FLY ASH WASTE MANAGEMENT – A CONGENIAL APPROACH

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ABSTRACT

India, the world's second largest populous nation with huge reserves of coal in the country, utilizes this resource for energy production. Hence, the maximum part of country's electricity production is through coal i.e. the maximum power generation depends upon coal. Fly ash, a waste generated by thermal power plants, a by-product of pulverized coal becomes a major problem because of its disposal and also of its hazardous effects to the environment. For humans toxics of coal ash have the potential to injure all the major organ systems, damage physical health and development, and even contribute to mortality. Fly ash is now being accepted as a resource material. The concerted efforts in Mission Mode that began in India about a few years back and had developed confidence in fly ash utilization technologies and its large-scale utilization. This paper is carried out to study the properties of fly ash and thus its utilization in cement concrete as a partial replacement of cement actually as an additive and usage in manufacturing of fly ash bricks so as to provide an environmentally consistent way of its disposal and reuse.

KEYWORDS: *bricks, building, cement, coal, fly ash.*

I. INTRODUCTION

Fly ash, a waste generated by thermal power plants, a by-product of pulverized coal (also known as powdered coal or coal dust) combustion in thermal power plants. Fly ash particles are light and have the potential to get airborne and pollute the atmosphere (such a big environmental concern).

In India, the availability of huge reserves of coal (about 8% of worlds' reserves) ensures that coal remains the predominant energy source for power production. With over 60% of power generation of the country based on coal, often containing nearly 40% ash, the country produces 80100 MT (million tonnes) of fly ash each year. But this in itself may not have been a problem if this ash, instead of being dumped as waste, found its way into various applications such as the manufacture of cement, concrete, and bricks, as is the case in many countries.

ICITSEM-16
ISBN : 978-93-86171-10-8

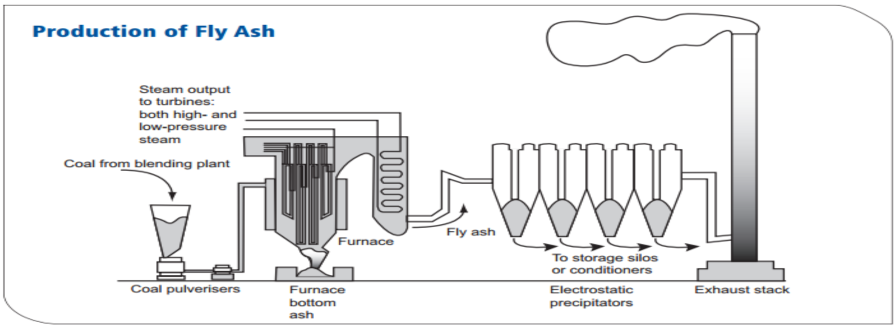

Figure 1: Fly ash generation

1.1 FLY ASH GENERATION

Fuel generally coal, is burnt in combustion chamber, where mineral impurities are fused to form suspension, combustible material like carbon burns off to release energy and the waste or flue gases cool to convert into spherical glassy particles called the Fly Ash.

Fly ash found its use during prehistoric times. Utilisation techniques for using fly ash has developed world over and has resulted into fly ash being used as a resource material in construction purposes as an additive in cement or raw material in brick manufacturing . Thus, for reasons of quantitative efficiency any waste management strategy which involves integration of by-product into existing supply chains, fly-ash is a natural choice for intervention due to India's energy dependency on coal based thermal power plants & its widespread distribution on all of the Indian mainland.

II. CHEMICAL COMPOSITION AND CLASSIFICATION OF FLY ASH

1.1. Composition of fly ash

Fly ash material solidifies while suspended in the exhaust gases and is collected by electrostatic precipitators or filter bags. Since the particles solidify rapidly while suspended in the exhaust gases, fly ash particles are generally spherical in shape and range in size from 0.5 µm to 300 µm. The major consequence of the rapid cooling is that few minerals have time to crystallize, and that mainly amorphous, quenched glass remains. Fly ash is a heterogeneous material. SiO_2, Al_2O_3, Fe_2O_3 and occasionally CaO are the main chemical components present in fly ashes. The mineralogy of fly ashes is very diverse. The main phases encountered are a glass phase, together with quartz, mullite and the iron oxides hematite and magnetite.

COMPONENT (%)	BITUMINOUS	SUBBITUMINOUS	LIGNITE
SiO_2	20-60	40-60	15-45
Al_2O3	5-35	20-30	20-25
Fe_2O_3	10-40	4-10	4-15
CaO	1-12	5-30	15-40
LOI (Loss on Ignition)	0-15	0-3	0-5

Table 1: Composition of fly ash

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1.2. Classification of fly ash

Fly ash is a pozzolanic material (concrete production) and has been classified into two classes, F and C, based on the chemical composition.

Class F fly ash	Class C fly ash
Produced from burning anthracite and bituminous coals	Produced from lignite and sub-bituminous coals
Has siliceous and aluminous material	Contains significant amount of calcium hydroxide (cao) or lime
No or low cementitious property, but with calcium hydroxide gains this property.	Have puzzolanic and cementitious properties

Table 2: Different classes of fly ash

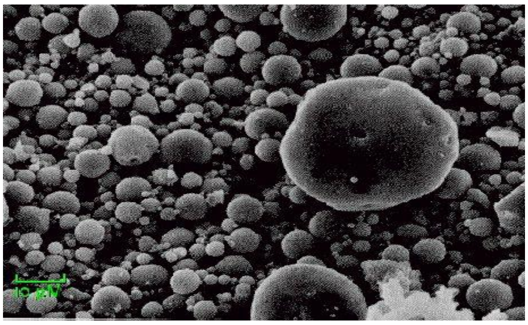

Figure 2: Fly ash (Cement like powder) and particles of fly ash

III. MATERIAL PROPERTIES

1.3. Physical Properties

Structure	fine, powdery particles
Shape	Spherical, either solid or hollow
Nature	mostly glassy (amorphous)
Particle size	less than a 0.075 mm or No. 200 sieve
specific gravity	2.1 to 3.0
specific surface area	170 to 1000 m^2/kg
Colour	tan to gray to black (colour intensity varies from light to dark with increased amount of carbon content)

Table 3: Physical Properties of fly ash

ISBN : 978-93-86171-10-8

1.4. Chemical Properties

The different types of coal (anthracite, bituminous, sub bituminous, and lignite), the techniques used for handling and storage forms the basis of the chemical properties of fly ash. The lignite and sub-bituminous coal fly ashes have a higher calcium oxide content and lower loss on ignition than fly ashes from bituminous coals. Lignite and sub-bituminous coal fly ashes may have a higher concentration of sulphate compounds than bituminous coal fly ashes.

II. HAZARDS CAUSED BY FLY ASH

Fly ash consists of the fine powdery particles of minerals, plus a small amount of carbon which moves up with smokestack by the exhaust gases. Arsenic, lead, mercury, cadmium, chromium and selenium, as well as aluminium, antimony, barium, beryllium, boron, chlorine, cobalt, manganese, molybdenum, nickel, thallium, vanadium, and zinc are present in fly ash from coal.

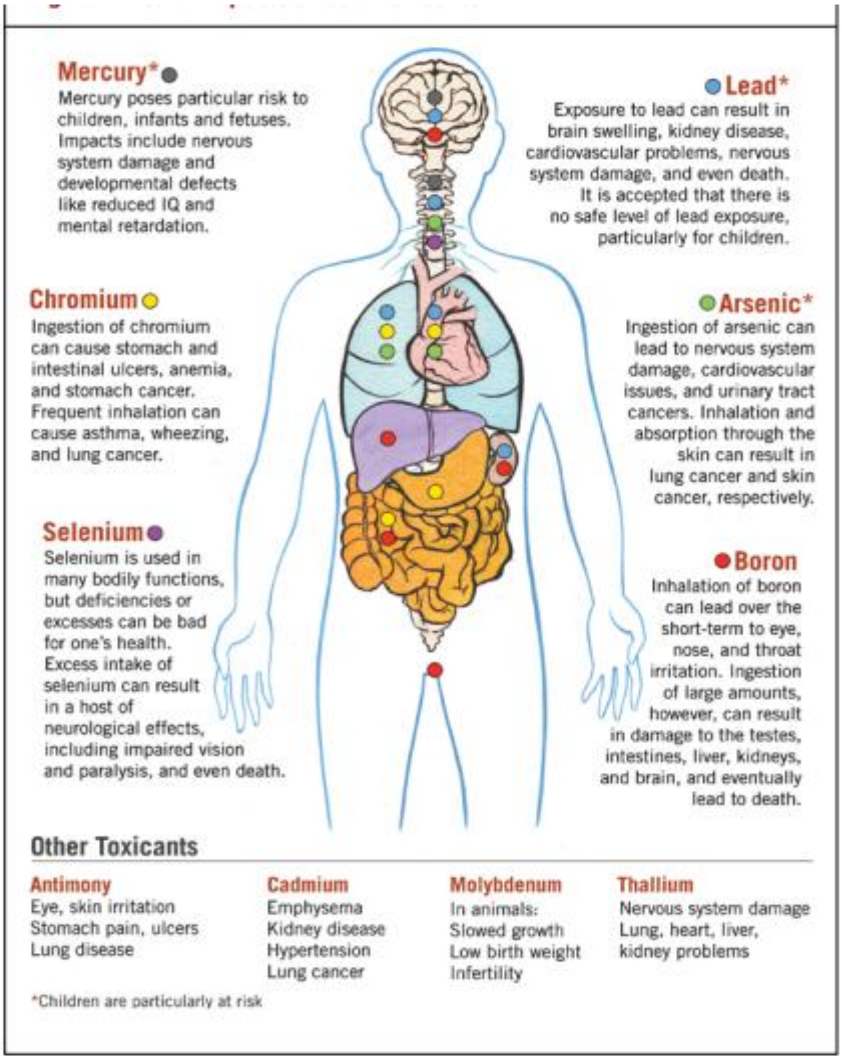

Figure 3: Hazards of fly ash to human body

All are highly toxic. On prolonged exposure, these toxic metals causes several types of cancer, heart damage, lung disease, respiratory distress, kidney disease, and reproductive problems, gastrointestinal illness, birth defects, impaired bone growth in children, nervous system impacts, cognitive deficits, developmental delays and behavioural problems. Some power plants mix coal with other fuels and wastes, such as used tyres and other hazardous wastes which further increases the toxicity level. In addition, when coal ash is disposed with coal refuse, it results in a highly acidic waste, which is significantly more toxic and prone to release metals into the environment. This greatly increases the cancer risk to nearby residents who get their water from drinking wells. This toxic substance can easily be converted into a safe and useful product by converting it into bricks or using it with cement and concrete.

III. VARIOUS POSSIBLE USES OF COAL ASH

- Concrete production, fly ash as a substitute material for Portland cement and sand
- Waste stabilization and solidification
- Soft soil stabilization
- As Aggregate substitute material (e.g. for brick production)
- Mine reclamation
- Cement clinkers production - (as a substitute material for clay)
- Agricultural uses: soil amendment, fertilizer, cattle feeders, soil stabilization in stock feed yards, and agricultural stakes
- Other applications include cosmetics, toothpaste, kitchen counter tops, floor and ceiling tiles, bowling balls, flotation devices, stucco, utensils, tool handles, picture frames, auto bodies and boat hulls, cellular concrete, geo-polymers, roofing tiles, roofing granules, binding agent, decking, fireplace mantles, cinder block, PVC pipe, structural insulated panels, house siding and trim, running tracks, blasting grit, recycled plastic lumber, utility poles and cross arms, railway sleepers, highway sound barriers, marine pilings, doors, window frames, scaffolding, sign posts, crypts, columns, railroad tiles, vinyl flooring, paving stones, shower stalls, garage doors, park benches, landscape timbers, planters, pallet blocks, moulding, mail boxes, artificial reef, paints and undercoating, metal castings, and filler in wood and plastic products.

The investigation reported in this paper is carried out to study the utilization of fly ash in cement concrete as a partial replacement of cement (as an additive) and an environmentally consistent way of disposal and reuse of fly ash is in manufacturing of fly ash bricks.

IV. FLY ASH FOR CEMENT CONCRETE

Fly ash is very much similar to volcanic ashes used in production of the earliest known hydraulic cements. A pozzolana is a siliceous or siliceous / aluminous material which when mixed with lime and water forms a cementitious compound. Fly ash is the best known, and one of the most commonly used, pozzolans in the world.

4.1 Cement concrete

Fly ash is considered to be stronger, more environmental friendly and durable cement as compared to Portland cement. It is the most widely used construction material in the world. It consists of cement, aggregates (fine and course) and water. In the concrete, cement chemically reacts with water and produces binding gel that binds other component together and creates stone type of material by a process called 'hydration', along with formation of some amount of lime [Ca $(OH)_2$]. The coarse and fine aggregates act as filler in the mass. Thus, the fly ash in Concrete could be an expensive replacement for Portland cement in concrete and using it, improves strength, segregation and ease of pumping concrete.

WORKING MECHANISM OF FLYASH WITH CEMENT

Ordinary Portland Cement (OPC) is a product of four principal mineralogical formations. These formations include Tricalcium Silicate- C_3S ($3CaO.SiO_2$), Di-Calcium Silicate – C_2S ($2CaO.SiO_2$), Tri-Calcium Aluminate C_3A ($3CaO.Al_2O_3$) and Tetra-Calcium alumino-ferrite - C_4AF ($4CaO.\ Al_2O_3.Fe_2O_3$) formations. The setting and hardening of the OPC is a result of reaction between these principal compounds and water. The reaction between these compounds and water are shown as under:

$$\mathbf{2C_3S + 6H \longrightarrow C_3S_2H_3 + 3CH \ldots\ldots\ldots\ldots (1)}$$

C-S-H gel

$$\mathbf{2C_2S + 4H \longrightarrow C_3S_2H_3 + CH \ldots\ldots\ldots\ldots (2)}$$

The hydration products from C_3S and C_2S are similar but quantity of calcium hydroxide (lime) formed is higher in C_3S as compared to C_2S.

Gypsum in OPC supplies sulphate ions which makes the reaction of C_3A with water very fast and is shown as under:

$$\mathbf{C_3A + 3(CSH_2) + 26H \longrightarrow C_3A\,(CS)_3H_{32}\ \text{(ettringite)} \ldots\ldots\ldots\ldots (3)}$$

$$\mathbf{C_3A + CSH_2 + 10H \longrightarrow C_3ACSH_{12}\ \text{(mono sulpho aluminate hydrate)} \ldots\ldots\ldots\ldots (4)}$$

Above reactions indicate that during the hydration process of cement, lime is released out and remains as surplus in the hydrated cement. Durability of the cement is affected by this leached out surplus lime which renders pernicious effect to concrete by making the concrete porous, developing micro- cracks, weakening the bond with aggregates .

If fly ash is available in the above mixture, this surplus lime forms additional C-S-H gel. The reaction of fly ash with surplus lime continues as long as lime is present in the pores of liquid cement paste.

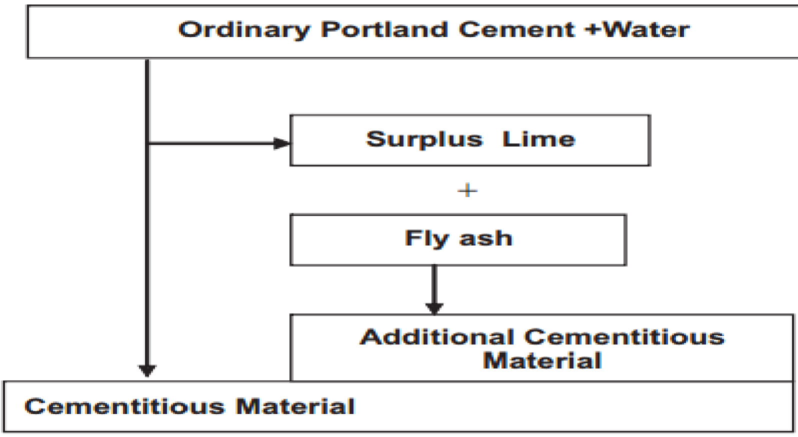

Figure 4: Fly ash with cement

4.2 Advantages of Fly Ash in Concrete

- **Fly Ash improves concrete workability and lowers water demand.** Fly Ash particles are mostly spherical tiny glass beads. Ground materials such as Portland cement are solid angular particles. Fly Ash particles provide a greater workability of the powder portion of the concrete mixture which results in greater workability of the concrete and a lowering of water requirement for the same concrete consistency.
- **Fly Ash generally exhibit less bleeding and segregation** than plain concrete. This makes the use of Fly Ash particularity valuable in concrete mixtures made with aggregates deficient in fines.
- **Sulphate and Alkali Aggregate Resistance.** Class F and a few Class C Fly Ashes impart significant sulphate resistance and alkali aggregate reaction (ASR) resistance to the concrete mixture.
- **Fly Ash has a lower heat of hydration.** Portland cement produces considerable heat upon hydration. In mass concrete placements the excess internal heat may contribute to cracking. The use of Fly Ash may greatly reduce this heat build up and reduce external cracking.
- **Fly Ash generally reduces the permeability and adsorption of concrete.** By reducing the permeability of chloride ion egress, corrosion of embedded steel is greatly decreased. Also, chemical resistance is improved by the reduction of permeability and adsorption.
- **Fly Ash is economical.** The cost of Fly Ash is generally less than Portland cement depending on transportation. Significant quantities may be substituted for Portland cement in concrete mixtures and yet increase the long term strength and durability. Thus, the use of Fly Ash may impart considerable benefits to the concrete mixture over a plain concrete for less cost.

4.3 Environmental benefits of fly ash use in concrete

- Use of fly ash in concrete imparts several environmental benefits and thus it is eco-friendly. It saves the cement requirement for the same strength thus saving of raw materials such as limestone, coal etc required for manufacture of cement.
- Due to low calorific value and high ash content in Indian Coal, thermal power plants in India, are producing huge quantity of fly ash. This huge quantity is being stored / disposed off in ash pond areas. The ash ponds

ISBN : 978-93-86171-10-8

acquire large areas of agricultural land. Use of fly ash reduces area requirement for pond, thus saving of good agricultural land.

4.4 Increasing trends of fly ash been utilized in cement concrete

With increasing awareness, availability of good quality fly ash in modern efficient thermal power station and concept of Ready Mixed Concrete, the use of fly ash as part replacement of cement and sand is showing increasing trends. Few examples wherein fly ash has been utilized in cement concrete are as under:

- Fly ash from NTPC's Dadri Thermal power stations is being utilized in prestigious Delhi Metro Rail Corporation (DMRC) works at New Delhi. : More than 60,000 tonne of fly ash has been utilized in the work so far. In this project, the requirement of cement concrete was high strength, high durability (less shrinkage and & thermal crakes), low heat of hydration, easy placement, cohesiveness and good surface finish. Use of fly ash in concrete has fulfilled the entire above requirements. According to the data and study replacing cement by fly ash has (i) reduced the peak temperature by 8 C, (ii) the time attaining peak temperature has been extended and (iii) heat generation pattern was more uniform and gradual.
- Self-Compacting concrete using fly ash from Kota thermal power station has been utilized for structural members of Rajasthan Atomic Power Project. Self-compacting concrete was used due to difficulties in placing concrete in structures having heavily congested reinforced bars and openings.
- Recently, about 38,000 m fly ash concrete has been used in main plant civil work of Rajasthan Atomic Power Project (RAPP) unit 5 &6.
- Ready Mixed Concrete (RMC) plants located in Mumbai, Delhi and adjoining areas are using fly ash in concrete. These RMC plants are taking fly ash from Nasik and Dahanu thermal power stations located near Mumbai and Dadri near Delhi and supplying fly ash based concrete for various housing and infrastructure projects.
- For constructing residential buildings at Gurgaon Haryana, by DLF and Unitech Prefab using fly ash obtained from NTPC Dadri in concrete

Use of ash in road embankment

Figure 5: Uses of fly ash prepared cement

V. FLY ASH IN BRICKS MANUFACTURING

5.1 Raw Materials for Fly Ash based bricks:

- Fly Ash, Sand and Cement (Ordinary Portland Cement)
- Fly Ash, Sand, Lime and Gypsum
- Consumption of Fly Ash to produce a single fly ash based brick is 1.250gm.

Main ingredients include fly ash, water, quicklime or lime sludge, cement, aluminium powder and gypsum. The block hardness is being achieved by cement strength, and instant curing mechanism by autoclaving. Gypsum acts as a long term strength gainer. The chemical reaction due to the aluminium paste provides AAC its distinct porous structure, lightness, and insulation properties, completely different compared to other lightweight concrete materials. The finished product is a lighter Block - less than 40% the weight of conventional Bricks, while providing the similar strengths. The specific gravity stays around 0.6 to 0.65. This is one single most USP of the AAC blocks, because by using these blocks in structural buildings, the builder saves around 30 to 35 % of structural steel, and concrete, as these blocks reduce the dead load on the building significantly.

Figure 6: Bricks manufactured from fly ash

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MANUFACTURING PROCESS

Fly ash brick (FAB) contains class C fly ash and water. Fly ash (70%) Lime (10%) Gypsum (5%) and sand (15%) are manually feed into a pan mixer where water is added to the required proportion for homogeneous mixing. The proportion of raw material may vary depending upon quality of raw materials. After mixing, the mixture are allowed to belt conveyor through feed in to automatic brick making machine were the bricks are pressed automatically. Than the bricks are placed on wooden pallets and kept as it is for two days thereafter transported to open area where they are water cured for 10 -15 days. The bricks are sorted and tested before dispatch.

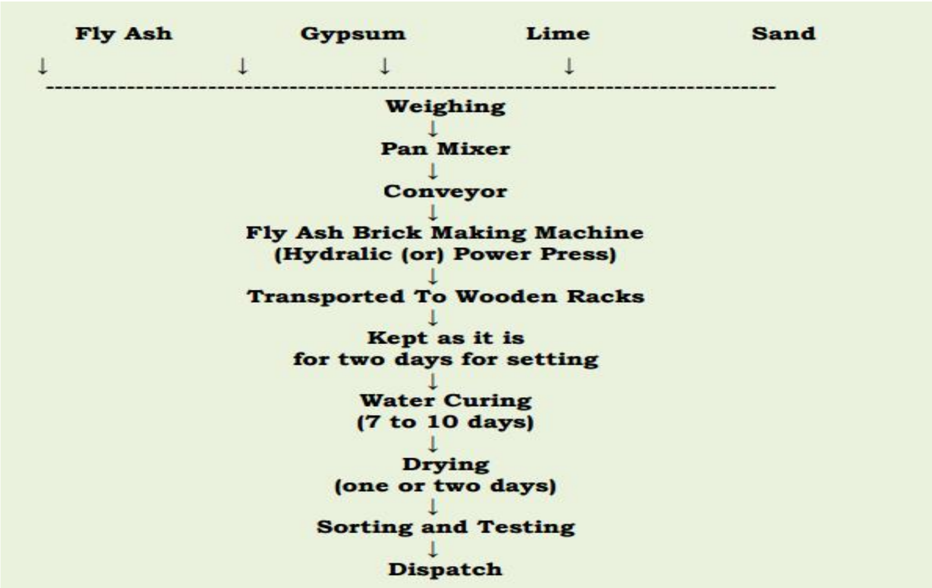

Figure 7: Manufacturing of fly ash bricks

The technology adopted for production of fly ash bricks is eco-friendly. It does not require steaming or auto-calving as the bricks are cured by water only. Since firing process is avoided. There are no emissions and no effluent is discharged. Facial masks and dust control equipment may be provided to the employees to avoid dust pollution more over all the raw materials are kept under covered by polythene sheet to avoid air pollution.

5.2 Advantages of using Fly Ash Bricks

- Multi-storeyed building construction is preferred by using fly ash bricks as they are light weight as compared to clay bricks, less weight means less stress on building, safety assured.
- FAB (fly ash bricks) absorbs less heat than normal bricks, which helps in keeping the buildings cool even in summer, hence most suitable for Indian conditions.
- As these bricks are machine made therefore even in shape and requires less mortar in construction.

- Less porous, absorbs very little water, in comparison to burnt clay bricks which absorbs more water during construction. Saves money on water during construction and even keeps your building strong during rainy seasons.

5.3 Disadvantages of using Fly Ash Bricks

- Mechanical strength is low and is improved by adding marble waste or mortar between blocks.
- Only modular size bricks can be produced as large size will have more breakages.

5.4 Use of fly ash bricks

- NTPC has manufactured more than 54 crores of ash bricks and has utilized them in various construction activities
- Bricks used for constructing cafeteria and management school buildings by IIT, Delhi.
- Bricks used for office building construction by Greater Noida Development Authority.
- Bricks used for construction of houses by private parties in various metro cities of the country.

VI. CONCLUSION

Thus, we could conclude that the fly ash produced in the processing being a waste, instead of being dumped as waste, found its way into various applications such as the manufacture of cement, concrete, and bricks With increasing awareness, availability of good quality fly ash in modern efficient thermal power station and concept of ready mixed concrete, the use of fly ash as part replacement of cement and sand is showing increasing trends. Similarly the fly ash bricks have been started being utilised in construction of various multi-storey structures. Both the processes being advantageous also support the environment and leads manufacturing of eco-friendly products thus the further waste problem could be resolved.

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