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Exploring the viability of fly ash bricks as an alternative material for building construction

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Abstract. Fly ash, which is recovered from the gases produced when coal is burned to produce power, is essentially a fine glass powder. Fly ash is a siliceous substance that has an amorphous or glassy bulk associated with it. These tiny earth elements are mainly composed of silica, alumina, and iron. When flyash is combined with lime and water, a cementitious substance is created. Under conditions of high steam pressure and temperature, the components of flyash combine with lime to form calcium silicate-hydrate and calcium aluminate hydrate. Portland cement and this newly produced solvent have characteristics that are very comparable. Due to their similarity, fly ash and cement can be substituted as a fundamental element in concrete, with fly ash having certain clear quality advantages. The surfaces produced by this concrete's formation are smoother, tighter, and denser, improving the characteristics of fly ash. In developing countries, flyash bricks are an economical and efficient means of low and medium-rise building construction, using very less resources. This paper examines the case of Flyash bricks for load-bearing wall construction as well as filler material and also discusses the engineering viability and properties of such Flyash bricks. The paper comes to the conclusion that Flyash bricks are a practical substitute for traditional bricks with more ancillary advantages.

Keywords. Flyash bricks, sustainable, building, material, architecture, construction.

1. Introduction

Fly ash bricks are masonry units made of class C or class F fly ash and water. They are used in construction. The bricks can withstand more than 100 freeze-thaw cycles when compressed at 28 MPa (272 atm), cured for 24 hours in a 66 °C steam bath, and toughened with an air-entrainment agent. The brick is referred to as "self-cementing" because class C fly ash contains a lot of calcium oxide. The production process uses less energy, emits less mercury into the atmosphere, and frequently costs 20% less than making clay bricks the old-fashioned way. In place of burned clay bricks, cement, fly ash, and phosphor-gypsum are used. Fly ash, lime, and gypsum chemistry's strength is used in this innovative technique. By tapping a hydrous mineral phase to its threshold limits through an adequate limit of gypsum, the sluggish chemistry of fly ash and input is controlled. As a result, it avoids the need for a heavy-duty press or autoclave that would be necessary if only fly ash and lime were used. The method necessitates drying and curing outdoors without the use of fossil fuels. Autoclaving with steam curing can be used to gain strength quickly. Bricks and blocks, fly ash, lime (from OPC), and gypsum are well-known minerals that are frequently utilized in various industries and are therefore components of the units. All of these minerals can be found as wastes and byproducts. Bricks and blocks of high quality that produce lime can be substituted with Ordinary Portland Cement (OPC) if lime is not readily accessible in sufficient quantities. There is evidence that this technique is both environmentally sound and safe.

When pulverized coal is burned in thermal power plants, a byproduct called fly ash is produced. Indian coal has a high ash concentration that ranges from 30% to 50% [1]. Historically, waste coal from businesses and residences has been collected. In the nineteenth century, "scavengers" would take coal ash and carry it to nearby brickworks, where it would be combined with clay. Normally, the proceeds from the sale of ash would cover the cost of garbage collection [2]. Usually, the clay is trapped when coal is formed. The incombustible clay particles are left behind as ash when coal is burned. The boilers and aggregates of inflammable ash become cinders during a long period of residence. Due to its increased energy efficiency, pulverized coal technology is now the favored option. In this instance, powdered clay and fuel gases escape and settle as ash in bag filters or electrostatic precipitators (ESPs). The term "fly ash" originates from this [3]. Fly ash bricks are depicted with a frog in Figure 1.

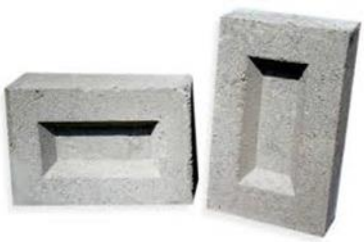

Figure 1. Fly Ash bricks having frogs

2. Ancient Lime-Pozzolanic Chemistry

The reactive silicates and aluminates that develop into hydrated mineralogy when fly ash and lime are combined are as follows:

$Ca(OH)_2 + SiO_2 + H_2O \rightarrow C_3S_2H_3$

$Ca(OH)_2 + Al_2O_3 + H_2O \rightarrow$ C-A-H

Calcium silicate hydrates with the aforementioned mineralogy do provide strength but require more time to develop. Despite the fact that calcium aluminate hydrates do form quite early in life, their mineralogy only allows for weak strength.

There must be a solution to these rheological issues for commercial production. It is that which Fal-G is. Older methods of making fly ash bricks recommended using a heavy-duty press along with an autoclave to get over the drawback of the delayed reactions between fly ash and lime. The cost-prohibitive nature of the product is caused by the cascading effects of the capital-intensive plant and machinery and the energy-intensive process operations on the final cost of the product. Due to the low marketing costs for walling material, this situation precluded the use of fly ash in the brick industry, especially in second- and third-world nations [4].

3. Types of Fly Ash Bricks

Fly ash bricks can be divided primarily into two kinds based on the basic material:

Bricks made of fly ash and cement as a binder

In these bricks the raw materials consist of: Sand, cement, and fly ash

Lime used as a binder in fly ash bricks

In these bricks, the raw materials consist of Fal-G is a compound made up of fly ash, lime, gypsum, and sand.

Fly ash is a fine residue obtained from thermal power stations using ground or powdered coal as boiler fuel. It can be utilized in various forms as a building material. The thermal power stations in the country throw large quantities of flyash which goes to waste but could be effectively used as a partial replacement for cement.

Flyash obtained from various thermal power plants has quite varied physical and chemical characteristics. Depending on the coal that the power stations utilize, even if the fly ash is sourced from the same power station, there will be a significant change in these attributes. The majority of the flyash collected from power plants can be used as pozzolanic material, nevertheless, due to the large range of variation that is permitted in terms of chemical property. The permitted range of compounds and their concentrations are provided in IS: 3812 (Part II). While the flyash that is typically obtained has a specific surface area of 2500 to 6000 cm^2/gm, the BIS specifies a fineness that corresponds to a specific surface area of 3200 cm^2/gm. The grade I and grade II flyash that is typically obtained completely complies with the BIS's requirement for a minimum Pozzolanic activity of 200m^2 per kilogram.

4. The Fal-G Technology

The chemistry of fly ash-lime has roots in the two millennia of civil engineering traditions. The majority of Roman structures were built using pozzolanic-lime mixtures. In the absence of chemical engineering explanations, the formulations of the time were dependent on empirical assessments. However, physical behavior was used to determine a product's quality. The need to optimize pozzolanic-lime chemistry was less of a problem after the introduction of Ordinary Portland Cement (OPC). Since the end of the 1960s, pozzolanic-lime chemistry—OPC being the source of lime—has once more become significant, as faith in OPC as a durable media has started to wane. This is how PPC as a cement blend came to be. FaL-G has emerged against this backdrop, demonstrating the innovation component in its composition through the optimized function of calcium aluminium sulphate mineralogy [3].

A novel cementitious binder called FaL-G is capable of producing structural concrete with good microstructure characteristics. In order to utilize the potential of calcium sulfo aluminate hydrates, it can be thought of as an extension of the lime-pozzolanic binder as follows:

$Ca(OH)_2 + Al_2O_3 + SO_3 + H_2O \rightarrow C_6AS_3H_{32}$

5. Specifications and Characteristics of Fly ash Bricks

5.1. General Requirements

The bricks must be sound, compact, and of a consistent shape visually. There must be no obvious cracks, warping, or biological material in the bricks. Whether the frog is there or not, the bricks must be sturdy. On one of its faces, the frog can be between 10 and 20 mm deep.

5.2. Dimensions and Tolerances

The standard modular sizes of fly ash bricks are given in Table 1.

Table 1. The modular sizes of flyash bricks

Length (L)mm	Width (W)mm	Height (H)mm
190	90	90
190	90	40

The non-modular sizes of the bricks which are produced are given in Table 2.

Table 2. The non-modular sizes of flyash bricks

Length (L) mm	Width (W) mm	Height (H) mm
230	110	70
230	110	30

5.3. Tolerances

Bricks must test with a length tolerance of 3 mm, a width tolerance of 2 mm, and a height tolerance of 2 mm.

5.4. Classification

The different classes of fly ash lime bricks, depending upon their average compressive strength are given in Table 3.

Table 3. The different categories of Fly-Ash bricks

Class Designation	Average Compressive Strength - Kg/cm^2 (approximate)
30	300
25	250
20	200
17.5	175
15	150
12.5	125
10	100
7.5	75
5	50

6. Physical Characteristics of Flyash Bricks

6.1. The Compressive Strength

Fly ash lime bricks must have an average compressive strength that is at least as high as the minimum value listed for each class in IS: 3495 (Part-I)-1976. Any single brick's compressive strength must not be more than 20% less than the minimum average compressive strength required for the relevant class of bricks.

6.2. Drying Shrinkage of Bricks

When tested using the procedure outlined in IS: 4139-1989, the average drying shrinkage of the bricks, being the average of three units, shall not be greater than 0.15 percent.

6.3. The Efflorescence Test

The efflorescence rating for bricks evaluated in accordance with the guidelines in IS:3495 (Part-3)-1976 must be no higher than "moderate" up to class 10 and "slight" for higher classes.

6.4. Water Absorption of Flyash Bricks

The bricks must have an average water absorption of less than 20 percent by mass up to class 12.5 and less than 15 percent by mass for higher classes when tested according to the procedure outlined in IS:3495 (Part-2)-1976 after being submerged in cold water for 24 hours.

7. Properties of Fly Ash Affecting the Strength of Fly ash Bricks

The strength and appearance of fly ash bricks are influenced by the following fly ash characteristics:

Loss on Ignition (LOI): Because of the carbon and water it contains, fly ash loses weight when it burns at around 1000°C. Loss on Ignition (LOI) is the term used to describe the weight loss that results from carbon combustion and moisture evaporation. A percentage is used to represent this. The quality of fly ash will improve with a smaller ignition loss. According to BIS, it shouldn't be higher than 5%.

Finesse: The fly ash that is finer has a larger surface area that can react with lime. This raises Pozzolanic activity, which helps make fly ash bricks stronger. It shouldn't be greater than 320 m^2/kg, according to BIS.

CaO (calcium oxide) content High calcium fly ash has a higher Pozzolanic reactivity than other types of fly ash. The strength of fly ash brick increases with increasing Pozzolanic activity. Fly ash is divided into two categories by ASTM C618: Class C fly ash contains more than 10% lime and Class F fly ash contains less than 10% lime.

Fly ash can also be divided into LT (low temperature) and HT categories depending on how the boiler is operating (high temperature). While HT fly ash, which contains glassy reactive phases, is produced at temperatures above 1000 °C in super-thermal plants, LT fly ash, which contains amorphous phases, is produced at boiler temperatures of no more than 800 °C. While HT fly ash works well with OPC, LT fly ash works well with lime [3].

8. Benefits of Fly ash Bricks for the Environment

Every year, the rise in greenhouse gases—of which CO_2 is one of the main components-drives up global warming, resulting in droughts and floods. At 1990 levels, there were 24,960 million tons of CO_2 emissions globally. One of the largest contributors is the cement and construction materials sector. About 90 million tons of CO_2 are emitted from the production of cement and 49 million tons from clay bricks in India. According to current Indian methods, each million clay bricks use 200 tons of coal (or any other fuel with an equivalent number of thermal values) and emit roughly 270 tons of CO_2 into the atmosphere. The production of fly ash bricks using an energy-free method completely eliminates emissions, making the project eligible for the Clean Development Mechanism (CDM) as envisioned by the Kyoto Protocol for the sake of Mother Earth [5]. The FaL-G is one of the few technologies that can support all of the Sustainable Development Indicators. Table 4 provides a summary of them.

Table 4. The different classes of Fly-Ash bricks

Sustainable Development Indicators	Redeeming features and tangible results in the field
Conservation of Natural Resources	Saves priceless topsoil that would have been used to make clay bricks.
Conservation of thermal energy and fossil fuels.	Saves coal because there is no need for sintering, as is done with clay bricks.
Environment friendly	Utilized industrial waste materials including fly ash, lime, and chemical gypsum to reduce pollution.
Employment generation	Provides yearlong employment, unlike clay bricks where the production activity is seasonal (November to May), with more scope in rural areas.
Appropriate and eco-friendly technology	Produces longer-lasting, more durable products for housing and infrastructure uses, protecting the nation's mineral and financial resources.

9. The Durability of Fly ash Bricks

It has been observed that there is an increase in Cold Crushing Strength (CCS) of Flyash bricks, which concludes that the buildings constructed with Fly ash bricks will grow stronger with time. Efflorescence is another cause of worry for the buildings constructed using burnt clay bricks, particularly in areas with high salinity in the underground water or the atmosphere. Fly ash brick is impervious to efflorescence being free of soluble salts. The absence of salts in Fly ash bricks protects it completely from salinity. It is thus ideal for constructions on seafronts or where underground water is high in salinity and where clay bricks cannot endure burnt. However, the quality of fly ash bricks is of utmost importance to ascertain durability which is why fly ash bricks are usually not recommended in foundations.

10. Advantages of Fly ash Bricks

There are several advantages of using Flyash bricks in the building construction. Due to its small weight, it decreases the dead load on structures (2.6 kg, dimension: 230 mm X 110 mm X 70 mm). More bricks will cover the same area than clay bricks. The flyash bricks have very excellent fire resistance. There is very minimal breakage during transit or use due to great strength. Bricks of uniform size result in a nearly 50% reduction in the amount of mortar needed for joints and plaster, as well as a significant reduction in water penetration and brick seepage. These bricks don't need a backing coat of lime plaster; the gypsum plaster can be placed directly to them. These bricks don't need to soak in water for a full day. Before use, a light misting of water is sufficient. Due to their superiority over locally accessible clay bricks, Flyash bricks can be a benefit in the building construction industry.

11. Disadvantages and Limitations of Fly ash Bricks

There are several disadvantages of using Flyash bricks in the building construction The mechanical strength of a combination might vary. By placing marble dust or cement between the blocks, this can be partially fixed. Depending on the combination of materials, larger sizes may see more breaks. High thermal conductivity is present. Greater insulation is needed in colder climates. It is unknown how long fly ash bricks will last in the subsoil. Thus, it is currently not advised to utilize it in foundations. The majority of clay bricks sold in the market are of poor quality. While being stacked and transported, the edges are shattered. More water is absorbed by these bricks. The quality of the lime, the way the components are mixed, and the curing time all affect the final product's quality. In addition, the producers use shortcut techniques that reduce the quality of fly ash bricks. Due to their tiny production capacities, the brick makers are unable to stack them or keep them for an extended period of time to allow the full curing process to take place. It is advised to utilize 5% to 7% of cement by weight in order to create fly ash bricks that are high-quality in terms of their strength, form, and size, as well as having sharp edges. Shrinkage cracks are produced when cement is mixed in excess of 7%. However, the uniform strength of bricks can be maintained by properly dry mixing all of the materials. With time and without eroding, the use of well-made fly ash bricks in exposed brickworks has produced good results. The gradual interaction between cement/lime and fly ash strengthens the connections in the masonry over time.

12. Comparative Analysis of Fly ash Bricks with Clay Bricks

Fly ash bricks are modern, high-quality bricks with several improvements that are used to build brick masonry structures. They offer superior qualities to regular clay bricks and are utilized in their place. In comparison to traditional clay bricks, fly ash bricks are cost-effective and offer tremendous indirect advantages. The use of fly ash bricks contributes to the preservation of natural resources and the environmental protection [5]. In Table 5, a comparison of clay and fly ash bricks is presented. Figure 5 depicts an illustration of modular fly ash bricks used in a four-story, load-bearing building at Baprola in New Delhi, India.

Table 5. Comparison of Fly ash Bricks with Clay Bricks

Properties	Red Bricks / Clay Bricks	Fly Ash Bricks	Remarks
Density	1600-1750 kg/m^3	1700-1850 kg/m^3	Higher load-bearing
Compressive strength	30-35 kg/cm^2	90-100 kg/cm^2	Higher load bearing
Absorption	15-25%	10-14%	Less dampness
Dimensional stability	Very low tolerance	High tolerance	Saving in mortar up to 25%
Wastage during transit	Up to 10%	Less than 2%	Saving in cost up to 8%
Cement Mortar	Cement mortar required is 23–25%	Cement mortar required is 8–10%	Saving in mortar due to even shape
Plastering	Thickness varies on both sides of the wall	Even on both sides	Saving in plaster up to 15%.

Figure 5. Application of Modular Fly ash bricks in a 4-storied housing at Baprola, New Delhi, India

13. Conclusions

Since Portland cement is a significant CO_2 generator and a rich source of cementitious industrial waste, substituting fly ash might significantly reduce greenhouse gas emissions. For many industrial and building applications, fly ash has grown in importance [6]. Fly ash is no more waste now. It is the potential resource for the production of brick, cement, and concrete. It is the most versatile material to serve the engineering properties right from brick to concrete without sacrificing the economics. Ignoring goods like fly ash that have several benefits for all stakeholders would be a gross error of the highest degree. Fly ash was subjected to such abuse during the '70s, in the absence of knowledge and awareness. It is time that the availability and distribution of this potential material are channelized and supported by technical bulletins and education. Improper use of any material is detrimental to its performance.

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