Experimental Investigation on Geopolymer Bricks

L. Periyasamy[1], N. Harishkannan[2], K. Ajay kumar[3], S. Balamurali[4]
[1]*Professor, Civil Engineering, Tamilnadu College of Engineering, Coimbatore, India*
[2,3,4] *UG Students, Civil Engineering, Tamilnadu College of Engineering, Coimbatore, India*

***Abstract*—Collectively, the growing demand for sustainable building materials has led to increased interest in geopolymer technology as an alternative to traditional brick products and Portlandbased products. This study focuses on the development and evaluation of geopolymer stones using industrial byproducts such as flight ash, ground granular furnace slag (GGBS), and manufactured sand (Msand). These materials provide low carbon alternatives, while simultaneously contributing to waste management and resource maintenance. The geopolymer binder system was activated using an alkaline solution containing sodium hydroxide (NaOH) and sodium silicate (Nasioâ) to maintain a 1:2 water alkaline resolution ratio. An optimal water binding ratio of 0.416 was used to ensure proper treatment and strength development. The bricks were cast to a standard dimension of 70 mm, 230 raw, and were healed under ambient conditions. Various mixing ratios of flight ash, GGB and M stars have been examined to identify the optimal formulation in terms of compressive strength, water absorption and dimensional stability. The results were compared to traditional sound bricks. The results show that geopolymer stones with flying ash, GGB and Msand have excellent mechanical properties and durability, making them a viable and environmentally friendly alternative for buildings under construction, especially in areas with high rainfall or aggressive environments. This study highlights the potential for geopolymer stones to meet both environmental issues and infrastructure requirements due to sustainable material innovation**

1. INTRODUCTION

The construction industry is a major contributor to global carbon emissions, primarily due to the extensive use of Portland cement in concrete and clay in fired bricks. The need for sustainable alternatives has led to the exploration of geopolymer technology, which utilizes industrial by-products and reduces environmental impact without compromising structural performance. Geopolymers are inorganic, alumino-silicate materials synthesized through the activation of silica and alumina-rich precursors with alkaline solutions. This process results in a hardened binder that exhibits high strength, chemical resistance, and low water absorption.

Fly ash, a fine particulate residue from coal combustion in thermal power plants, is one of the most commonly used materials in geopolymer synthesis due to its high silica and alumina content. Ground Granulated Blast Furnace Slag (GGBS), a by-product of the iron and steel industry, is also known for its latent hydraulic and pozzolanic properties, contributing to early strength gain and improved durability. Manufactured Sand (M-sand), produced by crushing hard granite stones, serves as a sustainable and quality-consistent alternative to natural river sand, improving the overall workability and gradation of the brick matrix.

The combination of fly ash, GGBS, and M-sand in geopolymer brick production not only enhances mechanical and physical properties but also provides a productive use for industrial waste materials. In this study, an alkaline activator solution composed of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) was used to initiate geopolymerization. Bricks were cast in a standard dimension of 230 × 110 × 70 mm, and the influence of various mix ratios on compressive strength, water absorption, and durability was investigated.

The aim of this research is to develop an eco-friendly and structurally efficient alternative to conventional fired clay bricks, particularly suitable for regions prone to heavy rainfall and environmental degradation. By optimizing the mix design and curing conditions, the study seeks to demonstrate the potential of geopolymer bricks in reducing the carbon footprint and resource depletion associated with traditional masonry materials

2. OBJECTIVES

The objectives of this study is,

i. To utilize industrial by-products such as fly ash, Ground Granulated Blast Furnace Slag (GGBS), and Manufactured Sand (M-sand) in the production of geopolymer bricks, thereby promoting waste valorization and environmental sustainability.
ii**.** To determine the optimal mix ratio of raw materials that yields the best performance in terms of workability, compressive strength, and durability.
iii. To analyze the physical and mechanical properties of the geopolymer bricks, including compressive strength, water absorption, and efflorescence test.

3. MATERIALS AND IT'S PROPERTIES

3.1 FLY ASH

Fly ash is generated as a by-product in the thermal power plants due to the combustion process of pulverized coal. The low-calcium (ASTM Class F) fly ash was collected from Ennore thermal power plant, Tamil Nadu and used in this experiment. The chemical and physical properties are as follows.

Table-1: Chemical Composition of Fly ash (Class-F)

Chemical composition of Fly ash	Weight in %
Silica	55-65
Aluminium oxide	22-25
Iron oxide	5-7
Calcium oxide	5-7
Magnesium oxide	<1
Titanium oxide	<1
Phosphorous	<1
Sulphates	0.1
Alkali oxide	<1
Loss of ignition	1-1.5

Table-2: Physical Properties of Fly ash (Class-F)

Sieve Size (micron)	Weight Retained (Grams)	% Passing
90	95	92
75	122	83
45	704	62
Specific Gravity	1.8	
Fineness	519 m2/Kg	

Fly ash is generated as a by-product in thermal power plants due to the combustion process of pulverized coal. The low-calcium (ASTM Class F) fly ash was collected from Ennore Thermal Power Plant, Tamil Nadu, and used in this experiment. Class F fly ash is rich in silica and alumina, which makes it highly suitable for geopolymer applications due to its excellent pozzolanic reactivity. The particles are generally spherical and fine, enhancing the workability of the mix and reducing the water demand. In this study, the fly ash was used as a primary binder material, replacing traditional Portland cement and clay components. Prior to use, the fly ash was sieved through a 300-micron sieve to remove any coarse impurities and ensure uniform particle distribution. Its chemical composition was characterized by high contents of SiO_2, Al_2O_3, and Fe_2O_3, contributing to the strength and durability of the geopolymer matrix when activated with an alkaline solution. The incorporation of fly ash not only improves the long-term performance of bricks but also significantly reduces the carbon footprint of the production process, aligning with sustainable construction goals.

Fig-1: FLYASH Material

3.2 GGBS

Ground Granulated Blast Furnace Slag (GGBS)**,** a by-product of the iron and steel industry, is obtained by rapid quenching of molten slag from blast furnaces. Rich in calcium, silica, and alumina, GGBS contributes significantly to the strength and durability of geopolymer composites when used as a supplementary binder. In this study, GGBS was used in combination with fly ash to enhance early strength development and improve the long-term performance of the geopolymer bricks.

Fig-2: GGBS Material

3.3 M. SAND

Manufactured Sand (M-sand) is an engineered fine aggregate produced by crushing hard granite stones through a controlled mechanical process. It is a sustainable alternative to natural river sand, offering uniform particle size distribution, better angularity, and improved bonding characteristics. In this study, M-sand was used as a fine aggregate to enhance the workability, compaction, and surface finish of geopolymer bricks. Its consistent quality and availability make it suitable for use in large-scale brick production, while also reducing dependency on depleting natural sand resources.

3.4 SODIUM HYDROXIDE (NaOH)

Sodium hydroxide is an inorganic compound, used as a base in chemical reactions. It can easily dissolve in water and forms series of hydrates (NaOH.nH2O). For this experiment, several concentrated NaOH solutions (in terms of molarity) were prepared by using sodium hydroxide pellets.

3.5 SODIUM SILICATE (Na2SiO3)

Sodium silicate is colourless transparent solids or white powders, adhesive in nature and soluble in water in various degrees. Usually stable as a chemical compound, sodium silicate produces alkaline solution when it dissolves in water. In this research activity, various concentrated (in terms of molarity) sodium silicate solutions were made out of its powder form.

Fig3: Material test

4.MIX DESIGN AND PROPORTIONING

4.1 Preparation of Alkaline Solution (For Molar ratio-7.5,8,8.5 M)

Sodium Silicate (Na2SiO3) Solution

As we know, the molecular weight of sodium silicate (Na_2SiO_3) is 212.14 g/mol. To prepare a 1 M solution, 212.14 grams of Na_2SiO_3 powder should be dissolved in 1000 ml (1 liter) of distilled water. For a 7.5 M solution, the required amount of Na_2SiO_3 increases proportionally.

To calculate the amount of Na_2SiO_3 needed:Required mass=7.5×212.14=1591.05 grams per 1000 ml\text{Required mass} = 7.5 \times 212.14 = 1591.05 \text{ grams per 1000 ml}Required mass=7.5×212.14=1591.05 grams per 1000ml So, for 7.5 M solution:If using 1000 ml of distilled water, add 1591.05 g of Na_2SiO_3 powder.If using 100 ml of distilled water, then:1591.0510=159.11 grams\frac{1591.05}{10} = 159.11 \text{ grams}101591.05=159.11 grams. Thus, to prepare 100 ml of 7.5 M Na_2SiO_3 solution, dissolve 159.11 grams of sodium silicate powder in 100 ml of distilled water, and stir until fully dissolved

Sodium Hydroxide (NaOH) Solution

As we know, the molecular weight of sodium hydroxide (NaOH) is 40 g/mol. For a 1 M solution, 40 grams of NaOH pellets need to be dissolved in 1000 ml (1 liter) of distilled water. To prepare a 7 M solution, the required amount of NaOH increases proportionally.

To calculate the required mass for 7 M:

Required mass=7×40=280 grams per 1000 ml\text{Required mass} = 7 \times 40 = 280 \text{ grams per 1000 ml}Required mass=7×40=280 grams per 1000 ml

So, for a 7 M solution:

If using 1000 ml of distilled water, add 280 g of NaOH pellets. If using 100 ml of distilled water, then:28010=28 grams\frac{280}{10} = 28 \text{ grams}10280=28 grams ,Therefore, to prepare 100 ml of 7 M NaOH solution, dissolve 28 grams of NaOH pellets in 100 ml of distilled water, and stir gently until fully dissolved. Caution should be taken as the dissolution of NaOH is exothermic and releases heat.

4.2 Mix Proportioning and Material Quantity

The various proportions of materials were used and mixed for the casting of geopolymer bricks that are as follows-GGBS:FLYASH:MSAND (100%)+Alkaline Solution (NaOH : Na2SiO3)

1.60% soil :20% fly ash :20%m sand+1:2(8.5M) Alkaline solution (NaOH : Na2SiO3)

2. 50% soil :30% fly ash :20%m sand+1:2(8M) Alkaline solution (NaOH : Na2SiO3)

3. 40% soil :40% fly ash :20%m sand+1:2(7.5M) Alkaline solution (NaOH : Na2SiO3)

Table-3: Quantity of materials

5. MIXING, CASTING AND CURING

The process involves preparing a homogeneous dry mix of fly ash, GGBS, and M-sand in predetermined ratios, followed by blending with an alkaline activator solution (sodium hydroxide and sodium silicate) to form a workable paste. This mixture is cast into oil-coated 230×110×70 mm molds in layers, with each layer compacted using a tamping rod or vibration to eliminate air voids, and the surface is finished smoothly. The specimens remain in the molds for 24 hours at ambient temperature (25–30°C) for initial setting, covered with a damp cloth to prevent moisture loss. After demolding, the bricks undergo ambient curing in

shaded, humid conditions (60–80% RH) for 7–28 days, covered with damp burlap or plastic sheets to maintain moisture, with optional light water spraying if needed. Finally, the specimens are air-dried for 24 hours before testing to ensure consistent results, leveraging GGBS for early strength and M-sand for reduced shrinkage, all without thermal curing.

Fig-4: Mixing of Materials

Fig-5: Casting

6.TESTS AND RESULTS

6.1: Compressive Strength Test

Compressive strength of the bricks is tested with the help of compression testing machine. The compression testing machine is having a capacity of 2000 KN, and loaded at a constant rate of loading at 200kg/cm2/min as per Indian standard procedure for clay bricks and fly ash bricks (IS: 1077-1992 and IS: 12894-2002). The compressive strength check is done for both 7-, 14- and 28-days specimens with combinations of different material ratios and different molar ratios of the alkaline solution. The results are as follows-

Fig-6: After curing and Demoulding

Material Ratio (GGBS:FLYASH:M SAND)	Molar ratio of alkaline solution	Results for 7 days specimen	
		Weight of Bricks (kg)	Compressive strength(N/mm2)
60:20:20	1:2 (8.5M)	2.30	19
50:30:20	1:2.5(8M)	2.30	16.4
40:40:20	1:3(7.5M)	2.30	15

Table-4: Compressive Strength of Geopolymer Bricks

Fig-6: Under Compressive Strength test

Material Ratio (GGBS:FLYASH:M SAND)	Molar ratio of alkaline solution	Results for 14 days specimen		Results for 28 days specimen	
		Weight of Bricks (kg)	Compressive strength(N/mm2)	Weight of Bricks (kg)	Compressive strength(N/mm2)
60:20:20 (M1)	1:2 (8.5 M)	2.25	21	2.20	21.2
50:30:20(M2)	1:2.5 (8M)	2.24	17	2.18	19
40:40:20(M3)	1:3(7.5M)	2.21	15.6	2.12	16

Table-5: Compressive Strength of Geopolymer Bricks

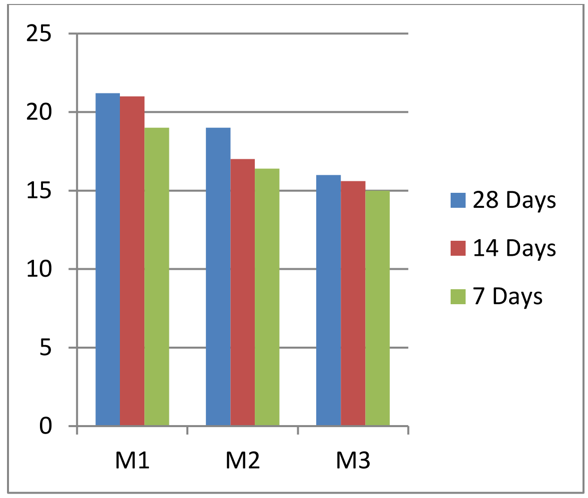

Chart-1: Compressive Strength of Geopolymer Bricks

6.2 Water Absorption Test

Water absorption test is conducted to check the durability property (such as degree of burning, quality and behaviour under weathering action etc.) of the bricks (IS: 3495, Part-II). Initially, the dry brick specimen is kept inside the oven (105oC to 115oC) till it reaches its constant mass. Then, the specimen kept for cooling at room temperature. After it attains the room temperature, its weight is noted (W1). The dry sample then immersed in clean water at a temperature (27+2)oC for 24 hours. Finally, the specimen was removed from the water and wiped with damp cloth to remove the surface water. The final weight of water absorbed brick is noted (W2). The formula for calculating water absorption

Material Ratio (GGBS:FLYASH: M SAND)	Initial Dry Weight (W1) in Kg	Final Weight after water absorption (W2) in kg	% of Water Absorption
60:20:20	2.20)	2.58	17.27%
50:30:20	2.18	2.49	12.22%
40:40:20	2.12	2.45	15.56%

Table-6: Water Absorption of Geopolymer Bricks

Water Absorption= [(W2- W1) / W1] X 100

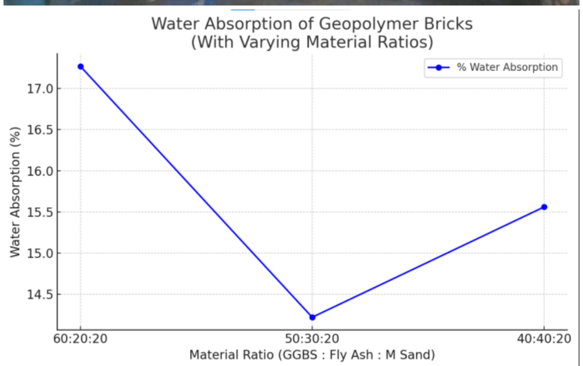

Chart-2: Water Absorption of Geopolymer Bricks

6.3 Efflorescence Test

Efflorescence is a whitish crystalline salt compound, consists of magnesium sulphate, calcium sulphate and carbonate of sodium and potassium. Wastewater is a link to whitish crystalline salts and is made up of carbonates made from magnesium sulphate, calcium sulphate, sodium and potassium. Deposition occurs on the brick surface due to wet conditions, condensation, and cold temperatures. The presence of phosphors in bricks has been reported to be zero, slightly, moderate, heavy and serious (IS: 3495, PART-III). So far, no white spots have been observed since the day of de form.

Fig-8: Efflorescence test

Material Ratio (GGBS:FLYASH:M SAND)	Efflorescence level
60:20:20	0.50%
50:30:20	1.50%
40:40:20	2%

Table-7: Efflorescence test

7. CONCLUSION

Based on the experimental studies carried out on geopolymer bricks with different material ratios and different ratios of alkaline solution, the following inferences are drawn-

- The combination of GGBS and fly ash, when activated with alkaline solutions, significantly improves the compressive strength of geopolymer bricks compared to traditional clay bricks.
- In case of 7, 14 and 28 days, the highest compressive strength 21.2 N/mm2 is exhibited by the geopolymer bricks with the material ratio of 60:20:20 (with a constant alkaline solution of (1:2 8M), compared to other combinations.
- With varying percentages of alkaline solution, the highest compressive strength is recorded in case of geopolymer bricks with the alkaline solution of 1:10 (with a constant material ratio of (60:20:20). This pattern is similar in the case for 7,14 and 28 days.
- The observed efflorescence levels of 0.5%, 1.5%, and 2% are within or close to the acceptable limit (usually ≤10%) as per IS 3495 (Part 3), indicating minimal salt leaching.
- Since geopolymerization avoids the high-temperature firing used in conventional bricks, it contributes to a lower carbon footprint.

Henceforth, it can be easily concluded that geopolymer bricks are lightweight and eco-friendly in nature. It has the almost similar compressive strength parameter and reduced water absorption factor when compared to conventional clay bricks.

REFERENCES

[1] H. M. Khater, M.Ezzat and A. M. El Nagar, “Engineering of Low Cost Geopolymer Building Bricks Applied for Various Construction Purposes” in International Journal of Civil

Engineering and Technology, Volume 7, Issue 4, July-August 2016, pp. 81–99

[2] Subharajit Roy, Sanjith J2, Jagath H R3, Chethan G4 "Experimental Investigation on Geopolymer Bricks" in International Research Journal of Engineering and Technology (IRJET) volume: 5, Issue:8, Aug 2018

[3] Raghulkumar, Thirugnanasambandam, "STUDY ON CONVENTIONAL AND GEOPOLYMER BRICKS" 2019 JETIR February 2019, Volume 6, Issue 2, (ISSN-2349-5162).

[4] Pavithra N, Divya G, "EXPERIMENTAL STUDY ON THE BEHAVIOUR OF GEOPOLYMER BRICKS" International Journal of Civil Engineering and Technology (IJCIET) Volume 9, Issue 2, February 2018, pp. 87 95, Article ID: IJCIET_09_02_010

[5] K. VARSHASRI, A. KALPANA, A. ANIL, B. BABY, "Experimental Investigation on Geo-polymer Bricks", International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056 Volume: 09 Issue: 07 | July 2022

[6] Priyanka Salunkhe, Abhijeet Keskar, Prathamesh Balip, Tejas Deshmukh, Siddesh Gadge, Prasad Vhanmane, "EXPERIMENTAL INVESTIGATION OF GEOPOLYMER BRICK FOR STRENGTH AND DURABILITY" 2021 JETIR October 2021, Volume 8, Issue 10 (ISSN-2349-5162).

[7] K. SRINIVASAN, S. VIGNESH, R. MOHAN, S. ABINASH, S. JEEVA, G. GOKULSHANKAR, "AN EXPERIMENTAL STUDY OF GEOPOLYMER BRICK BY USING OF WASTE PLASTICS" International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056 Volume: 06 Issue: 03 | Mar 2019