Fly Ash Utilisation for Value Added Products
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Fly ash - An emerging alternative building material

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ABSTRACT

Fly ash is produced by thermal power plants while generating electricity by burning pulverised coal and is a waste material. In India, the avialability of fly ash is substantial since the Indian coal contains as high as 40% ash much higher than the other countries. The disposal of this waste material is a matter of great concern from the environmental and ecological point of view. The safest and gainful utilisation of this material has been one of the topics of research over the last few decades. This paper is aimed to highlight the various applications of fly ash as building material such as lime / clay flyash bricks, Portland Pozzolana Cement, light weight aggregates replacing the conventional building material to some extent.

***Key words :** FAL-G, PPC, OPC, Fly ash utilisation, Building material*

1.0 INTRODUCTION

In India about 70% of electricity is produced by burning pulverised bituminous or sub-bituminous coal (lignite) which is producing about 75 million tonnes of fly ash; a solid waste from 77 thermal power plants.[1]. For a long time to come, India will have no option but to generate electricity by burning coal. Considering 10% annual growth in electrical power generation through thermal power plants, the annual fly ash generation is expected to exceed 100 million tonnes by 2000 AD. According to a general estimate, a coal based thermal power plant of 1000 MW capacity generates about 1200 tonnes of fly ash per day. The disposal of this solid waste is a matter of great concern today as it requires huge area of land at the power plant site, the management has to give full thrust for the gainful utilisation of fly ash. Only a very small percentage of fly ash (5 to 7%) generated in India is used for gainful applications whereas the corresponding figure for the other advanced countries varies from 30 to 80%. In some European countries the products like bricks, cement, concrete, mortars, light weight aggregates etc. are being produced utilising 100% of fly ash. With the awareness regarding the environment and ecological parameters, it is believed that in the years to come, at least 50% of the fly ash being generated by thermal power plants shall be used for manufacturing building materials.

The advantages of fly ash utilisation are

i) Saving of space for disposal ;

ii) Saving of natural resources ;

iii) Energy saving ;

iv) Protection of environment.

Fly ash is generally grey in colour, abrasive, acidic, refractory in nature[2] and it is finely divided residue from the combustion of pulverised coal possessing pozzolanic properties. The chemical Composition of fly ash varies with the coal source. The chemical composition of fly ash (world wide) is given in Table 1.

Table 1 : Chemical composition of fly ash (Worldwide)

Constituents (%)	France	Japan	U.S.A.	Russia	U.K.	India	IS-3812-1981
SiO_2	50.4-60.4	43.0	44.0-45.2	46.0-53.0	44.0-50.4	37.15-66.74	35.0 Min.
Al_2O_3	25.1-27.8	34.0	27.36-29.62	22.0-30.0	27.8-33.1	18.31-28.87	(SiO_2 + Al_2O_3 + Fe_2O_3) 70 min.
TiO_2	6.2-12.5	8.5	-	1.2	1.06-1.28	0.52-2.42	
Fe_2O_3	-	-	15.28-16.81	9.0-12.0	8.6-11.1	3.23-21.94	
FeO	-	-	-	0-1.5	-	-	
CaO	1.8-3.5	8.7	1.93-2.08	4.0-12.0	2.1-3.6	1.3-10.8	-
Mgo	0.7-1.7	1.9	0.94	0.5-2.5	2.4-2.6	0.8-5.25	5.0 max.
Na_2O	0.1-0.8	1.0	-	0-2.5	1.05-1.48	0.1-3.4	1.5 max.
K_2O	2.0-3.1	1.9	-	-	1.90-2.00	-	
SO_3	0.7-1.1	-	-	0-0.3	-	0.4-2.9	3.0 max.
L.O.I.	2.7-4.9	-	4.5-6.0	0.5-4.2	3.70-4.28	0.3-6.6	12.0 max.; 5.0 max. for RCC
Specific Surface Area, cm^2/gm	-	-	-	-	-	2184-6842	2500-3200
Magnetic Portion	-	-	-	-	3.16-7.3	3.0-6.0	-

Fly ash can be used for producing various products which may be used as building materials; these are listed below —

1. In the production of clay-flyash / fly ash-lime-gypsum (FAL-G) / Fly ash - sand lime building bricks;

2. In the production of sintered light weight bricks/ aggregates ;

3. As Pozzolana in the production of -

i) Portland Pozzolanic Cement (PPC)

ii) Ready-mixed fly ash concrete for use as a structural and in the production of precast concrete building units,

iii) As a part replacement of Portland Cement in mortars and concretes at the construction site.

4. In the production of cellular light weight concrete

Classification of fly ash[3] is given in ASTM : C-618-89 on the basis of chemical composition (Table 2A). Anthracite and bituminous or high ranking coals give low lime class F flyash, used by all thermal power plants except Neyveli Lignite Corporation. low rank sub-bituminous or lignite coals give high lime (>10% CaO) fly ash of class C (Table 2B). The mineralogical composition of fly ash indicates that a large quantity of glassy matter is present along with various other crystalline phases. The glassy phase generally exceeds 50 wt% and can be as high as 90 wt%. Typical phase composition of fly ash samples from different countries is given in Table 3. The crystalline phases are mainly mullite and magnetite with some amount of quartz and haematite.

Table 2 A : Classification of fly ash as per ASTM : C - 618 - 89

Class of Fly Ash	Type of Source	SiO_2+R_2O_3 Min (%)	CaO Min (%)	SO_3 Max (%)	H_2Oas Moisture(%)	LOI Max(%)
F	Bituminous Anthracite	70	-	5	3	6
C	Sub-bituminous Lignite	50	10	5	3	6

R_2O_3 = Fe_2O_3; LOI indicates So_3 + Unburnt Carbon

Table 2 B : Typical Chemical Composition of Fly ash

Constituents	Class F	Class C
SiO_2	34-60	25-40
Al_2O_3	17-31	8-17
Fe_2O_3	2-25	5-10
CaO	0.5 -10	10-38
MgO	1-3	1-3
L.O.I.	0-15	0-15

Table 3 : Mineralogical Composition of Fly ash

Mineral (%)	U.K.	U.S.A.	Japan
Quartz	1.0-6.5	0.0-4.0	5.4-11.8
Mullite	9.0-35.0	0.0-16.0	8.0-18.0
Magnetite	5.0 or Less	0.0-8.0	-
Haematite	5.0 or Less	1.0-30.0	0.5-5.3
Glass	50-90	50-90	69-84

The typical Sieve analysis of Indian fly ash is given in Table 4. Most fly ashes are composed of particles below 100 μm diameter and generally lie between 100 μm and 2 μm with medium sizes (50 wt%) being around 15-20 μm depending on the source and type of fly ash.

Table 4 : Typical sieve analysis of Indian fly ash

Mesh No. (Bss)	Opening (Microns)	Percentage Retained	Cumulative Percentage
+60	+251	1.33	1.33
-60+72	-251+211	0.67	2.00
-72+85	-211+178	2.00	4.00
-85+100	-178+152	5.33	9.33
-100+120	-152+124	2.00	11.33
-120+150	-124+104	8.00	19.33
-150+200	-104+76	6.67	26.00
-200+240	-76+66	8.00	34.00
-240+300	-66+53	11.33	45.33
-300+350	-53+45	8.67	54.00
* -350	-45	46.00	100.00

* Mean Diameter is 20 μm

2.0 FLY ASH UTILISATION

2.1 Brick making

The clay brick used for construction purposes is the age old product and is being used confidently by the consumers even today. With the fast urban development, the demand for bricks have been increasing allowing brick industry to exploit top soil which is a social crime. In order to meet the increasing demand of brick, the fly ash based brick can be an alternative with the improved engineering properties. Considering 25% based fly ash bricks at the national level, it can be envisaged to consume 30 - 45 million tonnes of fly ash every year.

Bricks made of fly ash[4] can be broadly classified into three groups - (i) Fly ash - sand-lime bricks (ii) Fly ash - gypsum/lime/ cement bricks, and (iii) Fly ash-clay (Sintered) bricks. The various suggested proportions of fly ash with sand, clay and lime/cement are as follows —

Lime Based Bricks : 70% fly ash ; 5-10% lime ; 20-25% sand.

Cement Based Bricks : 70% fly ash ; 10% Cement ; 20% sand

Clay Bricks : 30% fly ash ; 50% clay ; 20% sand

Fal-G Bricks : 65% fly ash ; 16% lime; 15% sand; 4% gypsum

It is important to know the end use of fly ash based bricks while considering them, eg. whether it is for load bearing Structure or for some other applications. If it is for load bearing structure, then to what loads or these being used for partitions or single storey buildings. Accordingly the specifications are fixed up for the bricks. Available technologies are capable of supplying the bricks from a strength of 50 kg/cm^2 to > 180 kg/cm^2.

In the case of clay-fly ash bricks, fly ash plays primarily the role of replacing the top soil and thus silica and other constituents play a normal role. The presence of unburnt carbon is very advantageous as it saves the fuel consumption during firing. In other words, the flyash with higher L.O.I is more useful for these applications. After mixing clay and fly ash in proper proportion; extrusion and drying; the bricks are fired in Hoffman kilns.

Fly ash- lime-gypsum (FAL-G) or lime based bricks are made by using fly ash, low cost course sand, gypsum and the lime sludge. Pond-ash from ash ponds can also be used by mixing with locally available clay. It is better to use lime sludge[5] in place of fresh lime as it is free from hard clinker and is available cheaply from acetylene plants. The manufacturing process of FAL-G bricks involves thorough mixing of all the ingredients, conveying the mix to the press and forming green bricks using press, stacking the bricks and curing them for about 20 days. Bricks are ready to use after nearly 30 days from the date of manufacturing.

Fly ash-lime-sand bricks are made by mixing the ingredients in the appropriate proportion using mechanical mixer with the addition of water. This prepared mixture is then stored for few hours to complete the hydration of lime. Green bricks are formed by pressing this mixture in an hydraulic press and kept for natural curing under a shed for approx. 24 hours and then steam cured at pressures higher than 1 atm. for about 5 to 7 hours at a temp. of 135^0-140^{0}C. Typical properties of burnt clay brick and fly ash (FAL-G) bricks are given in Table 5 and flowsheets are given in figure 1 and 2.

Table 5 : Typical properties of fly ash bricks (Fly ash+Sand+Lime+Gypsum) and burnt clay bricks[11]

Property	Burnt Clay brick	Fly ash brick
% Water absorption	21	15
App-Density (gm/cc)	1.44	1.80
Compressive strength (Kg/cm^2)	19-42	58-78

There are certain distinct advantages of fly ash based bricks[6] over the conventional red bricks and these are —

(i) Uniform and standard product size resulting in 10% less consumption of bricks per unit construction.

(ii) Cement Consumption is less in cement and mortar.

(iii) Compressive strength is more than conventional red bricks (> 100 kg/ cm^2) and further increase with the passage of time.

(iv) Less load on foundation due to light weight.

(v) Due to the property of less water absorption and no weathering effects, surfaces can be left exposed without plastering and direct application of paint is also possible.

The available Indian standards for fly ash based building materials are given in table 6.

Table 6 : Available Indian standards for fly ash based building materials

(1)	Manufacturing of portland pozzolana cement (PPC) with fly ash	BIS : 1489 (I)-1991
(2)	Masonary cement	BIS : 3466-1988
(3)	Fly-ash -lime -gypsum bricks	BIS : 12894 -1990
(4)	Fly-ash as raw material for OPC	BIS : 269-1967
(5)	Oil well cement with fly ash	BIS : 8229-1986
(6)	Autoclave aerated concrete blocks	BIS : 2185(3)-1984
(7)	Use of fly ash in concrete	BIS : 3812-1981

2.2 Portland Pozzolana Cememt (PPC)

Pozzolans are the clay matter either natural or synthetic, which when ground with lime or clinker and mixed with water, produce cementitious compounds[7] when highly reactive flyash is mixed with Portland cement clinker and ground with 5-6% of gypsum the

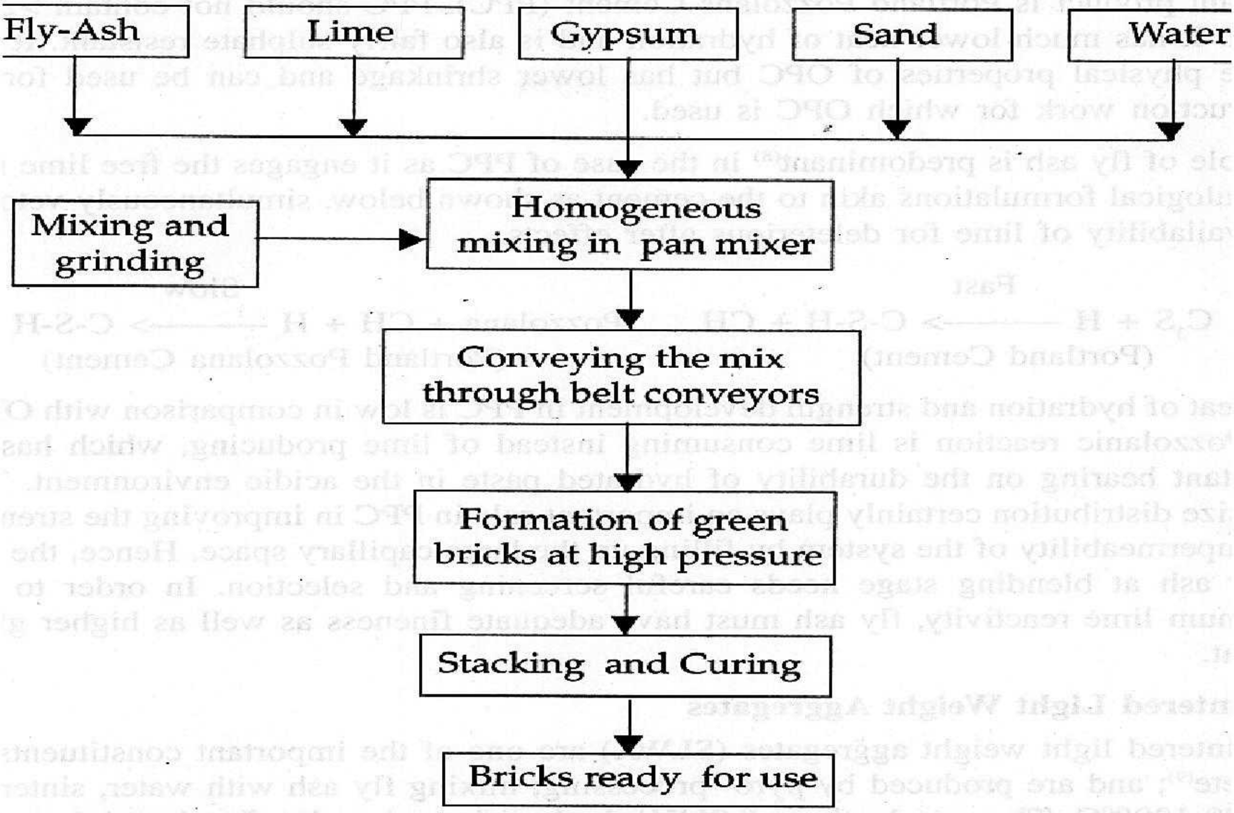

Fig 1 : Flow Sheet for the manufacture of FAL-G bricks[12]

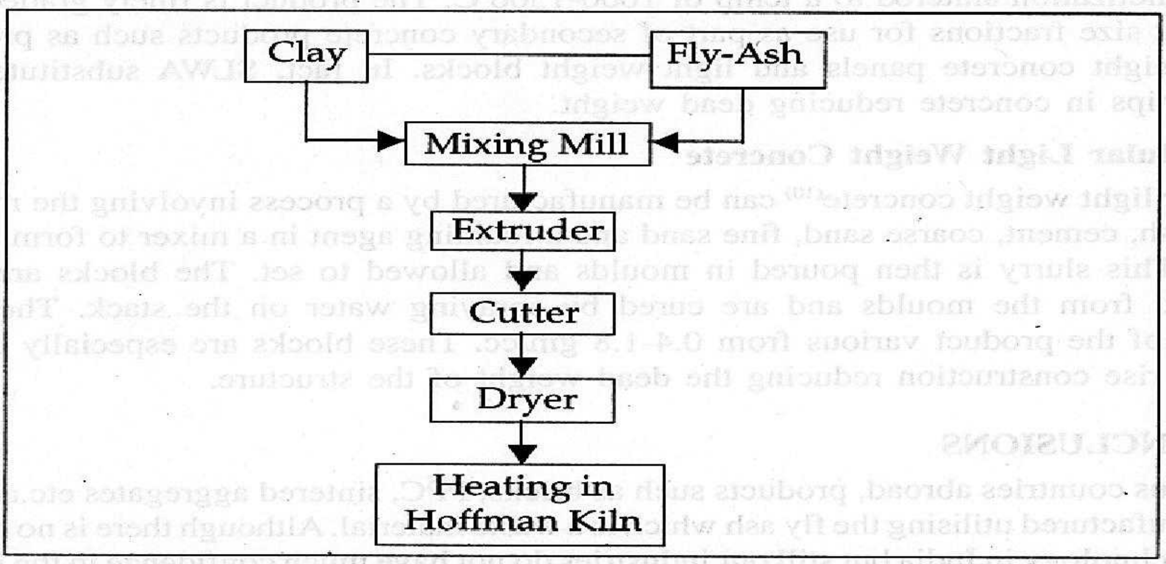

Fig 2 : Flow sheet for the manufacture of clay- fly ash bricks[13] resultant product is Portland Pozzolans Cement (PPC). PPC should not contain >25% flyash. It has much lower heat of hydration and is also fairly sulphate resistant. It has all the physical properties of OPC but has lower shrinkage and can be used for all construction work for which OPC is used.

The role of fly ash is predominant[8] in the case of PPC as it engages the free lime into mineralogical formulations akin to the cement as shown below, simultaneously vetoing the availability of lime for deleterious after effects.

$$C_3S + H \xrightarrow{\text{Fast}} C\text{-}S\text{-}H + CH \qquad \text{Pozzolana} + CH + H \xrightarrow{\text{Slow}} C\text{-}S\text{-}H$$

(Portland Cement) (Portland Pozzolana Cement)

The heat of hydration and strength development in PPC is low in comparison with OPC. The Pozzolanic reaction is lime consuming instead of lime producing, which has an important bearing on the durability of hydrated paste in the acidic environment. The pore-size distribution certainly plays an important role in PPC in improving the strength and impermeability of the system by filling up the large capillary space. Hence, the use of fly ash at blending stage needs careful screening and selection. In order to get maximum lime reactivity, fly ash must have adequate fineness as well as higher glass content.

2.3 Sintered Light Weight Aggregates

The sintered light weight aggregates (SLWA) are one of the important constituents of concrete[9]; and are produced by pyro- processing; mixing fly ash with water, sintering at 1000-1300°C. The production of SLWA is done by using dry flyash, mixing with water with the addition of high carbon fly ash or carbon. This homogeneous material after pelletization sintered to a temp of 1000-1300°C. The product is finely graded into different size fractions for use as part of secondary concrete products such as pre-cast light weight concrete panels and light weight blocks. In fact, SLWA substitutes the stone-chips in concrete reducing dead weight.

2.4 Cellular Light Weight Concrete

Cellular light weight concrete[10] can be manufactured by a process involving the mixing of fly ash, cement, coarse sand, fine sand and a foaming agent in a mixer to form a thin slurry. This slurry is then poured in moulds and allowed to set. The blocks are then removed from the moulds and are cured by spraying water on the stack. The bulk density of the product various from 0.4-1.8 gm/cc. These blocks are especially useful in high rise construction reducing the dead weight of the structure.

3.0 CONCLUSIONS

In various countries abroad, products such as bricks, PPC, sintered aggregates etc.are being manufactured utilising the fly ash which is a waste material. Although there is no dearth of the technology in India but still our industries do not have much confidence in the indigenous know-how and the import of technology from abroad in going on, thus discouraging the indigenous R&D efforts. The fly ash disposal can be usefully made if the local entrepreneures preferably from near by thermal power plants, come forward to install brick making plants using fly ash. Fly ash bricks because of greyish in colour are hesitated by the customers (public) to switch over from the usual reddish burnt clay bricks. Moreover, because of high strength, the masons are also reluctant in using the same. However, for better utilisation of fly ash bricks and other building materials, more publicity should be given to the actual users. Government agencies also should come forward in using such materials in its construction work. The increased utilisation of such materials will definitely help in the reduction of the usage of the conventional raw materials like clay/ shales, thus saving valuable natural resources. In brief, in order to have the efficient utilisation of fly ash based building materials, the need of the hour is

(i) The development of coal -- ash based marketable products having potentiality for bulk utilisation.

(ii) The development of environment-friendly ash-disposal methodology.

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