alternative building material, contributing to a global economy by reducing reliance on cement and its derivatives, while promoting the eco-friendly reuse of waste materials like fly ash.**

***Index Terms*—flyash, geopolymer, mud blocks, mortar, compressive strength**

I. INTRODUCTION

Masonry construction is one of the oldest methods of construction. In this method, a masonry structure is created using masonry units and mortar. The key component of a masonry construction is masonry units. They form the majority out of all the building materials used in the construction. Masonry units have a significant impact on the masonry's compressive strength and ability to withstand structural loads. Masonry units are chosen taking into account the required compressive strength, affordability, availability, and ease of workability. Burnt clay bricks, concrete blocks are the most commonly used masonry units. Burnt clay bricks in production uses a significant quantity of fertile soil from our Earth, causing a concern on conservation of soil. And, concrete blocks use conventional cement for its production, the drawbacks of which have been well researched quoting that during the cement manufacturing process, the same quantity of carbon di-oxide is released into the atmosphere. There are many articles quoting that cement companies produce 5% of all carbon dioxide emissions, which accounts for the environmental pollution.

Cement usage must be decreased because greenhouse gas emissions are rising. Hence, there is a need to develop alternative materials in order to sustain the rapid growth in construction field in the longer run. Stabilized mud is a type of mud which is mixed with a binder. The process involved in improving the properties of blocks by adding binders is called stabilization. This stabilization process results in enhanced water resistance and compressive strength. Some of the binders that are commonly used are lime, cement and bitumen. Nowadays, geopolymers are being used as an alternative binder. The material and production losses are negligible compared to that of burnt clay bricks. Geopolymers are superior to traditional Portland concrete in terms of physical performance and provide additional advantages, even when subjected to extreme conditions, thereby significantly reducing greenhouse gas emissions.[2] Geopolymers also provide strong resistance to temperature and fire and have been suited to extreme exposure conditions and are resistant to corrosion, acid as well as alkaline attack. Through the use of geopolymer technology, materials like fly ash, ground granulated blast furnace slag (GGBFS), coal ash, metakaolin, calcined clay, agricultural waste ashes, and industrial sludge waste can be used in place of ordinary cement. Professor Joseph Davidovits in the year 1978, used and coined the word ‘geopolymer’. The main constituent of geopolymer are silicon and aluminium which are offered by thermally activated natural materials like kaolinite or industrial derivatives like fly ash and an alkaline activating solution that polymerizes these materials into molecular chains and complexes to create hardened binder. This is also known as inorganic polymer binder or alkali-activated material. The use of class F fly ash which is low in calcium is produced by the process of burning of bituminous and anthracite coal. The amount of lime in class F fly ash is less compared to OPC. Fly ash is generally finer than OPC and the properties are also similar to that of OPC. Good strength and long-term durability are recorded with the use of Fly ash in construction field [1]. Geopolymer concrete specimens have shown greater thermal durability up to 800° C and have less embodied energy than the ordinary Portland concrete specimens. [8]. This study aims to show the strength of stabilized geopolymer mud block with varying compositions of mortar in the laboratory conditions. The masonry unit and various proportions of mortars has been cast and tested for their strength and other properties. Finally, masonry prisms with stabilized geopolymer mud blocks and various mortars were cast and tested for their strength and the failure patterns were observed.

II. LITERATURE REVIEW

Using fly ash, GGBFS and alkaline solution as the binding agent in place of conventional cement, geopolymer technology is emerging as an eco-friendly construction material for sustainable development [2-5]. Radhakrishna et al have stated that, geopolymer masonry units can be manufactured using class F fly ash as binder by ambient curing.[4]. The use of geopolymers resolves two emerging issues. i.e., reduction in carbon di-oxide emissions from manufacturing of ordinary Portland cement and successful utilization of industrial and commercial waste products such as fly ash, slags from thermal power plants, etc. by reducing the use of OPC. [6-7]. H.M. Khater et al, studied that use of Nano clay materials in geopolymer microstructures and recorded that the Nano materials lead to improvement of properties and also an increase up to 1% in compressive strength and better mechanical properties [8]. K Vijai et al have concluded that there is higher strength with age of ambient cured specimens than those with heat cured specimens [9] V. Srividya et al have stated that geopolymers are extremely resistive to sulphuric acid and hydrochloric acid. Fly ash based geopolymer mortar specimens exposed to acids show reduced weight loss [10]. 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 [2-7]. Researchers have concluded that concentration of 8M-14M NaOH solution exhibit better strength, properties and durability characteristics. [5-6]., Alex et al have proved that the use of low calcium fly ash-based geopolymer concrete as a replacement for traditional concrete was suggested since it performs better and has fewer environmental difficulties. [9].

III. MATERIALS AND METHODS

Stabilized Geopolymer Mud Blocks (SGMB) of size (230 x 110 x 100) mm were cast using manually operated block making machine giving desired amount of pressure. The raw materials namely, Class F Fly ash as binder, Mud as aggregate and 12 M Sodium hydroxide and Sodium silicate as alkaline solution in the ratio of 1:1.5 were used in the process. The 12M NaOH showed optimum properties in the block when compared to alkaline solutions prepared with different concentrations of NaOH like 8M, 10M, 12M and 14M [5,6]. The ratio of solution and binder was maintained at 0.4 and binder to aggregate ratio 1:1 for the blocks. These materials were thoroughly mixed and fed into the machine mold and cured in ambient atmosphere, thus desired blocks were obtained. These blocks were tested as per IS codal testing procedures for water absorption, initial rate of absorption(IRA), dimensionality, density and results were tabulated. Compressive strength of SGMB was tested as per IS 1077. The stress-strain curve for SGMB was plot and results were tabulated.

A total of six different mortars were used for testing namely, cement mortar of mix 1:4 (CM1), 1:6 (CM2), Cement Soil Mortar of mix 1:2:5 (CSM1), 1:1:6 (CSM2) and fly ash based geopolymer mortar with 12M Sodium hydroxide and Sodium silicate as alkaline solution in the ratio of 1:1.5, binder to aggregate ratio of 1: 1 and solution to fly ash mix of ratios 0.3 (GPM1) and 0.5 (GPM2). The standard test for compressive strength of mortar was carried out following IS 2250, which involves compression testing on a set of 50 mm cubes. Compressive strength of each of the mortars were analyzed and results were tabulated. The construction and test procedures of masonry prisms were carried out according to the guidelines provided in the code ASTM C1314. This code covers the test procedures for masonry prism construction and testing, and procedures for determining the compressive strength of masonry. The code suggests testing of masonry prisms of minimum two units high with the prism's height-to-thickness ratio, hp/tp , between 1.3 and 5.0 for determining compressive strength of the masonry. Stack bonded masonry prisms were cast. Five SGMBs were placed one above the other with mortar in between maintaining a mortar thickness of 10 mm. Fig. 4 shows the geometry of stack bonded prism and dimensions of masonry prisms measured (230 x 110 x 540)mm. A set of prisms were built with various types of mortars namely CM1, CM2, CSM1, CSM2, GPM1 and GPM2. The test for compressive strength for stabilized geopolymer mud block prisms with various mortars after a period of 3, 7, 14, 28 days was carried out by gradually applying axial loading in the center of the bearing surface and results were tabulated. The stress strain curve was plotted to evaluate the behavior of the prisms and initial tangent modulus was calculated.

IV. RESULTS AND DISCUSSIONS

1. Compressive Strength of Stabilized Geopolymer Block

The properties of stabilized geopolymer mud block like dimensionality, water absorption test, initial rate of absorption, density of the blocks tested as per IS code is as shown in Table I. The tests were conducted as per IS 2185, water absorption of the blocks was found to be 8% which is considerably less compared to the conventional bricks [9] and also satisfy the codal requirements. IRA of the blocks as per IS 2185 geopolymer blocks at 28 days was found to be 3.5 kg/m2/min which is less than 5 kg/m2/min which implies that the masonry mortar has good water retentivity [9]. The density of the masonry block was in the range of 1800 to 2000 kg/m3 which satisfy the Indian Standard codal requirements. As per IS 1077, the dimensionality test of the masonry units was conducted and the test results of the blocks are within the permissible limits of codal provisions. The compressive strength of the masonry block tested as per IS 1077 at 3, 7, 14, 28 days age of casting the block were tabulated and the same is represented graphically as in Fig. 2. It was observed that the compressive strength of the masonry units at the age of 3 days comes to around 5 MPa, which is greater than the minimum compressive strength (3.5MPa) of block at the time of construction specified in code IS 1077. The strength ranges from 5-25 MPa along with age for the masonry unit. The stress strain characteristic of the SGMB block at the age of 28 days of casting and the variations recorded is as shown in Fig.3. The Initial tangent modulus of block at the age of 28 days was found to be 9916 MPa.

Table I. Properties of Stabilized Geopolymer Mud Block

Sl. No.	Property	Value	Codal Provision
1	Dimension	(225x110x100) mm	-
2	Water Absorption	8 %	< 20 %
3	IRA	3.5 kg/m^2/min	< 5 kg/m^2/min
4	Dry Density	1900 kg/m^3	1800 - 2000 kg/m^3

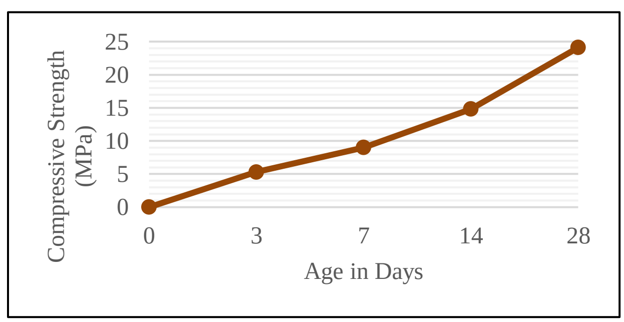

Fig. 1. Compressive Strength of Stabilized Geopolymer Mud Block

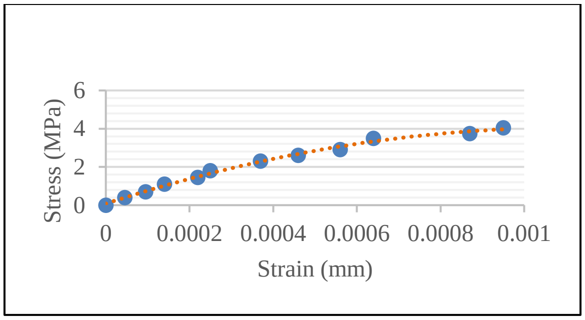

Fig. 2. Stress – Strain curve of Stabilized Geopolymer Mud Block

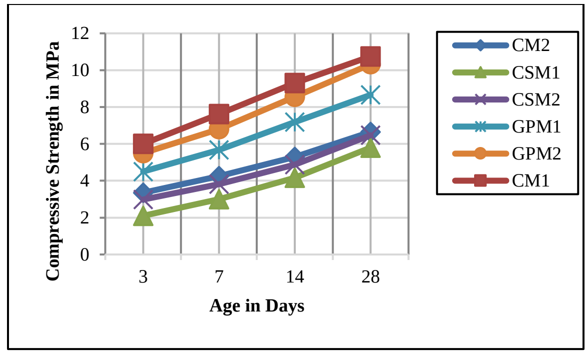

Fig. 3. Variations of Compressive Strength of various mortars with age

2. Compressive Strength of block with various mortars

The compressive strength test of mortars on different proportions were conducted as per IS 1905-1987 on a set of cube specimens of 50 mm for each proportion after a period of 3, 7, 14, 28 days. The details of mortar composition and the compressive strengths are shown in Table II. The compressive strength variations of each proportion are shown graphically in Fig. 3. From the results, it can be observed that the compressive strength increases with age in all the types of mortar. But due to the change in proportions, a difference in the strength can be noticed. The strength gained by the mortar at the age of 3 days ranges from 2MPa to 6MPa and has reached from 5 MPa up to 10 MPa at age of 28 days. According to IS 2250 - 1981, minimum compressive strength of masonry mortar at 28 days for any mortar used for structural purpose is 3 MPa. The selected varieties of mortar satisfy the codal requirements.

Table II. Compressive Strength of various mortars

Sl. No.	Mortar ID	Mortar Type	Strength (MPa) at 28 days
1	CM1	C :S – 1: 4	10.54
2	CM2	C :S – 1: 6	6.65
3	CSM1	C :So: S – 1: 2: 5	6.47
4	CSM2	C :So: S – 1: 1: 6	5.8
5	GPM1	Fly ash GPM S/FA 0.3	8.66
6	GPM2	Fly ash GPM S/FA 0.5	10.32

3. Compressive Strength of Masonry prisms

The geometrical configuration and test set-up of masonry prisms are as shown in Fig. 4 and Fig.5 respectively. From the literature, as the masonry strength increases with block strength and mortar strength for all the varieties of block types and all the mortar types. The variations of compressive strength of masonry prisms with cement mortar, cement soil mortar and fly ash based geopolymer mortar is shown in Fig. 6 and the values are as tabulated in Table.3. It was noticed that the strengths of CM1 and GPM1 lie in close proximity. The strength of CM ranges from 3.5 to 4MPa, CSM ranges from 3MPa to 3.7MPa and GPM ranges from 3.9 to 4.3MPa.

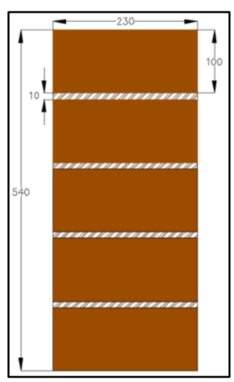

Fig. 4. Geometry of prism

Fig. 5. Test setup of masonry prism

The variations of typical stress-strain parameters for masonry prisms were plot as shown in Fig. 7, Fig. 8 and Fig. 9 for each type of mortars after normalizing the values. It can be observed that the variation of stress with strain is not linear. The initial tangent modulus for various prisms with CM mortars was found to be 10286 MPa. For the prism with CSM, modulus was 9786 MPa and prism with GPM was 10490 MPa. It was seen that the variation of modulus for prisms with CM and GPM had concurrent values.

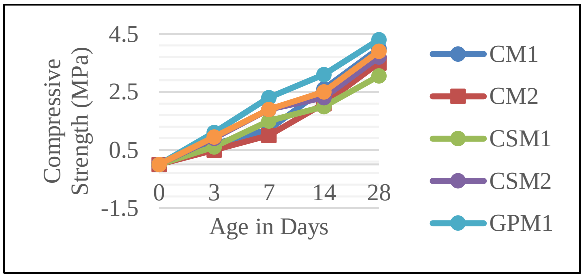

Fig. 6. Compressive Strength of SGMB masonry prisms with various Mortars

On the other hand, the modulus of masonry prism with CSM mortar was slightly lower compared to the masonry prisms with CM and GPM. The values are as tabulated in Table.III.

Fig. 7. Stress-strain plot of SGMB masonry prisms with CM1 and CM2

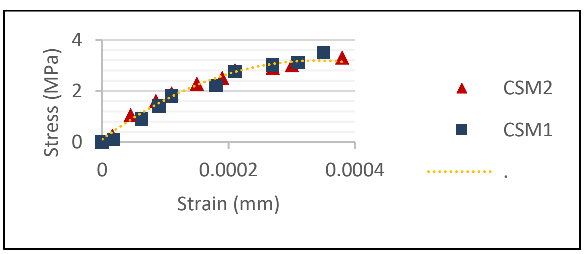

Fig. 8. Stress-strain plot of SGMB masonry prisms with CSM1 and CSM2

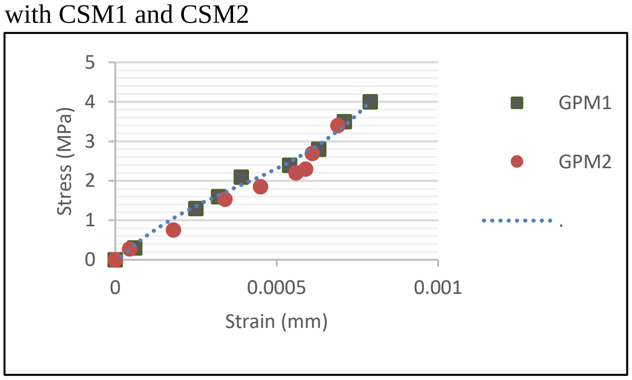

Fig. 9. Stress-strain plot of SGMB masonry prisms with GPM1 and GPM2

Table III. Properties of masonry prisms various mortars

Sl. No.	Masonry Prism with	Compressive Strength (MPa) at the age of 28 days	Initial Tangent Modulus (MPa)	Failure Pattern observed
1	CM1	4	10286	Vertical cracks seen and crushing of bottom most block
2	CM2	3.5	10112	
3	CSM1	3	9348	Vertical cracks and crushing of blocks
4	CSM2	3.7	9786	
5	GPM1	4.3	10490	Vertical cracks propagating from the top and spalling of last block at bottom
6	GPM2	3.9	10389	

It was observed that the strength of masonry prism with cement mortar and geopolymer mortar were similar and prisms with cement soil mortar showed slight difference . Vertical cracks were seen in the prisms which extended from top of the block and propagated till the bottom of the block in the prism. It was observed that that bottommost block in the prism was ruptured to a considerable extent compared to the other blocks.

V. CONCLUSION

Some of the conclusions noticed from the study are as follows:

- Stabilized geopolymer mud blocks are high strength and high-density blocks.
- Fly ash achieve good results when used as a binder and for the synthesis of geopolymers.
- The compressive strength of ambient cured fly ash based geopolymer blocks achieve good compressive strength of about 24MPa at age of 28 days and water absorption is less which makes it a good building material.
- The average compressive strength of various mortars was found to be:
  - 10.54 MPa for CM1 and 6.65 MPa for CM2.
  - 6.47 MPa for CSM1 and 5.80 MPa for CSM.

  - 8.66 MPa for GPM1 and 10.32 MPa for GPM2.
- The study on structural behavior of block masonry shows enhanced compressive strength of masonry with geopolymer mortar similar to cement mortar and a slightly lesser strength for masonry with cement soil mortar.
- The compressive strength of masonry ranges from 3MPa to 4MPa at the age of 28 days.
- As the masonry strength increases with block strength and mortar strength for all the varieties of block types and all the mortar types.
- The mode of failure was either Shear break type of failure or Face shell separation type of failure.
- Stabilized Geopolymer Mud Blocks can be used assuredly used as an alternative building material along with geopolymer mortar.

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