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# **STUDY ON GEOPOLYMER MASONRY AS SUSTAINABLE BUILDING MATERIAL**

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## **ABSTRACT**

Masonry the oldest method of construction is composed of masonry units and mortar. The traditional masonry units like burnt brick and regular cement blocks are not considered as sustainable. Burnt brick consumes fossil fuel and top fertile soil. Cement block need traditional cement which produces carbon dioxide during manufacturing. Hence there is a need develop and use alternatives to traditional masonry units. Geopolymer technology is one among many alternatives in which complete elimination of cement is achieved without compromising the strength and durability. This technology makes use of marginal materials like fly ash, blast furnace slag as binders. River sand can be replaced with m-sand and other recycled aggregates. The reported literature is silent about the use of geopolymer masonry blocks in the construction. The present study focuses on this sustainable technology to save the natural and scarce materials. Industrial by-products class F fly ash and slag were used as binders. Alkaline solution and manufacturing sand were used to prepare the geopolymer masonry blocks. They were cured in open air by conserving water. The properties of masonry blocks/ bricks were determined and used in the construction of a building. It was found that the masonry units exhibit better properties compared to the traditional masonry units. Geopolymer masonry units were satisfied the requirements of the standard codes of different countries. The building constructed using geopolymer masonry blocks performed better compared to traditional cement blocks. Hence the use of geopolymer masonry blocks can be recommended for the construction of buildings.

**Key Words :** Geopolymer, Masonry unit, Fly ash, Slag, Sustainability

## **INTRODUCTION**

Masonry is the popular and traditional method of construction which is composed of individual masonry units. Many old age masonry structures are the best examples of durable construction. The common traditional masonry units are burnt brick masonry and cement block masonry. They are not considered as sustainable due to many reasons. Burnt brick consumes fossil fuel and top fertile soil. Cement block needs traditional cement which produces carbon dioxide during manufacturing. There are efforts to replace these traditional masonry units. Geopolymer is an inorganic polymer which represents pioneering technology, it creating the large amount of interest in the construction industry because it is sustainable and environmental friendly material. In 1978, Joseph Davidovits introduced this technology this can be used as

an alternative binder to ordinary portland cement. In this, the source material would be rich in Silicon (Si) and Aluminum (Al) which reacts with highly alkaline solution through the process of geopolymerization to produce binding material. This has many benefits including reduction of CO<sub>2</sub> and effective utilization of industrial wastes such as fly ash, ground granulated blast furnace slag, etc.

The use of ASTM class F fly ash (low calcium) normally produced by burning of bituminous and anthracite coal. It is pozzolanic in nature the lime percentage is less than 5%. The class F fly ash is in combination with Portland cement to produce the structural masonry units. Fly ash when used as a component of cement have been several benefits like fresh properties ultimate strength and long term durability. Moreover use of fly ash supports the sustainability. This can lead to a number of environmental, technical and economical benefits.

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Ground Granulated Blast Furnace Slag (GGBS) is a byproduct of the manufacturing of iron in a blast furnace where iron ore, limestone and coke are heated up to 1500°C. When these materials melt in the blast furnace, two products are produced molten iron and molten slag. The molten slag is lighter and floats on the top of molten iron. The molten slag comprises mostly silicates and alumina from the original iron ore, combined with some oxides from the limestone.

The demand for the natural river sand as fine aggregate is increasing day by day for increase in the construction activities. The sand mining has caused ecological imbalance. Manufactured sand can be used as the alternative to this without compromising the properties. Fly ash, slag etc, which were once considered as waste materials, can be utilised in making useful products like masonry units economically.

Geopolymer masonry blocks/bricks are inorganic polymer composites, which have emerged as a prospective binding material like cement. It is an environment friendly sustainable material which has a potential to replace conventional cement blocks/bricks. The geopolymeric paste can be used to produce refractory concrete by adding quartz sand and alumina powder. Kamseu et.al<sup>1</sup> have developed a geopolymeric paste to be used to produce refractory concrete by adding quartz sand and alumina powder. It is reported that the total shrinkage in the range of 25–900 °C was less than 3%, reduced with respect to the most defused potassium or sodium based geopolymer systems, which generally records > 5% shrinkage. Villa et.al,<sup>2</sup> have investigated the influence of activator ratio, time and curing temperature on the strength of geopolymers synthesized from natural zeolites, activated by sodium silicate and hydroxide solutions. The results demonstrated that an increase in the activator ratio as well as that of curing time favors mechanical strength. In a research on geopolymers by Fang and Kayali.<sup>3</sup> The composition and microstructure of the fly ash as well as the geopolymers were characterized in each step using scanning electron microscopy and X-ray diffraction. It is suggested that the resulting geopolymer

compounds contain a measurable amount of non evaporable/combined water. A study by Liew et.al<sup>4</sup> on kaolin based geopolymers reveals that the solids-to-liquid and water glass to NaOH solution ratios affected the strength significantly and these ratios were optimized at 0.80 and 0.20 respectively. The densification of microstructure presence of amorphous gels and crystalline zeolite phases as well as the increase in the geopolymer bonding could be revealed in this study. In recent study on rheology of geopolymer by Romagnoli et.al<sup>5</sup>. It was found that rheological parameters have proven to be very sensitive to chemical changes in the studied system. In combination with DOE methodology, rice husk can be effectively used as base material in making geopolymer. Report by Kusbiantoro et.al,<sup>6</sup> suggests that the elevated temperature is suitable condition for rapid dissolution of silicate monomer and oligome, which supports the formation of supersaturated aluminosilicate solution in geopolymer system.

The acceptance criteria of IS : 456-2000 to GGBS based self curing geopolymer concrete was discussed by Rajamane et.al<sup>7</sup>. The authors considered the test results of GGBS based self curing concrete with 28 day compressive strength in the range of 56 to 71 MPa. Bond strength of ambient cured geopolymer concrete with different fly ash and GGBS contents was obtained experimentally by Rajamane et.al<sup>8</sup>. The bond strengths at critical slips of 0.025mm and 0.25mm peak bond strength with corresponding slip and bond strengths- slips at different load levels compared for geopolymer concrete and reference concrete as per IS:2770-1967. Anuradha et.al<sup>9</sup> have investigated the applicability of the existing 0.5 power relationship between the compressive strength and split tensile strength for OPC concrete to thermally cured geopolymer concrete also. The compressive strength of geopolymer concrete were nearly equal to that of control mixes tensile strength of river sand mixes were higher than that of manufactured sand mixes the test results suggested that 0.5 power relationship for normal concrete was not valid for GPCs. Fly ash based (GPC) and (GPCC) containing 90% fly ash and 10% (OPC) both activated by

alkaline liquid were synthesized in both ambient and heat curing conditions and results compared by Vijai et.al.<sup>10</sup> Sarker et.al,<sup>11</sup> have observed that the failure modes of the geopolymer concrete specimens were found to be more brittle with relatively smooth fracture planes as compared to the OPC concrete specimens. A study on the influence of aggregate content on the engineering properties of geopolymer concrete by Joseph and Mathew.<sup>12</sup> Reports that geopolymer concrete with proper proportioning of total aggregate content and ratio of fine aggregate to total aggregate, along with the optimum values of other parameters can have better engineering properties than the corresponding properties of ordinary cement concrete. The results of an experimental study by Ahmari et.al.<sup>13</sup> indicate that utilization of ground waste concrete together with fly ash can increase the compressive strength of the geopolymeric binder up to 50% GWC content. A comparative study of geopolymer and portland cement concrete by Nazari.<sup>14</sup> indicate that gene expression programming model is a powerful tool for predicting the compressive strength of the geopolymers in the considered range. Radhakrishna et al.<sup>15</sup> have reported that, it is possible to manufacture geopolymer masonry units using class F fly ash which is abundantly available though out the world.<sup>16-20</sup> It is also reported that phenomenological models can be developed to re-proportion the materials. There is no report of making masonry by replacing all the ingredients including water. In this paper the art of making structural masonry

units by replacing all the traditional ingredients has been reported.

**AIMS AND OBJECTIVES**

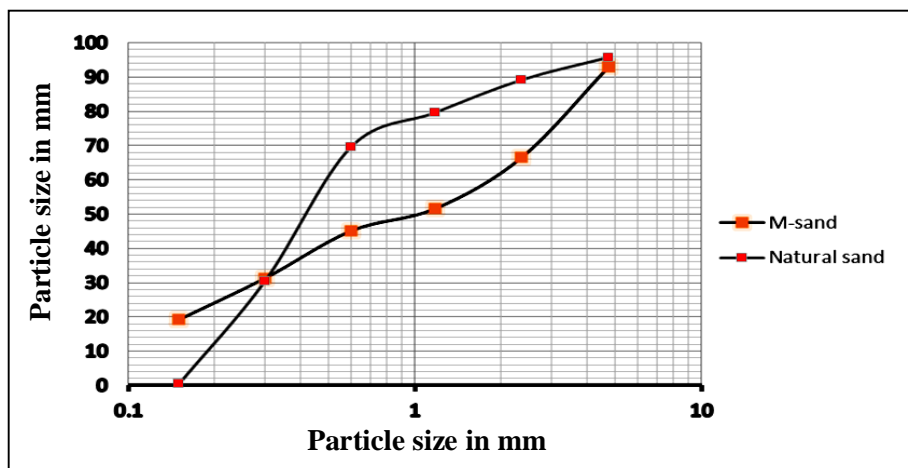
To characterize the properties of the materials like fly ash, GGBSF and M-Sand.To investigate the properties of the masonry units like compressive strength, water absorption, density test, dimensionality, temperature study and modulus of elasticity etc.

**MATERIAL AND METHODS**

The following materials were used to prepare geopolymer masonry blocks/bricks :

- Fly ash (Class F) and GGBFS
- Manufactured sand (M-sand)
- Recycled water
- Sodium hydroxide and
- Sodium silicate

Low calcium class-F fly ash and ground granulated Blast Furnace Slag (GGBFS) were used as binders.<sup>21</sup> The specific gravity of fly ash and ground granulated blast furnace slag were 2.40 and 2.90 respectively. The ratio of SiO<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub> of the fly ash is around 2, suitable to use for making low CO<sub>2</sub> elements. Manufactured sand was used fine aggregates. The specific gravity of manufactured sand was 2.61. The fineness modulus of manufactured sand was found to be 3.45 manufactured sands fall in zone-II. The moisture content of manufactured sand was found to be 0.401%. The grain size distribution of sand and M- sand are shown in **Fig 1**. The properties of the recycled water are given in **Table 1**.



**Fig.1.** Grain size distribution of natural sand and M-sand

**Table 1 : Properties of recycled water**

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

The most common alkaline activator used in geopolymerization is a combination of sodium hydroxide and sodium silicate.<sup>22</sup> The type and concentration of alkali solution affect the dissolution of the binders. Sodium hydroxide flakes was used in this investigation.<sup>23-27</sup> Currently no standardized methods of mix

design for geopolymer masonry are available. For standard cement masonry blocks were designed using IS 2185:2008 (part 4). The mix ratio was 1:1 and the fly ash to ground granulated blast furnace ratio was 80:20. The final mix proportions are given in **Table 2**.

**Table 2 : Mix proportion (kg/m<sup>3</sup>) and mix ratio**

Ingredients	Fly ash	Ground granulated blast furnace slag	Manufactured sand
Weight of the material, kg	720	180	900

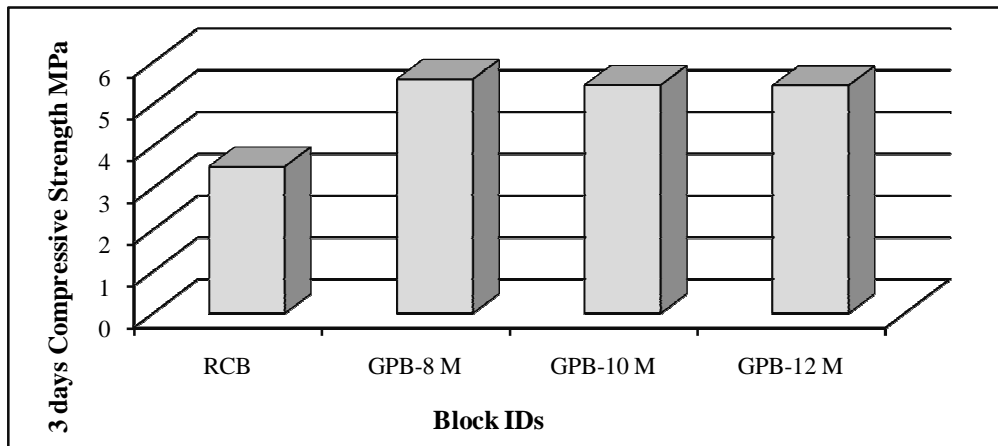
In this paper the properties of geopolymer masonry blocks/bricks is examined for the mix of 8, 10 and 12. The ratio of sodium silicate to sodium hydroxide was maintained at 2.5 and 1 respectively. The molecular weight of sodium hydroxide is 40gm/cc. To prepare 12m solution sodium hydroxide is required 480 gm and sodium silicate is required 1200 gm. 480 gm sodium hydroxide flakes are weighed and added to recycled water to make 1 liter sodium hydroxide solution. Then after the 30 minutes sodium silicate is added into it. The fly ash, GGBSF and M-sand were first mixed thoroughly in dry condition and then alkali solution was added to prepare geopolymer block/brick. The ratio of fluid binder alkali

solution is added 0.20 to get the good strength. The geopolymer masonry mortar was placed in standard size of the block like 225x107X75 mm.

**RESULTS AND DISCUSSION**

**Geopolymer brick/blocks**

The geopolymer bricks/blocks specimens which were casted and cured in ambient temperature. The average compressive strength of various molarities of geopolymer bricks/blocks is shown in **Fig. 2** to **Fig. 5** at different ages. The compressive strength of all the types of geopolymer block was relatively higher compared to the regular cement block as per IS : 2815-2005(Part1)



**Fig: 2.** Compressive strength of different geopolymer block at 3 days

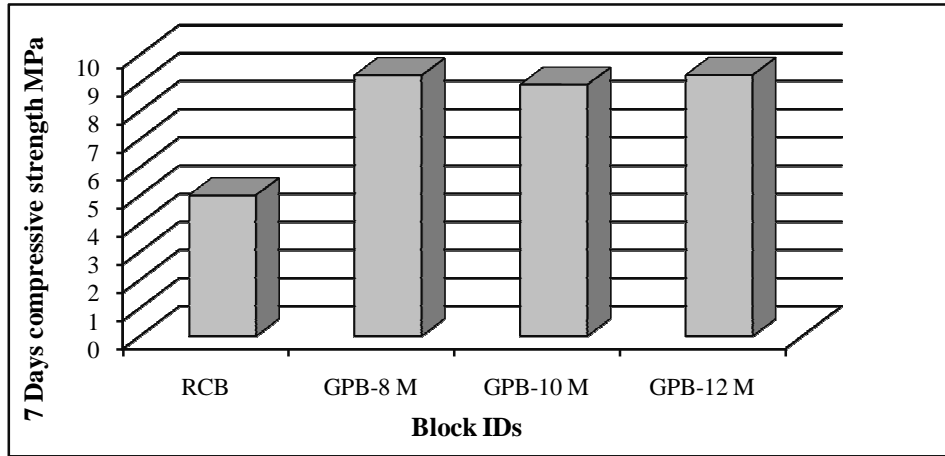


Fig. 3 : Compressive strength of different geopolymer block at 7 days

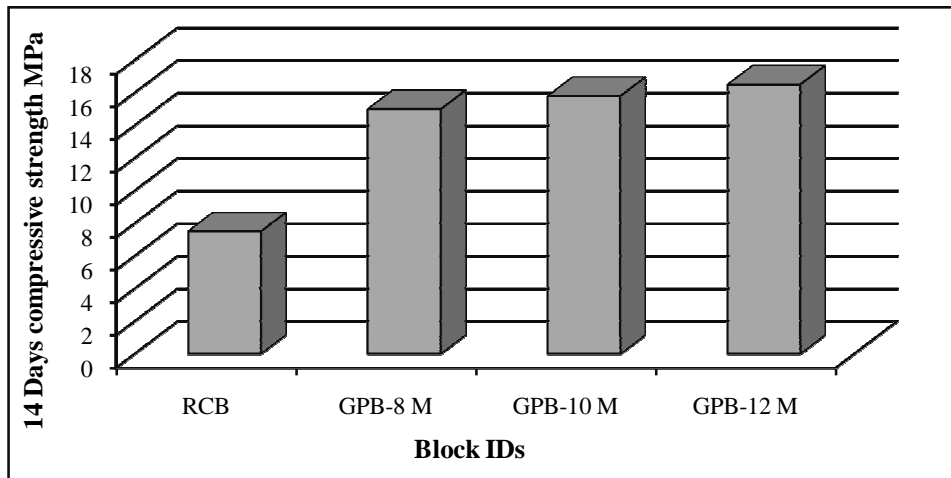


Fig. 4 : Compressive strength of different geopolymer block at 14 days

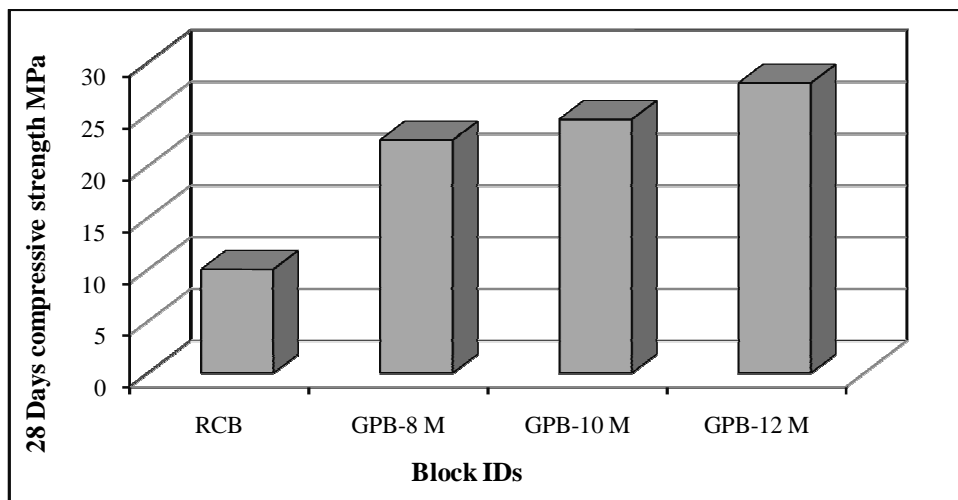


Fig. 5 : Compressive strength of various geopolymer block at 28 days

This is due to the good polymerization of the geopolymer bricks/blocks of different ages are materials. The water absorption of different shown in Fig. 6

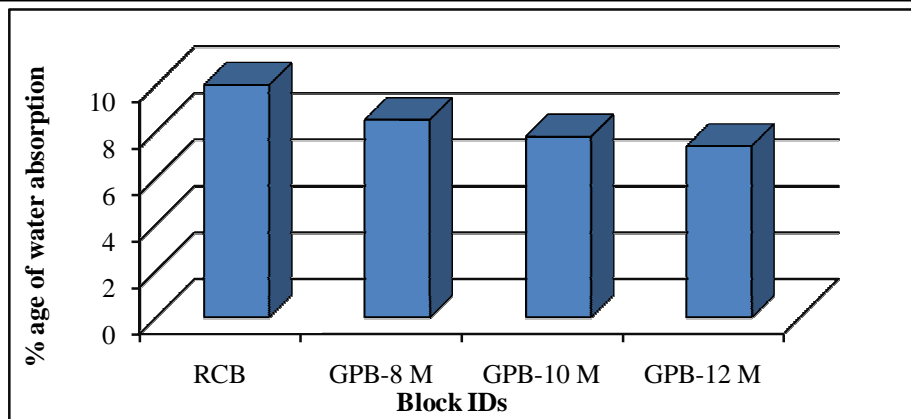


Fig. 6 : Water absorption of various geopolymer block/bricks

In geopolymer brick/block the water absorption is relatively very less as compared to the regular cement block, this is because of less voids, good geopolymerisation in the geopolymer brick/block. In geopolymer brick/block there is no changes in dimensions compared to the regular cement

block, this is because there is no change in sizes and volume in the geopolymer brick/block this test has been done according to IS 1077-1992. The density test for different geopolymer bricks/blocks of different ages are shown in Table 3.

Table 3 : Average density test (Kg/m<sup>3</sup>)

Average density test			
Type of masonry	Geopolymer with 8M	Geopolymer with 10 M	Geopolymer with 12 M
Geopolymer masonry block	1800	1845	1866
Regular cement block	1800 to 2000		

In geopolymer brick/block the density is relatively less as compared to the regular cement block as per IS : 2185-2008 (part 4) this is because of the unit weight of material like fly ash, GGBSF and alkaline solution. If the molarity is increases in geopolymer blocks/bricks the density also increases due the unit weight of the alkaline solution. Hence the geopolymer bricks/blocks can be recommended for the structural masonry works.

### CONCLUSION

It is possible to prepare geopolymer blocks by replacing all the traditional ingredients including the water. The masonry block prepared using waste materials to satisfy the requirements of IS 2185:2008 (part 4) and the blocks exhibited reduced water absorption and shrinkage. Geopolymer masonry blocks exhibits high early strength.

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