

Coal Fly Ash from Thermal Power Plants - Waste Management: A Green 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 byproduct of pulverized coal becomes a major problem because of its disposal and also of its hazardous effects to the environment. Current annual production of Fly ash, a by-product from coal based thermal power plant, is about 112 million tons. One of the major disadvantages of coal-based thermal power plants is the disposal problem of Fly ash. It was earlier considered as a total waste and an environmental hazard, thus its use was limited, without much understanding. Fortunately, its useful properties have now begun to be known as raw material for various applications as an outcome of their efforts, Fly Ash is being very effectively and economically used in building components such as bricks, cement, doors, door-frames, etc. Fly Ash is also being used in construction of roads and embankments with some design changes. It is also used as raw material in agricultural and wasteland development programmed. The paper illustrates that Indian fly ashes and the utilization avenues hold the potential to give returns worth more than a billion dollars excluding valuation of resultant cleaner/greener environment.

KEYWORDS: Fly ash, compressive, Eco-friendly, Construction material, Green concrete.

I. INTRODUCTION

Coal-based thermal power plants have been a major source of power generation in India where about 57% of the total power obtained is from coal-based thermal power plants. The coal-burning power plants, which consume pulverized solid fuels, produce large amounts of fly ash as a residue. The process of coal combustion results in coal ash, 80% of which is very fine in nature and thus known as fly ash. High ash content is found to be in range of 30% to 50% in Indian coal [1]. The quantum of fly ash produced depends on the quality of coal used and the operating conditions of thermal power plants. Presently the annual production of fly ash in India is about 112 million tones with 65000 acre of land being occupied by ash ponds and is expected to cross 225 million tones by the year 2017 [2]. The fly ash, solid waste from coal-fired thermal power plants, is becoming a serious concern to the environmentalists.

Fly ash is an extremely fine powder consisting of spherical particles less than 50 microns in size and produced approximately 420 million tons per year globally [3]. It consists of silica, alumina, iron oxide, lime, magnesia and alkali in varying amounts with some unburned activated carbon [4]. Fly ash is one of the construction industry's most commonly used pozzolans. Pozzolans are siliceous or siliceous/alumino materials possessing the ability to form cementitious compounds when mixed with lime (calcium hydroxide, or $\text{Ca}(\text{OH})_2$) and water. Due to environmental regulations, new ways of utilizing fly ash have to be explored in order to safeguard the environment and provide cost effective ways for its bulk utilization. Now, there is an urgent and imperative need to adopt technologies for gainful utilization and safe management of FA on sustainable basis. FA has a number of useful applications that serves to utilize some of the large amount being produced all over the world. Main applications of FA are in the field of manufacturing of cement and other construction materials [5-6].

A huge volume of Fly Ash produced from coal-based thermal power plants may bring several problems from environmental point of view. Fly Ash particles ranging in size from 0.5 to 300 micron in equivalent diameter, being light weight, have potential to get airborne easily and pollute the environment. If not managed properly fly ash disposal in sea/rivers/ponds can cause damage to aquatic life also. It can also contaminate the under-ground water resources with traces of toxic metals present in fly ash. Huge investments/ expenditures are made just to get Fly Ash out from the thermal power plants and dump it in the ponds. If understood and managed properly, it can prove to be a valuable resource material. Every year a crude estimation of more than 300 billion tones of fly ash is generated in the world [7] and is being consumed in the production of building construction materials, in agriculture, metal recovery, in water and atmospheric pollution control, etc. [8]. These applications could succeed up to some extent to consume the huge amount of fly ash.

The paper also discusses some of the economic drivers which determine the degree of commercial success. Simply depositing of waste materials in concrete products is unlikely to succeed except in unusual situations and providing eco-friendly (Green Concrete) construction material to make use of this solid waste, in order to save our environment.

II. GENERATION OF FLY ASH

In thermal power plant, Fly ash is generated when coal is fed to a series of mills that pulverize the coal to a very fine powder. This powder is then fed into a boiler which combusts the coal to produce heat (fly ash Australia). In general, three types of coal-fired boiler furnaces used in the thermal power plant. They are referred to as dry-bottom boilers, wet-bottom boilers, and cyclone furnaces. In them dry-bottom furnace is most commonly used. Fly ash is generated by burning of pulverized coal in the boiler furnace and carried by flue gas, passed in superheated from there it goes to the reheater, economizer and air pre-heater one by one. Finally reached in to electrostatic precipitator. The path followed by flue gas is given in **Fig. 1**.

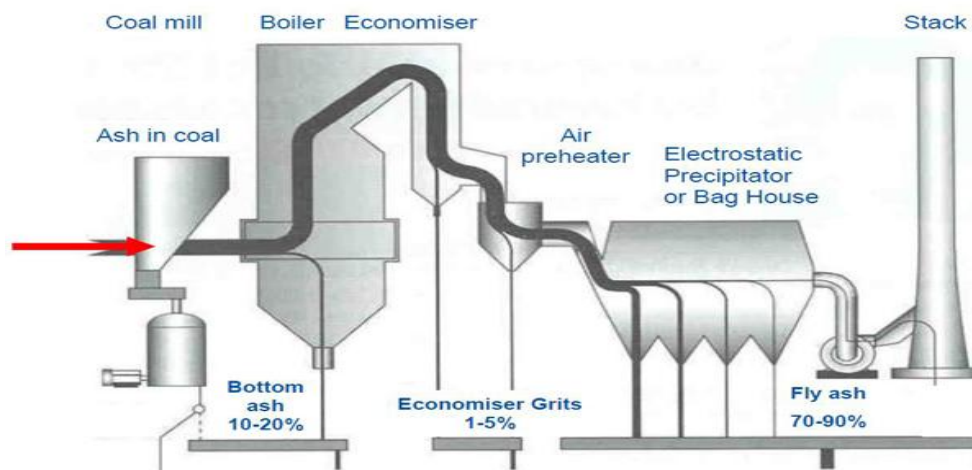


FIGURE 1: COAL FIRED POWER STATIONS

III. NATURE AND PHYSICO-CHEMICAL CHARACTERISTIC OF FLY ASH

Fly ash, the residue of combustion of coal, originally a mixture of vegetation, clay and rocks, comprises a wide range of inorganic matters. Physically, flyash occurs as very fine spherical particles, having diameter in the range from few μ to 100 μ , low to medium bulk density, high surface area. In physical properties of fly ash, colour is one of the important in terms of estimating the lime content qualitatively. It gives us a suggestion that darker colour suggest high organic content while lighter colour indicate the presence of high calcium oxide. Specific gravity another important physical property needed for the geotechnical use of fly ash. In general, the specific gravity of coal ashes lays around 2.0 but can vary to a large extent (1.6 to 3.0). Fly ash containing a relatively slighter specific gravity than the normal soils [9-11]. Specific gravity of fly ash depends considerably upon its carbon and iron content. More carbon content decreases its specific gravity, whereas presence of iron content increases the specific gravity [12]. The porosity and Water holding capacity of fly ash samples varies from the range of 51.15 to 53.27% and 50.70-55.11% [13]. The specific surface area of fly ash ranges between 170 to 1000 m²/kg. Particle sizes mostly depend on the fly ash source. Fly ash particles are spherical shape, various sizes and highly porous in nature. The finest ones are micro porous and coarser fractions are macro porous. The particles of fly ash usually range from less than 1 μ m to 150 μ m in size and are commonly finer than Portland cement.

Chemically, flyash is amorphous ferro-alumino silicate mineral with major matrix elements like, Si, Al, Fe together with significant amount of Ca, Mg, K, P, S. The concentration of total and available trace/ heavy metals and radionuclides in fly ash samples is in traces and their availability/ leachability is negligible. The texture and physico-chemical properties including trace/ heavy metals and radioactivity closely resemble with most of the field soils. The range of physico-chemical properties of flyash samples are given in **Table 1**. The glassy (amorphous) siliceous spherical particulates are the active portion of fly ash [14]. Typically, fly ash is 30–50% glass and higher glass content in the form of quartz is also present in the fly ash. Other metal oxides such as Mn₂O₃, TiO₂ etc. and minerals

like mullite, hematite, magnetite, ferrite, and rutile in fly ash [15-17] are desirable from the point of view of reactivity (Figure 2).

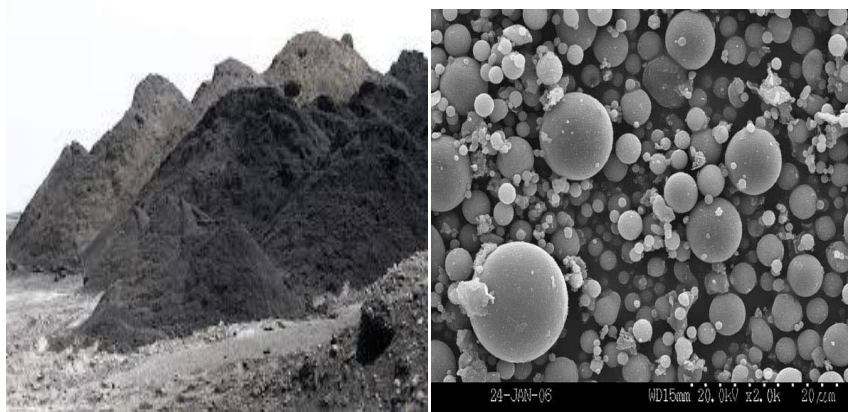


FIGURE 2: (A) COAL FLY ASH (B) SEM PHOTOGRAPH OF FA.

TABLE 1: PHYSICOCHEMICAL CHARACTERISTIC OF FLY ASH

Physical properties		Chemical composition	
Structure	fine, powdery particles	SiO ₂	38 – 63%
Nature	mostly glassy (amorphous)	Al ₂ O ₃	27 – 44%
pH	6.0 – 11.0	TiO ₂	0.4 – 1.8%
Specific gravity	1.66 – 2.55	Fe ₂ O ₃	3.3 – 6.4%
Porosity	44 – 55%	MnO	0.1 – 0.5%
Bulk density (mg/m ³)	0.85-1.2	MgO	0.01 – 0.5%
Electrical conductivity	0.15-0.45 (ds/m)	CaO	0.2 – 8.0%
Water holding capacity	45-60 %	K ₂ O	0.04 – 0.9%
		Na ₂ O	0.07 – 0.43%

IV. CLASSIFICATION OF COAL FLY ASH

On the basis of silica, alumina, and iron content the fly ash [18-19] can be classified into two types of fly ash: Class F and Class C. Class F fly ash contain particles covered in a kind of melted glass. This greatly reduces the risk of expansion due to sulfate attack, which may occur in fertilized soils or near coastal areas. Class F is generally low-calcium and has carbon content less than 5 percent but sometimes as high as 10 percent.

Class C fly ash is also resistant to expansion from chemical attack. It has a higher percentage of calcium oxide than Class F and is more commonly used for structural concrete. Class C fly ash is typically composed of high-calcium fly ashes with a carbon content of less than 2 percent.

V. ENVIRONMENTAL PROBLEMS

Environmental pollution by the coal based thermal power plants all over the world is cited to be one of the major sources of pollution affecting the general aesthetics of environment in terms of land use, health hazards and air, soil and water in particular and thus leads to environmental dangers. The greatest part of the radioactivity in coal remains with the ash but some of the fly ash from coal-fired power plants escapes into the atmosphere. Air pollution in the vicinity of a coal fired thermal power station affects soil, water, vegetation, the whole ecosystem and human health. The Fly Ash is a resource material, if not managed well, this may pose environmental and health problems.

VI. FLY ASH UTILIZATION

These earth elements primarily consist of silica, alumina & iron etc. and its physicochemical parameters are closely resembles with volcanic ash, natural soil and Portland cement etc. These properties, therefore, makes it suitable for use in ceramic industries and helps in saving the environment and Natural resources. Fly ash is oxide-rich and can be used as the raw material for different industries and construction. Few common modes of fly ash utilization that are presently followed in India are as follows:

- ❖ 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 suitable as a “Green Building” material (Green Concrete).

VII. ADVANTAGES OF USING FLY ASH IN CONCRETE

- Use of good quality fly ash in concrete has shown remarkable improvement in durability of concrete, especially in aggressive environment.
- Some of the technical benefits of the use of fly ash in Green Concrete are:
 - a) Higher ultimate strength
 - b) Increased durability
 - c) Improved workability
 - d) Reduced bleeding
 - e) Increased resistance to alkali-silica reactivity.
 - f) Reduced shrinkage.

VIII. NEED OF GREEN CONCRETE

Cement-based materials are the most abundant manufactured materials in the world. Today’s exciting trend is the Green building is in our country. The potential environmental benefit to society of being able to build with green concrete is huge. Green Concrete as the name suggests is ecofriendly and saves the environment by using waste products generated by industries in various forms like rice husk ash, micro silica, etc to make resource-saving concrete structures [20-22]. Use of green concrete helps in saving energy with emissions, waste water. Green concrete is very often also cheap to produce as it uses waste products directly as a partial substitute for cement, thus saving energy consumption in production of per unit of cement. Over and above all green concrete has greater strength and durability than the normal concrete. It is realistic to assume that the technology can be developed, which can reduce the CO₂ emission related to concrete production. Generally the construction industry accounts for a massive environmental impact due to its high demand of energy. As a result of the awareness built during the past few years about greenhouse effect and damage to the nature, more people and countries became conscious about their future. Traditional ready mix concrete is a significant cause of production of greenhouse gases, less in regards to GHG emissions per m³, but in particular in regards to the high quantity produced world-wide. New available technologies allow the use of different types of concrete and advanced ways of production which represent a lesser hazard to the environment. Green concrete

capable for sustainable development is characterized by application of industrial wastes to reduce consumption of natural resources and energy and pollution of the environment.

A. WHAT IS GREEN CONCRETE?

Today the word green is not just limited to colour, it represents the environment, which is surrounding us. Concrete which is made from concrete wastes that are eco-friendly are called as “Green concrete”. The other name for green concrete is resource saving structures with reduced environmental impact for e.g. Energy saving, CO₂ emissions, waste water. “Green concrete” is a revolutionary topic in the history of concrete industry. This was first invented in Denmark in the year 1998 by Dr.WG.

B. IMPACTS OF GREEN CONCRETE

Concrete serves as a better alternative for the utilization or recycle of the solid hazardous waste materials. Properties of mixed concrete can be listed as follows:

- Strength: different solid hazardous waste materials used in mixed concrete. It shows 70-85% strength of pure concrete.
- Leaching: About 85-90% of heavy metals and other contaminants are solidified and stabilized in the concrete matrix. Mixed concrete named “Green concrete”. It is used as filling materials, pavements and roadbeds, etc. This concrete also affects the cost of construction comparable to pure concrete
- Durability: concrete shows long-term durability by the use of mineral admixtures; many important structures are manufactured using the concrete with silica fume, which positively affects on durability aspects.

C. SUITABILITY OF GREEN CONCRETE IN BUILDINGS

The following advantages are concluded for using lightweight green concrete in Prefabrication in building;

- Reduce crane age load, allow handling, lifting flexibility with lighter weight.
- Good thermal and fire resistance, sound insulation than the traditional granite rock.
- Reduce the dead weight of a facade from 5 tons to about 3.5 tons.
- Allow maintenance flexibility with replaceable modules.
- Factory production of module enhances quality of product.
- Enhance green building and speed of construction, shorten overall construction period.
- Utilization of Coal fly ash in aggregate production resolves the waste disposal problems of ash and reduces the production cost of concrete.

D. BENEFITS OF GREEN CONCRETE

- Energy saving material.
- Green concrete having better workability than conventional concrete.
- No environmental pollution and sustainable development
- Reduction of the concrete industry's CO₂ emission by 30 %.
- Green concrete requires less maintenance and repairs
- Increased concrete industry's use of waste products by 20%.
- Less expensive to produce it.
- Good thermal resistant, fire resistant and also is more durable & corrosion resistant.
- Improve damping resistant of buildings.
- Flexural strength of green concrete is almost equal to that of conventional concrete.
- Use of concrete industries own residual products.

E. IMPROVED ENGINEERING PROPERTIES

- Mix can result in a reduced paste volume within the concrete structure resulting in a higher level of protection against concrete deterioration.
- Higher strength per kilogram of cement
- Increased durability & lower permeability

- More aggregates typically mean higher Modulus of elasticity.

F. GREEN CONCRETE TECHNOLOGY

It is a concept of thinking environment into concrete, considering every aspect from raw materials manufacture over mixture design to structural design, construction, and service life. Traditionally the concrete industry has been considered a major producer of GHG emissions, mainly due to the high environmental footprint of cement. The carbon footprint is a measure of the quantity of carbon dioxide emitted through fossil fuel combustion. It is often expressed as tons of carbon emitted per annum [23-24]. Currently the concrete industry is taking a number of steps to reduce the carbon footprint of concrete, from using less Portland cement and more fly ash or slag to enhance the mix with chemicals that allow working with less water. Further the introduction of coarse aggregate cooling systems help to find ways to more innovative solutions including carbon sequestration [25-28].

XI. CONCLUSIONS

The fly ash generated from the coal based thermal power plants are one of the major sources of pollution and affecting environment in terms of land use, health hazards, air, soil and water and thus leads to environmental dangers. Various approaches are cited in literature for the effective utilization of fly ash mainly limited to limited quantity. Therefore bulk utilization of fly ash is recommended to resolve the issue of storage and handling of fly ash in huge volume. Fly ash has become an important raw material for the various industrial and construction application. Concrete continues to play a pivotal role in overall economic growth both locally and globally. Green concrete technology is one of the major steps that a construction industry can implement to achieve sustainable construction with various means as discussed above. With Green concrete Technology we can save the natural materials for future use or the generations to come and sustain it for good amount of time. Hence green concrete consumes less energy and becomes economical. With waste material as alternative we can help reduce the environmental problems and protect the naturally available materials for future generations as well. The usage of green concrete ensures sustainable development and it's gaining its popularity ever since its inception. On the other hand it can safely be concluded that fly ash, which till recent years has been treated as a waste product of thermal power stations, is in fact a valuable resource material.

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BIOGRAPHY



Publications

International Journals: 20

National Journals: 5

National & International Conference Proceedings: 30

PhD (2013) in Chemistry, Assistant Professor of Chemistry, almost 14 Years of research and academic experiences , 25 publications in national and international journals and 10 publications in the proceedings of national and international conferences. One patent is also filed .Selected as an editorial board member of many international and national journals.

Research Interests:

- Development of innovative methods for synthesis of green catalysts
- Green Chemistry
- Nano Science: Synthesis of nano-particles by various methods.
- Biochemistry
- Material science and Pharmaceuticals.
- Bulk utilization of waste materials (fly ash, stone slurry wastes, red mud etc.) in a novel way