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Experimental study of sustainable geo polymer bricks

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ABSTRACT

Bricks are among one of the most commonly used and cheapest construction material and its demand is increasing every day. Manufacture of conventional bricks leads to depletion of natural resources such as red earth, clay etc. and causes several environmental problems. Therefore, alternative eco-friendly materials are required for the manufacture of bricks. In India, every year about 170 million tones fly ash is produced in thermal power plants and only 60% of this is effectively utilized and the rest is dumped as landfill. The dumping of these wastes to landfill causes severe environmental issues such as environmental pollution, contamination of ground water etc. Large quantities of bio-solids are produced in sewage treatment plants all over the world and proper disposal of these waste is a big environmental crisis. Thus, alternative, low cost and sustainable technologies are required to handle these wastes effectively. In this study an attempt has been made to produce eco-friendly bricks by using alkali activated fly ash, clay and bio-solid. The variables considered are, ingredient proportion, liquid activator to fly ash ratio, sodium silicate to sodium hydroxide ratio, molarity of sodium hydroxide and nature of curing. Test results revealed that the compressive strength, water absorption and efflorescence of geopolymer bricks conforms to IS specifications of conventional bricks. Therefore, geopolymer bricks can be considered as a better alternative to conventional bricks.

Keywords: Alkali activated, Fly ash, Clay, Bio-solid sodium silicate, Sodium hydroxide, Geopolymer bricks

INTRODUCTION

Bricks are considered to be one of the oldest and the most environmentally friendly building material. The term brick refers to small units of building material, which are often made from fired clay. Because of its small size, it is an ideal material for structures in confined and also curved spaces. Moreover, with minimal upkeep and maintenance, brick buildings generally last a long time. Bricks are usually used in the construction of buildings as walls, paving, and flooring. Clay bricks were mostly common in ancient days. However, production of clay bricks requires very high-temperature kiln firing and this also releases substantial quantity of greenhouse gases. It also leads to the vast usage of clay from the paddy fields. Concrete blocks are also widely used for the construction of walls in many parts of the world. But its production requires large quantities of natural resources and significant amount of energy. It also releases enormous amount of carbon dioxide, the potent greenhouse gas causing environmental pollution. Hence it is not an eco-friendly product. As a result of this, researches were performed to produce sustainable environment friendly alternative to traditional clay brick and concrete blocks. One such alternative is the "Fly ash brick". Fly ash is the fine waste material produced from the thermal power plants. Fly ash brick thus has also become a suitable economical solution for decomposing the waste material which otherwise would cause environmental problems. Geopolymer bricks can be made by mixing special and abundant earth like

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lateritic clay earth with simple geopolymer binder. It is compressed to give the shape of a brick which is then heated to above 60^0 C so as to attain the required strength. If heated at 250^0 C, it would resist freezing. At 450^0 C, it shows a significant strength increase so that it can be used to manufacture structural elements like beams for doors and windows. Compared to a traditional bricks that are fired at 1000^0 C in a kiln, the LTGS brick need about eight times lesser energy for an equivalent strength. LTGS bricks correspond to Low Temperature Geopolymer Setting bricks. Main disadvantage that the geopolymer bricks face is the low workability due to the use of chemical solution instead of water to achieve higher strength.

The use of waste materials in bricks can reduce the consumption of clay and reduce the environmental burden due to accumulation of waste materials, the best example for which is the fly ash brick. Even in terms of strength, it is quite advantageous to note that these bricks offer much strength and possess efficient quality.

TRADITIONAL BRICKS

Burnt clay bricks, commonly called as the traditional bricks are manufactured from red earth. These bricks were commonly used in ancient constructions at the time where clay and red earth were locally available in large quantities. Depending upon the way of treatment provided, these bricks are classified into many classes. Burning is the most preferable way of treating bricks which imparts sufficient strength to it and this procedure is done in special chambers which are called kilns. These kilns are constructed by aligning the bricks that are to be cured. Some kilns are temporary while some others may be permanent. Bricks are commonly burnt using firewood and coal. Bricks can also be made by curing it under the sun but the strength of sun burnt bricks are less than that of fire burnt bricks.

As per Bihar Baseline Study (2014), Bihar is the fourth largest clay brick producer in India. There are about 5700 number of brick kilns as per the government records. However, there is a deficit of bricks in the state. Bihar needs over 7500 million bricks in the next five years to fulfil the rural housing gap of 1.1 million dwellings per year as a part of the Indira Awaas Yojna. The raw materials used for the brick production are as follows:

Fuel

Coal is used as fuel in the state. 22 lakh tonnes of coal per year is consumed in the state. Coal is imported from Jharkhand and Assam.

Soil

The source of soil is agricultural (90%) and river land (10%). Almost 16,500,000 m^3 of clay is consumed in one year converting about 5500 acres of land into barren land.

Wood

Wood utilization has led to rampant deforestation depleting the forest cover. Currently 60,000 tonnes of wood are used per year.

FLY ASH BRICKS

Fly ash bricks are those which are completely made up of fly ash, the thermal power plant waste material. As per Cement & Concrete terminology, fly ash is defined as “finely divided residue resulting from the combustion of ground or powdered coal which is transported from the fire box through the boiler by flue gases”. Fly ash is generally classified into two different types; Class C and Class F. The Class F fly ash is normally generated due to the combustion of anthracite or bituminous coal and Class C is obtained by the burning of lignite or sub-bituminous coal combustion. Class C fly ash possesses calcium oxide in excess (10-40%) while Class F contains CaO less than 10%. Due to higher CaO content, Class C fly ash participates both in cementitious and pozzolanic reaction whereas class F fly ash mostly contribute to pozzolanic reaction during hydration process. And this property is the main reason for high strength good quality brick production. Fly ash bricks are lighter and stronger than traditional clay bricks

BIO-SOLIDS

Bio-solids are by-products that are produced in sewage treatment plants in large quantities. Bio-solids have pozzolanic property when they are crushed into fine material. These are treated sludge which is stabilized by undergoing different stabilization process like oxidation, anaerobic and aerobic digestion, drying, thickening etc. Human population is increasing day by day which leads to increase in sewage waste and its by-products. The wet slush which is a by-product in treatment plant is pumped to the nearby vacant land which causes so many environmental problems.

LITERATURE REVIEW

The audit of writing is relating to a portion of the imperative articles and review recorded by different specialist in their journals

Tay (1987) studied the utilization of dried sludge and sludge ash in brick production. 10-40% of dried sludge and 10-50% of sludge ash are incorporated in separate samples. The brick samples were then dried in an oven at 100° C for 24 hrs. The dried bricks were fired in a kiln at a temperature of more than 1,000° C for about 24 hrs. They recommended that a maximum of 40% of dried sludge and 50% of sludge ash can be incorporated in clay bricks separately. Water absorption of the bricks increases as the percentage of dried sludge increases. The large amount of organic matter present in the sludge resulted in high shrinkage of the bricks during firing.as the sludge content in the brick increases the compressive strength of brick decreases [1].

Liew (2004) reported the use of sewage sludge as raw material in clay brickmaking process. In the study, bricks were produced with sewage sludge additions ranging from 10 to 40% by dry weight. Bricks with sludge content up to 40% meet the required strength characteristics. Bricks with more than 30% sludge addition are not recommended since they are brittle and easily broken. A tendency for a general degradation of properties with sludge additions was observed due to its refractory nature. And the study resulted sludge bricks of this nature are only suitable for use as common bricks, which are normally not exposed to view, because of poor surface finishing [2].

Ukwatta and Mohajerani (2017**)** studied the use of bio-solids water treatment plant as a partial replacement of fired clay in brick production. Bricks were produced incorporating 5, 10, 15, 20, and 25% WTP bio-solids by weight which was fired at 1050 ^{0}C for 3 h with different heating rates of 0.7, 1.0, 1.5, and 2.0 ^{0}C min $^-$1. Standard Proctor compaction tests were carried out for different bio-solids-soil mixtures to determine the required optimum water content. As the bio-solid content in brick increases the volumetric shrinkage value also increased. Addition of WTP10 bio-solids caused a gradual increase in the cold-water absorption. Lower heating rates associated with longer sintering time could form bricks with connected pores, which could increase the water absorption capability of bricks [3].

Tuyan (2018) investigated the effect of alkali activator concentration and curing conditions on consistency and strength of waste clay brick powder-based geopolymer composites. Geopolymer mortars with twenty different activator concentrations were produced and those mixtures having optimum alkali activator concentration were subjected to different curing conditions. Test results indicated that the optimum alkali activator concentration corresponded to Ms (SiO_2/Na_2O) ratio of 1.6 and Na_2O content of 10% by weight of the binder. A maximum compressive strength of 36.2 MPa was achieved by curing at 90 °C, 40% RH for 5 days [4].

Mohajerani (2018) evaluated the environmental impacts of fired-clay bricks (FCB) incorporating bio-solids. The incorporation of bio-solids into bricks is environmentally favorable and is a promising alternative approach with respect to most of the environmental impacts except water depletion, which is mainly due to the higher water demand of bio-solids-amended bricks during the shaping process. They reported that the compressive strength of FCB with 25% bio-solids were over 16 N/mm^2.FCB with bio-solids showed lower firing shrinkage. Addition of bio-solids in FCB resulted in higher apparent porosity and thus lower density and compressive strength [5-7].

PROPERTIES OF MATERIAL USED

Fly ash

Fly ash used in the study belonged to ASTM class F collected from Thoothukudi thermal power plant, Tamil Nadu. Density bottle method is used to determine the specific gravity.

Property	Description/Values
Appearance	Grey colour, fine powder
Specific Gravity	2.515
$SiO_2+Al_2O_3+Fe_2O_3$	70%
CaO	9%
MgO	2%
Na_2O	1.5%
Moisture	2%
Loss of ignition	2%

Bio-solids

Bio-solids obtained from Muttathara sewage treatment plant was in hard mass form. Hard mass is crushed in to fine powder and its size is bought below 600 micron. It has dark grey colour and specific gravity of 1.634. For finding the heavy metal contents in bio-solids XRF diffraction test was conducted. XRF analysis detects the presence of the following heavy elements like Titanium (Ti), Manganese (Mn), Iron (Fe), Cobalt (Co), Zinc (Zn), Arsenic (As) and Lead (Pb).

Chemical	LOI	SiO_2	Fe_2O_3	MgO	CaO	Al_2O_3	TiO_2
Ratio	60.53	22.22	3.80	0.974	0.269	9.48	0.48

Clay

Kaolinite clay sample collected from the Thonnakkal region in Thiruvananthapuram district and passing through 600 micron IS sieve is used.

Properties	Values
Specific gravity	2.37
Liquid Limit (%)	51
Plastic Limit (%)	27
Plasticity Index (%)	24
Maximum Dry Density (g/cc)	1.52
Optimum Moisture Content (%)	28
Sand (%)	13
Silt (%)	50
Clay (%)	37
Unconfined Compressive Strength (N/mm^2)	131.7

Alkaline Activator

A mixture of sodium silicate solution and sodium hydroxide solution was used as the alkaline activator. Sodium silicate solution with module (ratio of SiO_2 to Na_2O) value 2, ie., SiO_2 = 29.4% and Na_2O = 14.7% and water 55.9% by mass. Sodium hydroxide pellets with 97-98% purity was used and mixed with water to prepare its solution with required molarity.

ANALYSIS AND RESULTS

Table 1 Effect of L /FA ratio on compressive strength of bricks

Liquid Activator/ Fly ash ratio	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.2
Compressive Strength (N/mm^2)	1.3	1.6	2.6	2.8	3.1	3.4	3.6	4.1

Table 2 Effect of molarity on compressive strength of bricks

Molarity of NaOH solution	4	6	8
One day compressive Strength (N/mm^2)	2.1	2.4	3.4

Table 3 Effect of Ingredient Proportion on compressive strength, density and volumetric shrinkage of bricks

Ingredient Proportion	**Strength (N/mm^2)**	**Density (kg/m^3)**	**Volumetric shrinkage (%)**
F40B50C10	4.2	1522	3.35
F40B40C20	4.5	1729	2.9
F40B30C30	4.45	1791	2.5
F50B50C0	3.33	1469	5.1
F50B40C10	4.06	1531	3.2
F50B30C20	5.67	1719	2.98
F60B40C0	3.33	1481	4.8
F60B30C10	3.67	1541	3
F60B20C20	4.67	1744	2.9

Table 4 Effect of Na_2SiO_3/ NaOH ratio on compressive strength of bricks

Na_2SiO_3/ NaOH ratio	1.5	1.75	2	2.25
Strength (N/mm^2)	5.76	6	6.4	6.5

CONCLUSION

Based on the investigations conducted on bio-solid geopolymer bricks the following conclusions were drawn

1. Three-day compressive strength of ambient temperature cured bio-solid geopolymer bricks is more than the minimum compressive strength prescribed in IS codes for conventional bricks.
2. The strength of bio-solid geopolymer bricks increased with the increase in curing period. When the ambient temperature curing period increased from 3 to 15 days the compressive strength increased by 137%.
3. Compressive strength of heat cured bio-solid geopolymer bricks increased with increase in curing temperature, for one day heat cured specimen, when the temperature increased from 40^{o}C to 60^{o}C, the strength increased by 57%.
4. Seven day compressive strength of ambient cured geopolymer bricks is almost equal to one day compressive strength of bio-solid geopolymer bricks cured at 60^{o}C.
5. The water absorption of bio-solid geopolymer bricks for all curing conditions is very less than that prescribed IS code values for conventional bricks.
6. Bio-solid geopolymer bricks undergo no efflorescence.
7. An empirical relationship is proposed for the compressive strength of bio-solid geopolymer brick in terms of curing temperature, percentage of fly ash, curing period, liquid activator to fly ash ratio, molarity of NaOH, percentage of bio-solids and Na_2SiO_3/NaOH ratio.

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