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Experimental Investigation on Geopolymer Bricks

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Abstract - *Fly ash, also known as "pulverized fuel ash" in many countries such as England, Northern Ireland, and Scotland etc. is a coal combustion product. It is composed of fine particles of burnt fuels and fuel gases emitted from coal-fired boilers. Though it was causing severe air pollution, in the past, fly ash was usually released into the atmosphere as it is mainly a thermal waste of coal firing thermal plants. But presently, according to air pollution control standards, it is captured prior to release by fitting pollution control equipment. Due to its pozzolanic nature, recycled fly ash is usually used as the production of hydraulic cement and a complete and/or partial replacement for Portland cement in concrete production. Potential of fly ash as a material is not only restricted to cement and concrete industries. It can be utilized as a raw material for brick production, which will be a positive answer towards both environmental and economic complications. The purpose of this particular study is to explore the performance of Geopolymer brick consists of fly ash as one of its chief material. The bricks were casted with clay soil to fly ash in the different proportion of 100:0, 80:20, 70:30, 60:40 and 50:50. Sodium fume solution was applied as an alkaline-activator and a ratio 1:2 of water to NaOH solution was used as the binder solution. With an optimum water/binder ratio of 0.416 and adopted dimension of (200 X 100 X 100) mm. The experimental outcomes were compared with locally available conventional bricks.*

***Key Words*: Light weight bricks, clay soil, fly ash (class-F), geopolymer, compressive strength, water absorption.**

1. INTRODUCTION

India, a country over a billion of its population and a total geographical area of 328.73 million hectares (MH), of which approximately 32% (105 MH) of its facing land degradation. With a whopping 82.6 million hectares as its gross irrigated crop area, India stands at the top of the world in agriculture, defeating countries such as The United States and China. Currently, India produces over 360 billion bricks annually for which the net consumption is over fifteen thousand hectares of land with a serious adverse impact on soil erosion and unprocessed emissions. To produce conventional bricks, brick manufacturing industries nearly uses 2,200 m^3 per billion bricks per annum of soil. Oversimplification of the data can be inferred as, for production of only millions of clay bricks, 0.75 hectares of land is required annually. Furthermore, concern arises as the Thermal Power Plants (TPP) of India produces over 120 millions of fly ash annually from approx. 260 million tons of coal (65% of India's coal production annually). This hefty amount of produced fly ash in India covers nearly 15,000 hectares of useful land as only 3% to 4% of the produced fly ash is being recycled, whereas countries like China, America, and European nations utilize 40% of their produced fly ash.

With the above-stated complications from brick manufacturing, fly ash production and urbanization, it is extremely important to rethink about the possibilities of alternative raw materials for brick manufacturing and sustainable development to protect the further land degradation. Concrete is still one of the most popular construction materials on earth. The cement manufacturing industries usually use fly ash as a partial and/or complete replacement to make Portland cement. Ordinary Portland cement (OPC) typically produces a large amount of carbon dioxide (CO_2) in the nature that significantly contributes to greenhouse gas emissions. Geopolymer solid brick is an innovative building material, normally produced by the chemical reaction of inorganic particles which has a huge potential to deplete the greenhouse emission by 80%. This study is to present the technology behind the producing of geopolymer solid bricks using low-calcium (Class-F) dry fly ash as its main source material and to discover and evaluate of the physical and durable properties of it.

1.1 Geopolymer

In the 20th century, Viktor Glukovsky of Kiev developed a concrete material which was then known as "Soil Cement or soil silicate concrete". When a French material scientist named Joseph Davidovits introduced geopolymer concept, both the definition and terminology of geopolymer became very diverse and often contradictory. With ongoing innovations in the polymer science, the definition of geopolymer became different for different groups of scientists (chemists, geopolymer material chemists, alkali-cement scientists, geopolymer ceramic chemists and ceramic scientists etc.). Generally, geopolymers are a typically inorganic and alumino-silicate (Si-O-Al) based ceramic material similar to zeolites. The formation of geopolymers is a quick reaction of the alkaline activated solution with silica-alumina minerals which further forms a three-dimensional polymeric long chain of an amorphous covalent bond network. The polymer study constitutes a diverse group which consists of polymer science, chemistry, and engineering. Polymers are of two kinds, either organic (carbon-based) or inorganic (Ex. Silicon-based). The organic polymers further classified as natural polymers (rubber, cellulose etc.), synthetic organic polymers (textile fibers, plastics, films etc.) and natural biopolymers (biology, medicine etc.). The name geopolymer derived from the rock-forming raw materials which are of geological origin and used in the synthesis process for silicon-based polymers.

1.2 Development of Geopolymer Bricks

Generally, fly ash of class F is rich with silica and alumina content. When fly ash (class-F) is used in the brick manufacturing, the high amount of silica and alumina reacts with alkali activated pre-mixed solution of sodium hydroxide and sodium silicate. This reaction activity results in gel formation which is known as the binder hence there is no requirement of cement in this brick production.

2. OBJECTIVES

The objectives of this study is,

i. To introduce substantial light weighted bricks in the field of construction.

ii. To develop and study salient properties of geopolymer bricks.

iii. To implement and investigate a process of casting and curing, which doesn't require an enormous amount of water.

3. MATERIALS and IT'S PROPERTIES

3.1 Clay Soil

For this experimental study, clay soil is excavated and gathered from the site in Chikkamagaluru, Karnataka and sieved with 4.75mm IS sieve. The physical properties of used clay soil are shown in the table below.

Table-1: Physical properties of Clay soil

Characteristics	Value	Unit
Specific gravity	2.20	-
Moisture content	1.80	%
Liquid limit	30	%
Plastic limit	14.58	%
Grain size distribution analysis i. Gravel ii. Sand iii. Silt & Clay	 30 53 17	%
Standard Proctor Test i. Maximum Dry Density (MDD) ii. Optimum Moisture Content (OMC)	 2.88 12	 g/cc %

Fig-1: Clay Soil (Source: Chikkamagaluru, Karnataka)

3.2 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-2: 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-3: 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 m^2/Kg	

Fig-2: Fly ash (Source: Ennore Thermal Power Plant, Tamil Nadu)

3.3 Water

Locally available portable water confirming to Indian standard code IS: 456-2000 is used.

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 ($NaOH.nH_2O$). For this experiment, several concentrated NaOH solutions (in terms of molarity) were prepared by using sodium hydroxide pellets.

3.5 Sodium Silicate (Na_2SiO_3)

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.

4. MIX DESIGN and PROPORTIONING

4.1 Preparation of Alkaline Solution (For Molar ratio- 1:10)

i. Sodium Silicate (Na_2SiO_3) Solution-

As we know, the molecular weight of Na_2SiO_3 powder is 212.14 gm. For 1M solution, 212.14 gm of Na_2SiO_3 needs to be dissolving into 1000 ml of distilled water. So for 1M solution, if we use a smaller quantity of water, (for example 100 ml of water) the required amount of Na_2SiO_3 powder will be 2.12 gm.

ii. Sodium Hydroxide (NaOH) Solution-

Similarly, the molecular weight of NaOH pellets is 40 gm. For 1M solution, 40 gm of NaOH needs to be dissolving into 1000 ml of distilled water. So for the preparation of 10M solution, 40 gm of NaOH dissolved in 100 ml of distilled water.

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-

1. 100% soil +0% fly ash +water
2. 50% soil +50% fly ash + Alkaline solution (NaOH + Na_2SiO_3) +water
3. 60% soil +40% fly ash + Alkaline solution (NaOH + Na_2SiO_3) +water
4. 70% soil +30% fly ash + Alkaline solution (NaOH + Na_2SiO_3) +water
5. 80% soil +20% fly ash + Alkaline solution (NaOH + Na_2SiO_3) +water

Sodium hydroxide and sodium silicate solutions were mixed together with an extra amount of water (if required) to prepare the alkaline solution. This compound alkaline solution was prepared just before it was mixed with the dry materials. During the early stages, for all of the above different material proportions, the molar ratio of the alkaline solution was kept constant at 1:10. In later stages of the experiment and with the help experimental data, soil to fly ash ratio 70:30 was selected as the best combination among the rest. With the constant soil to fly ash ratio, the molar ratios of the alkaline solution were varied as 1:8, 1:12, 1:14.

Table-4: Quantity of materials (With a constant molar ratio of 1:10)

Proportion	Soil (kg)	Fly ash (kg)	Molar ratio	Na_2SiO_3 (ml)	NaOH (ml)
100:0	3.3	0	1:10	10	40
50:50	1.65	1.65	1:10	10	40
60:40	1.98	1.32	1:10	10	40
70:30	2.2	1.1	1:10	10	40
80:20	2.7	0.6	1:10	10	40

Table-5: Quantity of materials (With a constant soil to fly ash ratio)

Proportion	Soil (kg)	Fly ash (kg)	Molar ratio	Na_2SiO_3 (ml)	NaOH (ml)
70:30	2.2	1.1	1:10	10	40
70:30	2.2	1.1	1:8	20	60
70:30	2.2	1.1	1:14	30	70
70:30	2.2	1.1	1:12	20	80
70:30	2.2	1.1	1:10	10	50

5. MIXING, CASTING and CURING

Rectangular moulds with a cross section of 20 cm x 10 cm x 10 cm were prepared. Initially, clay soil and fly ash were weighed according to the selected ratio. After that, both of the materials were mixed with dry hands until the uniform colour appeared (approximately for 3 minutes). Simultaneously, the alkaline solution was prepared with the help of sodium silicate and sodium hydroxide solutions. The final mix was prepared by mixing dry mixed material with the alkaline solution until a uniform mix was developed (approx. 3 to 4 minutes). During the casting process, a limited amount of water was added up to the level of requirement. This mix then immediately casted into moulds, the required amount of compaction was done and surface finishing was given to each moulds. The specimen then dry cured at an optimum temperature of 60°C inside an oven. After completion of the required curing period inside the oven, the brick specimens were kept inside the moulds for at least six hours in order to avoid a drastic change in the environmental conditions. After six hours, the specimens were finally de-moulded and were left to air-dry in the laboratory until the day of the test.

Fig-3: Dry Hand Mixing of Materials

Fig-4: Dry Hot Oven Curing

Fig-5: Geopolymer Bricks with Material Ratio 70:30

Fig-6: Geopolymer Bricks with Material Ratio 80:20

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/cm^2/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 and 14 days specimens with combinations of different material ratios and different molar ratios of the alkaline solution. The results are as follows-

Table-6: Compressive Strength of Geopolymer Bricks (Keeping molarity of alkaline solution as 1:10)

Molar Ratio of Alkaline Solution (1:10)				
Material Ratio (Soil : Fly ash)	Results for 7 days Specimen		Results for 14 days Specimen	
	Weight of bricks (Kg)	Compressive Strength (N/mm²)	Weight of bricks (Kg)	Compressive Strength (N/mm²)
100:0	3.20	2.30	3.14	2.50
50:50	2.70	2.00	2.65	2.40
60:40	2.76	2.50	2.76	3.00
70:30	2.82	2.75	2.70	3.40
80:20	2.96	2.30	2.88	2.40

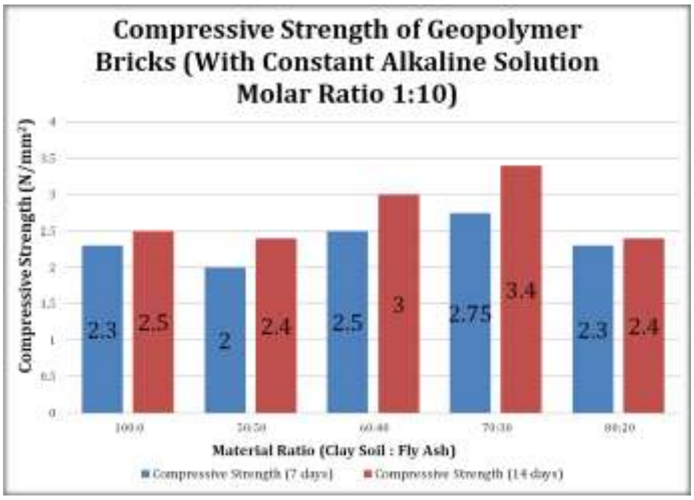

Chart-1: Compressive Strength of Geopolymer Bricks (Keeping molar ratio of alkaline solution as 1:10)

Table-7: Compressive Strength of Geopolymer Bricks (Keeping material ratio as 70:30)

Material Ratio (Clay Soil : Fly ash) = 70:30				
Molar Ratio of Alkaline Solution	Results for 7 days Specimen		Results for 14 days Specimen	
	Weight of bricks (Kg)	Compressive Strength (N/mm²)	Weight of bricks (Kg)	Compressive Strength (N/mm²)
1:8	2.82	2.70	2.75	3.25
1:10	2.82	2.85	2.70	3.45
1:12	2.80	2.63	2.78	3.10
1:14	2.80	2.68	2.80	3.30

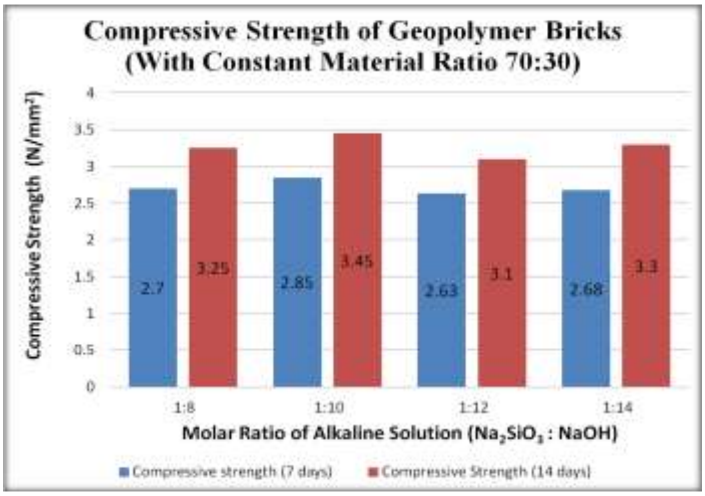

Chart-2: Compressive Strength of Geopolymer Bricks (Keeping material ratio constant as 70:30)

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 (105°C to 115°C) 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 (W_1). The dry sample then immersed in clean water at a temperature (27+2)°C 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 (W_2). The formula for calculating water absorption (% by mass) is as follows-

Water Absorption= $[(W_2 - W_1) / W_1] \times 100$

Table-8: Water Absorption of Geopolymer Bricks (Keeping molarity of alkaline solution as 1:10)

Molar Ratio of Alkaline Solution (1:10)			
Material Ratio (Soil : Fly ash)	Initial Dry Weight (W_1) in Kg	Final Weight after water absorption (W_2) in kg	% of Water Absorption
100:0	3.14	3.65	16.24 %
50:50	2.65	2.98	12.45%
60:40	2.76	3.20	15.94%
70:30	2.70	3.02	11.85%
80:20	2.88	3.23	12.15%

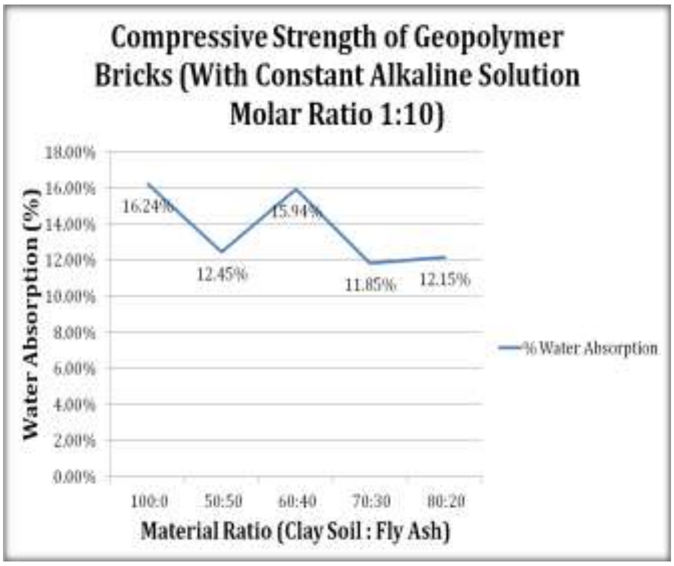

Chart-3: Water Absorption of Geopolymer Bricks (Keeping molarity of alkaline solution as 1:10)

Table-9: Water Absorption of Geopolymer Bricks (Keeping material ratio as 70:30)

Material Ratio (Soil : Fly ash) = 70:30			
Molar Ratio of Alkaline Solution	**Initial Dry Weight (W_1) in Kg**	**Final Weight after water absorption (W_2) in kg**	**% of Water Absorption**
1:8	2.75	3.22	17.09%
1:10	2.70	3.00	11.11%
1:12	2.78	3.12	12.23%
1:14	2.80	3.18	13.57%

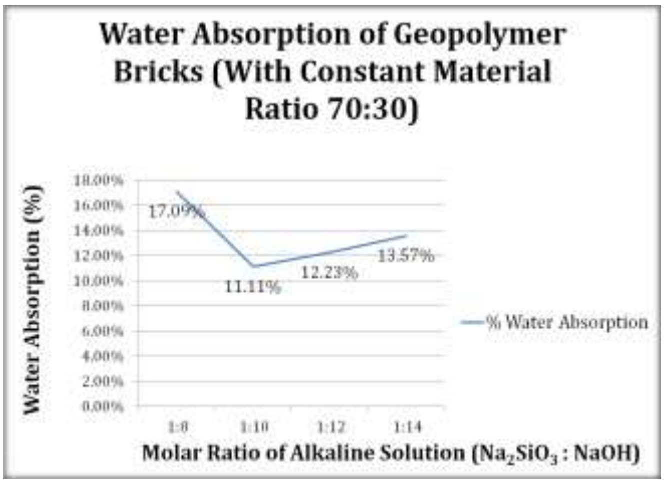

Chart-4: Water Absorption of Geopolymer Bricks (Keeping material ratio constant as 70:30)

6.3 Efflorescence Test

Efflorescence is a whitish crystalline salt compound, consists of magnesium sulphate, calcium sulphate and carbonate of sodium and potassium. Usually, efflorescence originates due to moist condition, condensation and low temperature etc and deposits on the surface of the bricks. The presence of efflorescence in bricks is reported as nil, slight, moderate, heavy and serious (IS: 3495, Part-III). From the day of de-moulding, till now no white patches are observed hence efflorescence is reported as nil.

6.4 Dimension Test

For dimension test, few sample bricks are selected randomly and their dimensions (length, width, height) are measured. These dimensions are checked in one or two lots of ten each as shown in fig.6. Allowed variations in brick dimensions are kept limited, within ±3% for class one bricks and ±8% for other classes (IS: 1077).

Fig-7: Dimension Test on Geopolymer Bricks

7. CONCLUSONS

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-

i. The weight of geopolymer bricks is relatively lower than the conventional clay bricks (reduction up to 25%).

ii. In case of both 7 and 14 days, the highest compressive strength is exhibited by the geopolymer bricks with the material ratio of 70:30 (with a constant alkaline solution of 1:10), compared to other combinations.

iii. 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 70:30). This pattern is similar in the case for both 7 days and 14 days.

iv. From the water absorption test, it is clearly observed that water absorption and penetration is less for geopolymer bricks than conventional ones. Geopolymer bricks show water absorption up to 12% when compared to normal clay bricks (16-20%).

v. Due to adaptation of dry oven curing method and geopolymerization process, a substantial amount of water is conserved in this geopolymer brick production.

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.

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