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GREENER BUILDING MATERIAL WITH FLYASH

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ABSTRACT

Large number of innovative alternate building materials and low cost construction techniques developed through intensive research efforts during last three to four decades satisfies functional as well as specification requirements of conventional materials/techniques and provide an avenue for bringing down the construction cost. Fly ash, a industrial by-product from Thermal Power Plants with current annual generation of approximately 108 million tones and its proven suitability for variety of applications as admixture in cement/concrete/mortar, lime pozzolana mixture (bricks/blocks) etc. is such an ideal material which attracts the attention of everybody. Flyash utilization in the building materials have many advantages like cost effectiveness, environmental friendly, increases in strength and conservation of other natural resources and materials.

Keywords: Flyash; clay brick; flyash brick; strength

1. INTRODUCTION

Large scale housing construction activities require huge amount of money running into thousands of crores of rupees. Out of the total cost of house construction, building materials contribute to about 70 percent costs in developing countries like India. Therefore, the need of the hour is replacement of costly and scarce conventional building materials by innovative, cost effective and environment friendly alternate building materials. The new material should be environment friendly and preferably utilize industrial/agro wastes because as a result of rapid industrialization, the generation of wastes has increased several folds during the last few years, which needs to be utilized / disposed safely on priority[1]. One of the essential requirements of the green building is to use environmental friendly building materials such as the industrial waste products like flyash – Greener materials [2]. Large number of innovative alternate building materials and low cost construction techniques developed through intensive research efforts during last three to four decades satisfies functional as well as specification requirements of conventional materials / techniques and provide an avenue for bringing down the construction cost [3].

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1.1 Flyash

Flyash or pulverized fuel ash, an artificial pozzolana is the residue from combustion of pulverized coal used as fuel. During the combustion of coal, the products formed are classified into two categories viz. bottom ash and flyash(Figure1). The bottom ash is that part of the residue which is fused into particles. The flyash is that part of the ash which is entrained in the combustion gas leaving the boiler. Most of this flyash is collected in either mechanical collectors or electrostatic precipitators.

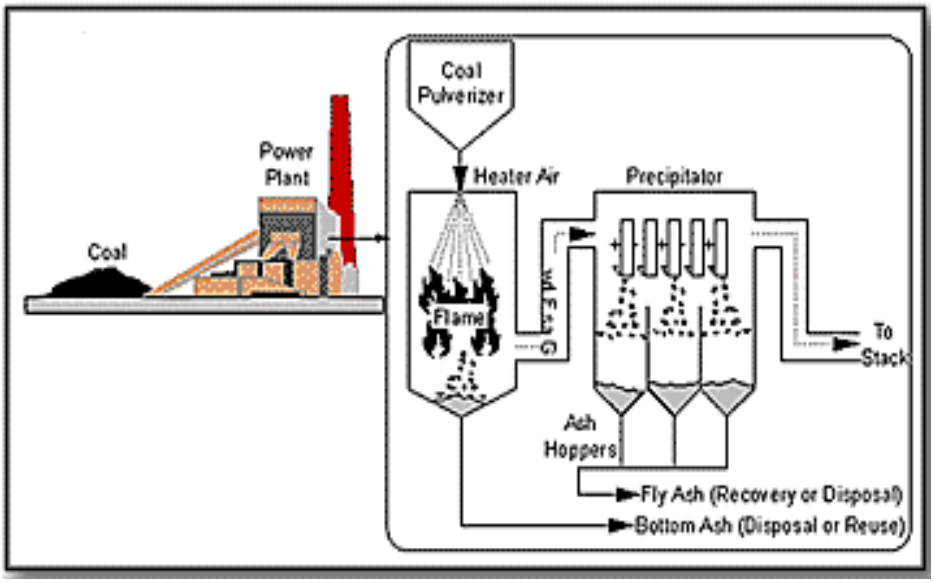

Figure 1. Production of flyash

Flyash is disposed of either by the dry or wet systems. Most of power plants in India use wet disposal system. Different types of coal produce different quantities of ash, depending on the concentration of mineral matter the respective type of coal. In India the coal contains very high percentage of rock and soil and therefore the ash contents are as high as 50%.

Ash may be classified into two groups as Class C and Class F, based on the nature of their ash constituents. One is bituminous ash (Class F) and the other is the lignite ash (Class C). Lignite ashes contain more calcium oxide and magnesium oxide than ferric oxide, but bituminous ash contains more ferric oxide than calcium and magnesium oxides[4]. The average particle size of lignite flyash is considerably coarser than the bituminous variety. Also free lime is present in all the lignite flyashes. The lignite ash (Class C) in India is produced at Neyveli Thermal Power Plant and the most of the other power plants in India produce bituminous ashes (Class F).

1.2 Flyash – the mineral admixture

Flyash is the finely divided residue, resulting from the combustion of pulverized coal,

transported from the precipitators. The recognition of the flyash frequently exhibits pozzalanic properties have led to its use. A pozzolana is defined as "a siliceous or siliceous and aluminous material which in itself possesses little or no cementitious value but which will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties". The mineral admixture is similar to cement but have very less binding property compared to cement. The finer particles will fill the pores of cement mortar paste and hence will reduce permeability and voids ratio. Hence mineral admixtures could be viewed as true friend of concrete and cement mortars.

1.3 Properties of Flyash

The properties of Flyash change with time, the nature of coal, its degree of grinding, boiler operations, the type of fuel used, the type of separators used etc.

1.4 Physical Characterization of Flyash

Colour: Carbon and iron affect the colour of the flyash. High carbon content changes the colour to grey or black. High iron content produces a tin coloured ash (Figure 2).

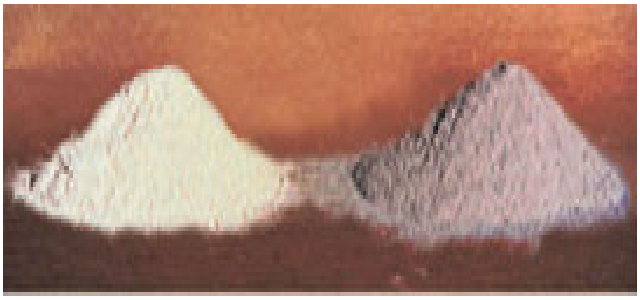

Figure 2. Typical ash colors

Fineness: Fineness of flyash is expressed in terms of specific surface area, which varies from $2x10^7$ to $5x10^7$ N/mm^2. Greater fineness of flyash increases the air entraining admixture demand. The large amount of surface energy is utilized to combine with lime. The fineness of the flyash used as a percentage by weight retained on 90 micron sieve is 9%.
Shape: The particles of flyash are spherical in shape. The size ranges from about 150 micron to less than 1mm.

1.5 Microstructure of fly ash

Fly ash is a fine, glass powder recovered from the gases of burning coal during the production of electricity. These micron-sized earth elements consist primarily of silica, alumina and iron. The particle size ranges from <1μm to 100μm. The majority of particles are of 20μm size. 10% to 15% of the particles should have a size more than 45μm (Figure 3).

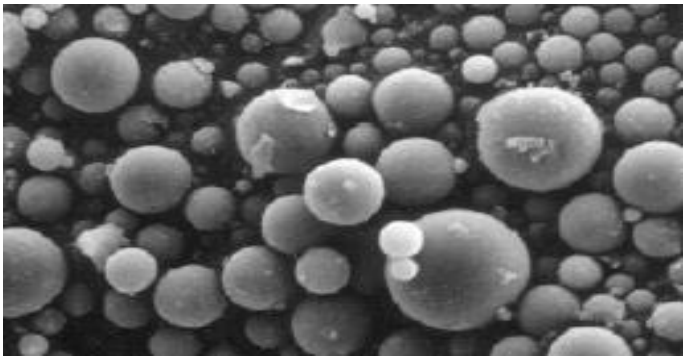

Figure 3. Microstructure of flyash

The difference between fly ash and portland cement becomes apparent under a microscope (Figure 4). Fly ash particles are almost totally spherical in shape, allowing them to flow and blend freely in mixtures. That capability is one of the properties making fly ash a desirable admixture for concrete.

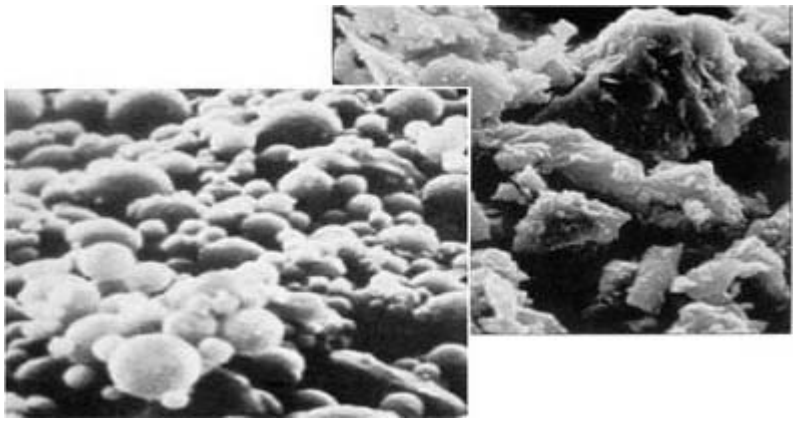

Figure 4. Microstructure of fly ash (left) and portland cement (right)

1.4 Chemical composition of Flyash

The differences between Class F flyash and Class C flyash is the amount of calcium, silica, alumina, and iron content in the ash (Table 1). The chemical properties of the fly ash are largely influenced by the chemical content of the coal burnt (i.e., bituminous, Sub-bituminous and lignite) [5].

Table 1: Chemical composition and classification

Component	Bituminous (Class F)	Sub-bituminous (Class C)	Lignite (Class C)	Portland cement
SiO_2 (%)	20-60	40-60	15-45	23
Al_2O_3 (%)	5-35	20-30	20-25	4
Fe_2O_3 (%)	10-40	4-10	4-15	2
CaO (%)	1-12	5-30	15-40	64
LOI (%)	0-15	0-3	0-5	0-4

2. CLASS F FLY ASH

The burning of harder, older anthracite and bituminous coal typically produces Class F flyash. This fly ash is pozzolanic in nature, and contains less than 10% lime (CaO). Possessing pozzolanic properties, the glassy silica and alumina of Class F fly ash requires a cementing agent, such as Portland cement, quicklime, or hydrated lime, with the presence of water in order to react and produce cementitious compounds. This fly ash has siliceous or siliceous and aluminous material, which itself possesses little or no cementitious value but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperature to form cementitious compounds. Progress of the pozzolanic reaction of class F flyash is slow.

3. CLASS C FLY ASH

Fly ash produced from the burning of younger lignite or subbituminous coal, in addition to having pozzolanic properties, also has some self-cementing properties. In the presence of water, Class C fly ash will harden and gain strength over time. Class C fly ash generally contains more than 20% lime (CaO). Unlike Class F, self-cementing Class C fly ash does not require an activator. Alkali and sulfate (SO_4) contents are generally higher in Class C fly ashes. Class C flyash which has a high lime content, reacts to some extent direct with water, in particular some C_2S may be present in the flyash and this compound reacts to form C-S-H. In addition, as with Class F flyash, there is a reaction of silica with calcium hydroxide produced by the hydration of portland cement. Thus, Class C flyash reacts earlier than Class F flyash, but some Class C flyashes do not show a long term increase in strength.

4. HYDRATION OF FLYASH

Formation of cementitious material by the reaction of free lime (CaO) with the pozzolans (AlO_3, SiO_2, Fe_2O_3) in the presence of water is known as hydration. The hydrated calcium silicate gel or calcium aluminate gel (cementitious material) can bind inert material together. For class C fly ash, the calcium oxide (lime) of the fly ash can react with the siliceous and aluminous materials (pozzolans) of the fly ash itself. Since the lime content of class F fly ash is relatively low, addition of lime is necessary for hydration reaction with the pozzolonas of the flyash. For lime stabilization of soils, pozzolanic reactions depend on the siliceous and aluminous materials provided by the soil [6].

4.1 The pozzolanic reactions are as follows

Portland cement Only	Tricalcium silicate	+	water	→	Calcium hydrate gel	+	Calcium hydroxide
	C_3S	+	H_2O	→	C-S-H	+	$Ca(OH)_2$
Portland cement + Flyash	Tricalcium silicate	+	water	→	Calcium hydrate gel	+	Calcium hydroxide
	C_3S	+	H_2O	→	C-S-H	+	$Ca(OH)_2$
and	Silica (from Flyash)	+	Calcium hydroxide product	→	Calcium hydrate silicate gel		
	SiO_2	+	$Ca(OH)_2$	→	C-S-H		

4.2 Engineering Properties of Flyash:

- ***Spherical shape***: Fly ash particles are almost totally spherical in shape, allowing them to flow and blend freely in mixtures.
- ***Ball bearing effect***: The "ball-bearing" effect of flyash particles creates a lubricating action when the mixture is in its plastic state.
- ***Higher Strength***: Flyash continues to combine with free lime increasing structural strength over time.
- ***Decreased Permeability***: Increased density and long term pozzolanic action of fly ash, which ties up free lime, results in fewer bleed channels and decreases permeability and increased durability. Dense flyash mixture helps to keep aggressive compounds on the surface, where destructive action is lessened. Flyash mixture is also more resistant to attack by sulfate, mild acid, soft (lime hungry) water, and seawater.
- ***Reduced Sulfate Attack***: Flyash ties up free lime that can combine with sulfate to create

destructive expansion.

- ***Reduced Efflorescence***: Flyash chemically binds free lime and salts that can create efflorescence and dense mixture holds efflorescence producing compounds on the inside.
- ***Reduced Shrinkage***: The largest contributor to drying shrinkage is water content. The lubricating action of flyash reduces water content and drying shrinkage.
- ***Reduced Heat of Hydration***: The pozzolanic reaction between flyash and lime generates less heat, resulting in reduced thermal cracking when flyash is used to replace Portland cement.
- ***Reduced Alkali Silica Reactivity***: Flyash combines with alkalis from cement that might otherwise combine with silica from aggregates, causing destructive expansion.
- ***Workability***: Easier to work with and to place with less effort, responding better to vibration to fill forms more completely. Ease of Pumping. Pumping requires less energy and longer pumping distances are possible.
- ***Improved Finishing***: Sharp, clear architectural definition is easier to achieve.
- ***Reduced Bleeding***: Fewer bleed channels decreases porosity and chemical attack. Bleed streaking is reduced for architectural finishes. Improved paste to aggregate contact results in enhanced bond strengths.
- ***Reduced Segregation***: Improved cohesiveness of flyash mixture reduces segregation that can lead to rock pockets and blemishes.
- ***Reduced Slump Loss***: Especially in hot weather, it is more dependable for greater working time.
- ***Excellent Thermal Insulation*:** The buildings using fly ash bricks are cool in summers and warm in winters. The high insulating property, with low embodied energy, of our products reduces the energy consumption of the buildings significantly by as much as 40-50%.
- ***Excellent Sound Insulation:*** Fly ash bricks are sound absorbent and restrict sound transmission keeping the interiors very pleasant and quiet.
- ***Fire Resistance:*** Fire resistance of fly ash bricks is very high as these bricks are composed of fly ash as its major constituents, which is the un-burnt residue of the coal fired in a thermal power plant.

4.3 FlyAsh - Building Material

Some of the innovative and commonly manufactured eco- friendly building materials utilizing Flyash are; clay flyash bricks, flyash bricks , road construction, cellular light weight concrete work etc[1,2&3].

5. BRICKS

Building bricks are usually made of a mixture of clay and sand, which are mixed and molded in various ways, after which they are dried and burnt. Clay for brick making must develop proper plasticity and be capable of drying rapidly without excessive shrinkage, warping or cracking and of being burnt to desired texture and strength [7]. Flyash are

utilized to make bricks and blocks in one of several ways: (a) As substitute for a portion of the cement and/or aggregates in making concrete bricks and blocks. This is a common use nowadays in many countries. (b) As substitute for a portion of the clay used in making clay bricks. This uses the same process for making clay bricks, requiring eating the adobes (green bricks) in kilns to more than 2000^0 F, which consumes much fossil fuel and generates air pollutants and carbon dioxides due to the combustion of the fossil fuel. (c) As substitute for all the clay used in making clay bricks, using the same process for making clay bricks which requires burning fossil fuel to heat adobes in kilns at over 2000^0F . This uses the same process and has the same drawback of (b) except that 100% fly ash is used in making bricks. Flyash content can be 20 to 60% depending on the quality of clay. Process of manufacturing is same as for the burnt clay bricks.

5.1 Conventional Clay Bricks

The bricks are the standard unit of traditional building construction. Bricks have been used since ancient times for walls and columns of residential and non-residential buildings. The bricks are made from soil and hence the property of bricks depends on the properties of soil.

5.2 Composition of Clay Brick

Raw materials: Raw materials required for manufacturing of clay bricks are clay, silt and sand as per IS 2117.

ALUMINA :(usage 20 -30 %) This constituent imparts plasticity to earth so that it can be moulded.

SILICA: (usage 50 – 60%). Presence of this constituent prevents cracking, shrinkage and warping during drying and burning.

LIME: (usage small quantity). It prevents shrinkage of raw bricks.

IRON OXIDE: (usage 5- 6%) It retains the red colour to bricks.

MAGNESIA: A small quantity of this constituent imparts yellow tint to bricks and it decreases shrinkages.

5.3 Manufacturing of clay bricks

The four distinct stages of manufacturing the hand mould clay bricks are, (i) preparing the brick earth, (ii) moulding clay in rectangular blocks of uniform size (iii) drying in sun and air and (iv) burning them in brick kilns. Burning of the brick during manufacture governs the quality and properties of brick.

The manufacturing process has six general phases: 1) mining and storage of raw materials, 2) preparing raw materials, 3) forming the brick, 4) drying, 5) firing and cooling and 6) de-hacking and storing finished products (Figure 5).

5.4 Flyash Bricks

Fly ash bricks manufacturing units can be set up nearby thermalpower stations. Since fly ash is being accumulated as waste material in large quantity near thermal power plants and creating serious environmental pollution problems, its utilisation as main raw material in the manufacture of bricks will not only create ample opportunities for its proper and useful

disposal but also help in environmental pollution control to a greater extent in the surrounding areas of power plants.

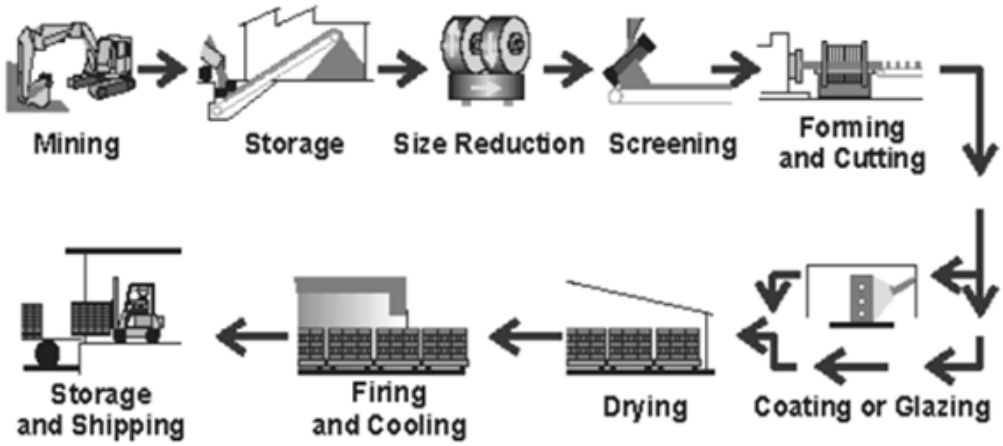

Figure 5. Diagramatic representative of clay brick manufacturing process

5.5 Composition of FlyAsh bricks

Raw materials: Raw materials required for manufacturing of Flyash bricks are Flyash, lime gypsum and sand (optional)

FLYASH: (usage 50-75%) Apart from conforming to IS Requirement the minimum requirement for manufacturing of flyash bricks are:

Loss on Ignition --- should be not more than 12%

Availability of MgO --- should be not more than 5%

Availability of SiO_2 --- should be not more than 35%.

Availability of Al_2O_3 --- should be not more than 15%

LIME :(usage 8-20 %) Lime is very important ingredient used for manufacturing of bricks; hence it should satisfy following minimum requirement:

Lime, while slaking process should not attain less than 600 Celsius temperature and slaking time should not be more than 15 minutes.

Availability of CaO should be minimum 20%

MgO content should be maximum of 5%.

GYPSUM: (usage 2 - 5%)It is added to the mix in order to accelerate hardening process and acquiring the early strength. It should have minimum 35% of purity.

SAND: (usage 20 - 30 %)Addition of sand is optional, but to enhance the gradation of the mix, addition of coarse sand is quite preferable. Addition of sand also enhances the resistivity of mix to formation of laminar cracks caused due to entrapped air.

5.6 Manufacturing of Flyash bricks

Required raw material like Fly ash, Gypsum, alum and stone crushing dust have to be mixed as per the ratio. The mixed product can be placed into automatic locking machine. This to be kept in moulds for manufacturing of automatic locking fly ash bricks. After the processing

the bricks have to be dried after applying required water on the bricks. After two days drying the bricks can be sold. It is a simple manufacturing process and it is represented in Figure 6.

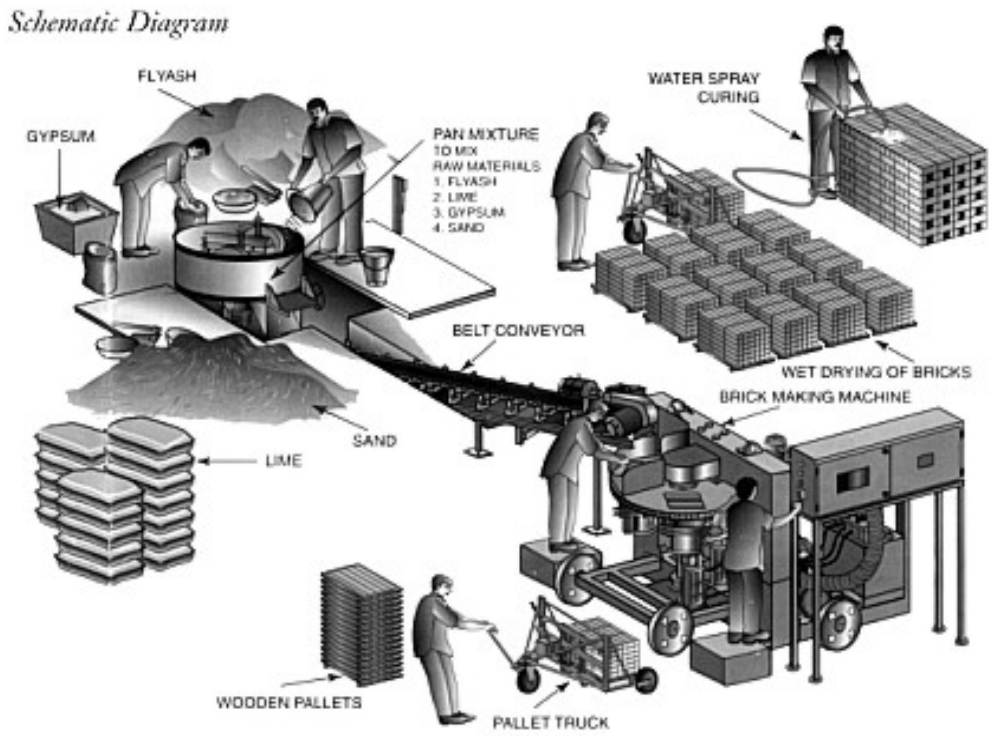

Figure 6. Diagramatic representative of flyash brick manufacturing process

Manufacturing clay brick requires kilns fired to high temperatures. That wastes energy, pollutes air and generates greenhouse gases that contribute to global warming. In contrast, fly ash bricks are manufactured at room temperature. They conserve energy, cost less to manufacture, and don't contribute to air pollution or global warming. The innovative bricks using the residual fly ash are considered high quality building materials by the manufacturers that will potentially decrease some of the negative environmental impact of coal-fired power generation while meeting increasing demands for greener building materials.

Most of the developing countries face energy scarcity and huge housing and other infrastructure shortage. Ideally in these countries materials for habitat and other construction activities should be energy efficient (having low energy demand). The following table shows some examples of energy savings achieved through the use of Fly Ash in the manufacture of conventional building materials[8]. It should be noted that use of Fly Ash also improves the properties of building material;

Table 2: Energy savings in the manufacturing of building materials with the use of flyash [9]

Building Material	Composition	Material Compared	Energy savings (%)
Portland pozzolana cement	75% Ordinary Portland cement 25% Fly Ash	100% Ordinary Portland Cement	20
Lime-pozzolana mixture	25% Acetylene gas lime 75% Fly Ash	25% Lime 75% Calcined brick	75
Calcium silicate brick	90% Fly Ash tailings 10% lime	Burnt clay brick	40
Burnt brick	75% Clay 25% Fly Ash	Burnt clay brick	15
Flyash brick	50% Fly Ash 28% sand 20% lime 2% gypsum	Burnt clay brick	>40

Manufacturing each ton of fly ash bricks instead of clay bricks will reduce emission of carbon dioxide – the major greenhouse gas - by 0.0434 ton [6]. If in the future fly ash bricks can replace 50% clay bricks there will be a reduction of clay bricks by 10 million tons each year, which will reduce the emission of greenhouse gas (carbon dioxide) by 435,000 tons each year, equivalent to removing 400,000 cars from road. Furthermore, it will reduce total air pollutants (CO, NOx, SOx, particulate matters, and volatile organic compounds) by an amount equivalent to 920 million vehicle miles of truck use.

6. EXPERIMENTAL PROGRAM

The flyash was procurred from Mettur thermal power plant. The conventional clay bricks of size 230x110x70mm were procured from Sadivayal, near Coimbatore and the flyash bricks of size 230x110x70mm were procured from Saravanampatti near Coimbatore. The bricks were tested for their mass, water absorption, compressive strength and flexural strength as per IS 3495 [10] and their results were discussed below.

6.1 Flyash

Chemical constituents of fly ash mainly depend on the chemical composition of the coal. However, fly ash that are produced from the same source and which have very similar chemical composition, can have significantly different ash mineralogies depending on the coal combustion technology used. The flyash used for this study was collected from Mettur

thermal power plant, Tamil Nadu, India. The following Table 3 gives the XRD detail that is obtained for the flyash used in this study.

Table 3: Comparison of XRD data obtained on fly ash material (collected from mettur power plant, India) used in this study with standard JCPDS data

Standard XRD data for SiO_2 (JCPDS No. 89-1668) (2θ values)	**Standard XRD data for Al_2O_3 (JCPDS No. 88-0107) (2θ values)**	**Standard XRD data for CaO (JCPDS No. 82-1690) (2θ values)**	**Standard XRD data for MgO (JCPDS No. 89-7746) (2θ values)**	**Powder XRD data for fly ash material**	
				(2θ values)	**I/Io**
9.109	--	--	--	8.8738	7
20.456	21.201	--	--	20.9116	18
--	21.315	--	--	21.4366	3
26.773	--	--	--	26.6957	100
27.365	--	--	--	27.1553	5
27.756	--	--	--	27.7921	8
--	28.235	--	--	28.0500	28
28.141	--	--	--	28.6111	4
36.696	36.953	37.401	36.863	36.6172	6
39.517	40.023	--	--	39.5304	5
45.756	45.988	--	--	45.8548	7
--	51.026	--	--	50.8024	4
--	57.139	--	--	57.4901	12
--	60.686	--	--	60.0364	5
--	67.910	67.467	--	68.2064	4
--	76.293	--	--	76.8941	3
--	81.136	--	--	81.1921	5
--	--	88.659	--	90.8898	5

Figure. 7 shows the XRD pattern obtained on fly ash material (collected from mettur power plant, India). Katsioti et.al [11] studied the substitution of limestone filler with pozzolanic additives in mortars. They reported that the major portion of fly ash material consisting of SiO_2 (48.09%), Reactive SiO_2 (35%) Al_2O_3 (21.38%) and CaO (13.37%). Celik et.al [12] characterized the fly ash material and studied its effect on the compressive properties of Portland cement. They studied the percentage of oxides present in 5 different fly ash materials. They reported that their fly ash material consisting of SiO_2 (22- 57 %), Al_2O_3 (5.9 – 23.2 %) and Fe_2O_3 (3.6 – 9.8 %). We carried out the XRD studies on our sample and compared the XRD data of our sample with the standard JCPDS XRD data of SiO_2, Al_2O_2, CaO and MgO. We found that the major portion of 2θ values are matched with the JCPDS patterns for SiO_2 (JCPDS card No. 89-1668) and Al_2O_3 (JCPDS card No. 88-0107). Few peaks of our samples matched with the JCPDS pattern of CaO (JCPDS card No. 82-1690) and MgO (JCPDS card No. 89-7746). The comparison data is indicated in Table -3. From the XRD measurements, it is concluded that the flyash material has the oxides such SiO_2(S), Al_2O_3(A) , MgO (M) and CaO(C) (Figure 7).

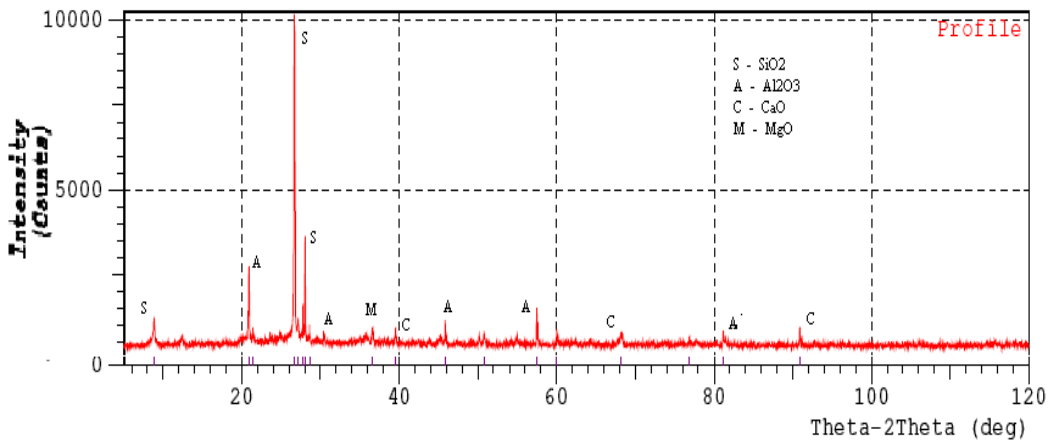

Figure 7. XRD pattern of fly ash

6.2 Mass

The tendency of an object to resist changes in its state of motion varies with mass. Mass is that quantity which is solely dependent upon the inertia of an object. The more inertia which an object has, the more mass it has. A more massive object has a greater tendency to resist changes in its state of motion. The mass of the bricks have been taken. They weigh 10% less than clay bricks because of the aeration and the use of fly ash (Figure 8)

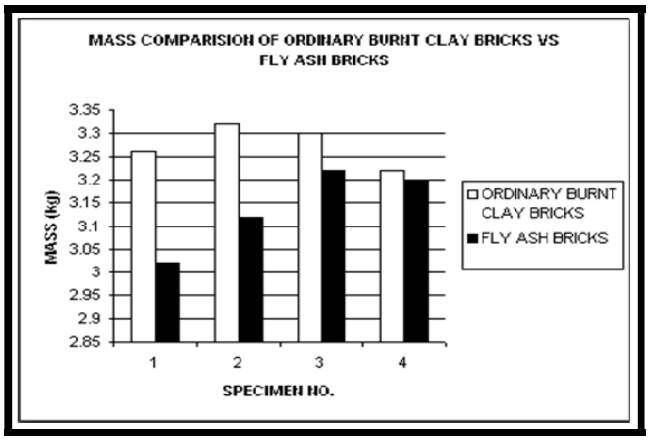

Figure 8. Mass comparison of conventional bricks and the flyash bricks

6.3 Water Absorption test

Water Absorption tests were performed on flyash bricks and ordinary burnt clay bricks. Immerse the specimens in water at room temperature (22 °C) for 24 h. Weigh the specimens and record as Ws (saturated weight). Then, dry all specimens and record the weight of dried specimens as Wd (dry weight), where Ws and Wd are in Kg.

The water absorption is calculated as

Absorption (%) = [(Ws-Wd)/Wd)] ×100

More the water absorption, more the porosity and less the durability of the building unit (Figure 9).

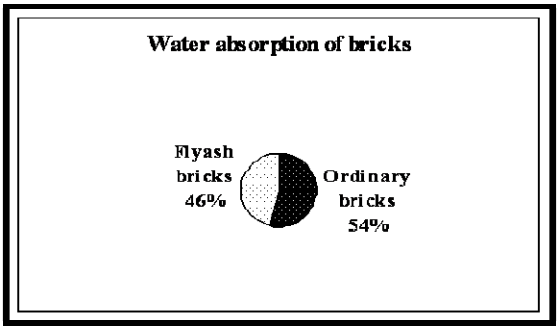

Figure 9. Water absorption of conventional bricks and the flyash bricks

6.4 Compressive strength of Bricks

Compressive strength tests were performed on Compression testing machine using ordinary brick and Flyash brick samples. Three samples per batch were tested with four different orientations. The loading rate on the brick is 0.1 mm/min and the results were compared.

The Flyash bricks carried higher strength than the conventional clay bricks in all the orientation. The compressive strength of the Flyash bricks are 40% to 80% higher than the conventional bricks (Figure 10).

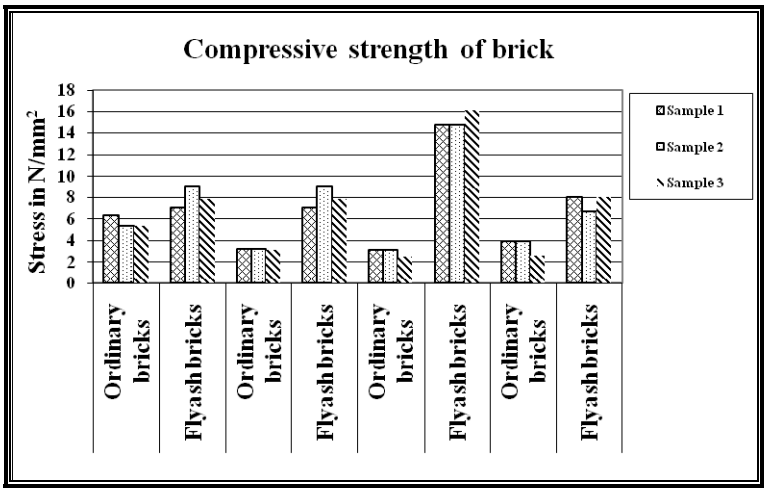

Figure 10. Compressive strength of conventional bricks and the flyash bricks

6.5 Flexural Strength of Brick

The bed of the testing machine is provided with two steel rollers of 40mm diameters, on which the specimen is supported. The central point loading was applied. The load was divided equally between the two rollers and all rollers were mounted in such a manner that the load applied axially and without subjecting the specimen to any torsional stresses or restraints. The load was applied without shock and increasing continuously till the specimen fails, and the maximum load applied to the specimen during the test was recorded (Figure 11).

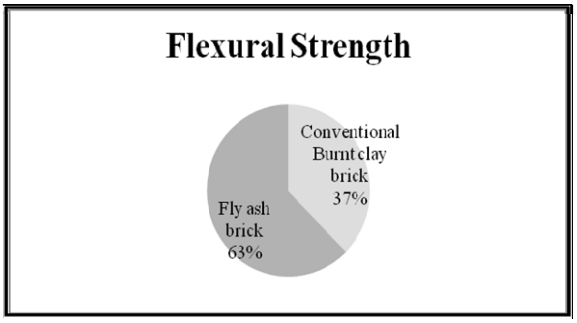

Figure 11. Flexural strength of brick

The Flyash bricks had higher flexural strength than the Conventional clay bricks. Hence the Flyash brick structure can withstand for higher load than the conventional clay bricks.

6.6 Initial rate of suction

The bond between brick and mortar is largely influenced by the tug-of- war between the capacity of the brick to absorb water and the ability of the mortar to retain the water. This water is needed for the proper hydration of cement where the mortar contacts the brick.

If the brick wins this tug-of- war (and sucks the water too quickly from the mortar), the mortar strung out for the bed joint stiffens so rapidly that the bricks in the next course cannot be properly bedded. If the mortar retains too much water the bricks tend to float on the mortar bed, which makes it difficult to lay plumb walls at a reasonable rate. In either case there will be poor bond. The power of a brick to absorb water is measured by the initial rate of absorption. Figure 12. Initial rate of absorption or IRA is defined as the number of grams of water absorbed in one minute over 30 square inches of brick bed area (ASTM C 67) [14]. Excessive water suction in the brick can lead to considerable reduction in brickwork strength, because bricks absorbs excess amount of water from the mortar and thus interfere with complete hydration of the cement.

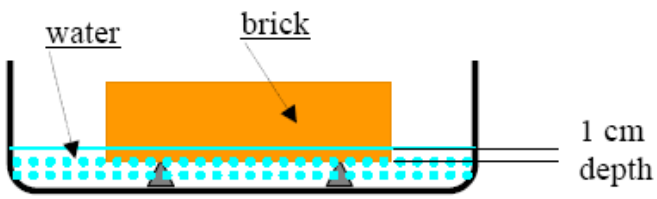

Figure 12. IRA Test on brick

Masonry walls built using brick units with a low Initial Rate of Absorption (IRA) often have lower bond strength than walls built with moderate IRA units because very little water is available to be absorbed into the unit during installation into the wall. Clay brick has the lower Initial rate of absorption than the flyash brick and thereby bond between the brick and the cement mortar is less. The initial rate of absorption (IRA) or suction is the rate of how much water a brick draws (sucks) in during the first minute after contact of the bed surface with water. The suction has a direct bearing on the bond between brick and mortar. Therefore, high suction brick should be wetted prior (3 hrs to 24 hrs) to laying in order to reduce the suction and allow the brick's surface to dry. Drysdale et al [15] observed that if IRA is less than 0.25Kg/m^2/min, which is a case for low absorption or low suction bricks, then such bricks may tend to flow on mortar particularly if the bricks are damp. On the other hand if IRA is more than 1.5Kg/m^2/min a poor brick mortar bond may result because of rapid suction of water in mortar by bricks.

The comparative study on flyash brick and conventional clay bricks is given in Table 3;

Table 3: Properties of flyash brick and clay bricks

S. No	Properties	Flyash Bricks	Clay Bricks
1	Basic Raw Material	Pozzolana – Flyash	Clay
2	Fuel	Not required	Required
3	Size & Quality	Uniform (Factory made)	Uneven (mould made)
4	Number of Joints in construction	Less (uniform size)	More (uneven size)
5	Mortar requirement	Less	More
6	Plastering	Less	More
7	Direct Gypsum Plaster	Possible	Not Viable
8	Compressive strength MPa	10.8 MPa	5.48 MPa
9	Flexural strength	More	Less
10	Standards	IS:12894 – 2002	IS:3495(Pt.I)1976
11	Water Absorption (%)	12.75	12.41
12	Initia Initial rate of absorption (IRA) ($g/cm^2/min$)	0.63	0.15
13	Poisson's ratio	0.15	0.11
14	Green material rating [2]	A Scale	B Scale
15	Mercury from environment [15]	Adsorbs	Emits

8. CONCLUSION

- Much fossil fuel is used in heating clay bricks in kilns. Burning such fuel generates air pollution and greenhouse gas (CO_2), contributing to global warming. By manufacturing fly ash bricks (at room temperature) instead of clay bricks (at over 2,000°F), emission

of air pollutants and greenhouse gas is avoided at brick plants, which helps to reduce air pollution and global warming.

- Greenest Bricks not only meets the IS standard for building bricks, it also has appealing colors and uniform shape and size, features that make brick laying easier and more cost effective than laying clay bricks.
- Compressive strength of fly ash bricks is higher than the conventional clay bricks by 40% to 80%.
- 10% lighter in weight than conventional clay bricks
- It has low water absorption within 20% of its weight as per IS 1077-1976
- It costs 20% less than conventional clay brick manufacture.
- Cost effective, energy-efficient & environment friendly (as it avoids the use of fertile clay soil)
- There is good demand for fly ash bricks nowadays and the awareness among the people is required.

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