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Utilization of Coal Fly ash in concrete Industry to Protect the Environment

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ABSTRACT

Coal fly ash is an abundant industrial waste product, known to be a good pozzolanic material and has been used to increase the ultimate compressive strength and workability of fresh concrete. For this simple reason it is rapidly becoming a common ingredient in concrete all over the world; it is already present to some degree in half the concrete. The use of fly ash as a performance-enhancing ingredient in concrete is one of the most outstanding examples of industrial ecology-i.e., making effective use of waste resources, and ultimately eliminating the concept of waste altogether. Concrete is an environmental friendly material and the overall impact on the environment per ton of concrete is limited. The paper covers the aspect on how to choose a material for Construction industry. It presents the feasibility of the usage of by product materials like fly ash, query dust, marble powder/ granules, plastic waste and recycled concrete and masonry as aggregates in concrete. The use of fly ash in concrete contributes the reduction of green house emissions with negative impacts on the economy. It has been observed that 0.9 tons of CO_2 is produced per ton of cement production. Also, the composition of cement is 10% by weight in a cubic yard of concrete. To avoid the pollution and reuse the material, the present study is carried out. Thus, concrete is an excellent substituent of cement as it is cheaper, because it uses waste products, saving energy consumption in the production. The trend is clear, Fly Ash will soon be considered as a resource material and its potential will be fully exploited. Through development & application of technologies, Fly Ash has shifted from "Waste Material" category to "Resource Material" category. Thus fly ash management is a cause of concern for the future.

Keywords: Fly ash, compressive, Eco-friendly, Construction material, efficient concrete

1. 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 tonnes with 65000 acre of land being occupied by ash ponds and is expected to cross 225 million tonnes by the year 2017 **[2].** The fly ash, solid waste from coal–fired thermal power plants, is becoming a serious concern to the environmentalists. 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 **[3]** and is being consumed in the production of building construction materials, in agriculture, metal recovery, in water and atmospheric pollution control, etc**. [4].** These applications could succeed up to some extent to consume the huge amount of fly ash.

Fly ash is an extremely fine powder consisting of spherical particles less than 50 microns in size **[5].** It consists of silica, alumina, iron oxide, lime, magnesia and alkali in varying amounts with some unburned activated carbon **[6].** 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 $Ca(OH)_2$,) 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 **[7, 8].** Concrete is one of the most widely used construction materials in the world. However, the production of Portland cement, an essential constituent of concrete, leads to the release of significant amount of CO_2, a greenhouse gas. One ton of Portland cement clinker production creates one ton of CO_2 and other greenhouse gases (GHGs). Environmental issues will play a leading role in the sustainable development of the cement and concrete industry in this century.

The paper also discusses some of the economic drivers which determine the degree of commercial success. Simply deposing of waste materials in concrete products is unlikely to succeed except in unusual situations. This paper deals with detail 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 construction material.

2. Coal Fly Ash:

2.1 What is fly ash?

Fly ash closely resembles volcanic ashes used in production of the earliest known hydraulic cements about 2,300 years ago. Fly ash is the best known, and one of the most commonly used, pozzolans in the world. Instead of volcanoes, today's fly ash comes primarily from coal-fired, electricity-generating power plants. These power plants grind coal to powder fineness before it is burned. Fly ash the mineral residue produced by burning coal is captured from the power plant's exhaust gases and collected for use. The Fly Ash is finely divided residue resulting from the combustion of ground or powdered coal. Fly ash is generally captured from the chimneys of coal-fired power plants; it has pozzolanic properties, and is sometimes blended with cement for this reason. The physical, chemical, and engineering properties of fly ash are dependent on the type and source of coal, method and degree of coal preparation, handling and storage methods etc. Fly ash properties may vary due to changes in boiler load. Fly ash that is produced from the burning of lignite or sub bituminous coal has some self-cementing properties (ability to harden and gain strength in the presence of water alone). Fly ash consists of fine, non plastic and powdery particles that are predominantly spherical in shape, either solid or hollow and mostly glassy (amorphous) in nature.

Table 1: Normal range of chemical composition of Indian fly ash produced from different coal types (expressed as percent by weight).

Component	Bituminous	Subbituminous	Lignite
SiO_2 (%)	20-60	40-60	15-45
Al_2O_3 (%)	5-35	20-30	20-25
Fe_2O_3 (%)	10-40	4-10	4-15
CaO (%)	1-12	5-30	15-40
LOI (%)	0-15	0-3	0-5

2.2 Physical properties of fly ash

The physical characteristics of fly ash depend on a number of factors. Chemical composition and pH values of fly ash possess a wide range of depending on the nature of coal and process of coal burnt. Due to low sulfur content of coal and presence of hydroxides and carbonates of calcium and magnesium the pH of fly ash 6.52 which generally highly alkaline **[9-10]**. 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 **[11-13]. Table 2** shows the typical physical characteristics of fly ash.

2.3 Chemical composition fly ash

Fly ash is a silico-aluminate material consisting of SiO_2, Al_2O_3, Fe_2O_3 as the major constituents and varying amount of CaO,MgO, SO_3 with unburned carbon. Besides these, some minor elements such as Hg, As, Ge, Ga, and traces of heavy metals (Cr, Co, Cu, Pb, Mn, Ni, Zn) and rare earths may also be present in fly ash.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 Mn_2O_3, $TiO2$ etc. and minerals like mullite, hematite, magnetite, ferrite, and rutile in fly **ash [15-17]** are desirable from the point of view of reactivity. In fly ash silica content is between 38 and 63%, alumina content ranges between 27 and 44%, calcium oxide is in the range of 0 to 8%. In the fly ash, the elements present in declining order of their plenty are O, Si, Al, Fe, Ti, K, Ca, P and Mg. Moreover, trace quantity of Mn, Cr, Ni and Cu are identified in some of the fly ash **(Table 2).**

Table 2: Physicochemical Characteristic of Fly ash

Physical properties		**Chemical composition**	
Structure	fine, powdery particles	**SiO_2**	38 – 63%
Shape	Spherical, either solid or hollow	**Al_2O_3**	27 – 44%
Nature	mostly glassy (amorphous)	**TiO_2**	0.4 – 1.8%
Particle size	1 μm to 150 μm (less than a 0.075 mm or No. 200 sieve)	**Fe_2O_3**	3.3 – 6.4%
specific gravity	2.1 to 3.0	**MnO**	0.1 – 0.5%
specific surface area	170 to 1000 m2/kg	**MgO**	0.01 – 0.5%
Porosity	44 – 55%	**CaO**	0.2 – 8.0%
pH	6.0-11.0	**K_2O**	0.04 – 0.9%
Colour	tan to gray to black (colour intensity varies from light to dark with increased amount of carbon content)	**Na_2O**	0.07 – 0.43%

2.4 Classification of coal fly ash

On the basis of silica, alumina, and iron content the fly ash can be classified into two classes:

(A) Class F fly ash

The burning of harder, older anthracite and bituminous coal typically produces Class F fly ash. This fly ash is pozzolanic in nature, and contains less than 7% 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-mixed with water to react and produce cementitious compounds. Alternatively, adding a chemical activator such as sodium silicate (water glass) to a Class F ash can form a geopolymer **(Figure 1).**

(B) Class C fly ash

Fly ash produced from the burning of younger lignite or sub-bituminous coal, in addition to having pozzolanic properties, also has some self-cementing properties. In the presence of water, Class C fly ash hardens and gets stronger 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. Alkaliand sulfate (SO4) contents are generally higher in Class C fly ashes. **[18-19]**

Figure 1: Type of fly ash

3. 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.

4. Fly ash Utilization:

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

Fly ash is a very fine-particulate material that looks and feels like talcum powder and can be a tan to gray color, depending on its source. It is classified as a pozzolan and with its high silica content is used by concrete producers as a component in the range of 10 to 25% of the cementitious portion of concrete mixtures. Fly ash forms calcium silica hydrate (cementitious material) in addition to that produced by hydration of portland cement. Worldwide, concrete is used twice as much as all the other building products combined.

5. Why Use Fly Ash in Concrete?

First of all, the spherical shape of fly ash creates a *ball bearing* effect in the mix, improving workability without increasing water requirements. Fly ash also improves the pump-ability of concrete by making it more cohesive and less prone to segregation. The spherical shape improves the pump-ability by decreasing the friction between the concrete and the pump line. In addition, some fly ashes have been shown to significantly decrease heat generation as the concrete hardens and strengthens. The biggest reason to use fly ash in concrete is the increased life cycle expectancy and increase in durability associated with its use. During the hydration process, fly ash chemically reacts with the calcium hydroxide forming calcium silicate hydrate and calcium aluminate, which reduces the risk of leaching calcium hydroxide and concrete's permeability. Fly ash also improves the permeability of concrete by lowering the water-to-cement ratio, which reduces the volume of capillary pores remaining in the mass. The spherical shape of fly ash improves the consolidation of concrete, which also reduces permeability **[20, 21].** Other benefits of fly ash in concrete include resistance to corrosion of concrete reinforcement, attack from Alkali-silica reaction, sulfate attack and acids and salt attack. The use of fly ash has positive environmental impacts, as it conserves landfill space, reduces energy and water consumption, and helps reduce greenhouse gases.

6. How much fly ash in concrete?

Typically, concrete designers use fly ash as a partial replacement for portland cement at values up to 30 percent of the total cementitious composition. The use of high percentages (high volumes) of fly ash has been studied extensively over the last 15 years, and the benefits of this type of concrete have been well documented. When properly designed and constructed, the increased benefits of concrete made with 40, 50 and 60 percent fly ash replacement include dramatically reduced concrete permeability and excellent resistance to all forms of premature deterioration. The use of high volume fly ash concrete has gained increasing acceptance by structural engineers and architects from an environmental standpoint, as well as the life cycle cost approach. When designing and specifying concrete for strength and durability, the proper selection of constituent materials depends on the exposure conditions, type of structure and intended use. For applications such as footings, columns, walls and beams, where surface exposure is minimal, high volume fly ash concrete mixes may be used effectively. For mass concrete placements such as mat or raft foundations, the use of even higher quantities of fly ash is recommended.

7. How fly ash helps in concrete?

7.1 Reduced Heat of Hydration

In concrete mix, when water and cement come in contact, a chemical reaction initiates that produces binding material and consolidates the concrete mass. The process is exothermic and heat is released which increases the temperature of the mass. When fly ash is present in the concrete mass, it plays dual role for the strength development. Fly ash reacts with released lime and produces binder as explained above and renders additional strength to the concrete mass. The unreactive portion of fly ash act as micro aggregates and fills up the matrix to render packing effect and results in increased strength. The large temperature rise of concrete mass exerts temperature stresses and can lead micro crackes. When fly ash is used as part of cementitious material, quantum of heat liberated is low and staggers through pozzolanic reactions and thus reduces micro-cracking and improves soundness of concrete mass.

7.2 Workability of Concrete

Fly ash particles are generally spherical in shape and reduce the water requirement for a given slump. The spherical shape helps to reduce friction between aggregates and between concrete and pump line and thus increases workability and improve pumpability of concrete. Fly ash use in concrete increases fines volume and decreases water content and thus reduces bleeding of concrete.

7.3 Effect of fly ash on Carbonation of Concrete

Carbonation phenomenon in concrete occurs when calcium hydroxides (lime) of the hydrated Portland cement react with carbon dioxide from atmospheres in the presence of moisture and form calcium carbonate. To a small extent, calcium carbonate is also formed when calcium silicate and aluminates of the hydrated Portland cement react with carbon dioxide from atmosphere. Carbonation process in concrete results in two deleterious effects (i) shrinkage may occur (ii) concrete immediately adjacent to steel reinforcement may reduce its resistance to corrosion. The rate of carbonation depends on permeability of concrete, quantity of surplus lime and environmental conditions such as moisture and temperature. When fly ash is available in concrete; it reduces availability of surplus lime by way of pozzolanic reaction, reduces permeability and as a result improves resistance of concrete against carbonation phenomenon.

7.4 Sulphate Attack

Sulphate attacks in concrete occur due to reaction between sulphate from external origins or from atmosphere with surplus lime leads to formation of etrringite, which causes expansion and results in volume destabilization of the concrete. Increase in sulphate resistance of fly ash concrete is due to continuous reaction between fly ash and leached out lime, which continue to form additional C-S-H gel. This C-S-H gel fills in capillary pores in the cement paste, reducing permeability and ingress of sulphate ions.

7.5 Corrosion of steel

Corrosion of steel takes place mainly because of two types of attack. One is due to carbonation attack and other is due to chloride attack. In the carbonation attack, due to carbonation of free lime, alkaline environment in the concrete comes down which disturbs the passive iron oxide film on the reinforcement. When the concrete is permeable, the ingress of moisture and oxygen infuse to the surface of steel initiates the electrochemical process and as a result-rust is formed. The transformation of steel to rust increases its volume thus resulting in the concrete expansion, cracking and distress to the structure. The use of fly ash reduces availability of free limes and permeability thus results in corrosion prevention.

7.6 Reduced alkali- aggregate reaction

Certain types of aggregates react with available alkalis and cause expansion and damage to concrete. These aggregates are termed as reactive aggregates. It has been established that use of adequate quantity of fly ash in concrete reduces the amount of alkali aggregate reaction and reduces/ eliminates harmful expansion of concrete. The reaction between the siliceous glass in fly ash and the alkali hydroxide of Portland cement paste consumes alkalis thereby reduces their availability for expansive reaction with reactive silica aggregates.

8. How Fly Ash Contributes to Concrete Workability

First, fly ash produces more cementitious paste. It has a lower unit weight, which means that on a pound for pound basis, fly ash contributes roughly 30% more volume of cementitious material per pound versus cement. The greater the percentage of fly ash “ball bearings” in the past, the better lubricated the aggregates are and the better concrete flows.
Second, fly ash reduces the amount of water needed to produce a given slump. The spherical shapeof fly ash particles and its dispersive ability provide water-reducing characteristics similar to a waterreducing. Typically, water demand of a concrete mix with fly ash is reduced by 2% to 10%, depending on a number of factors including the amount used and class of fly ash.
Third, fly ash reduces the amount of sand needed in the mix to produce workability. Because fly ash creates more paste, and by its shape and dispersive action makes the paste more “slippery”, the amount of sand proportioned into the mix can be reduced. Since sand has a much greater surface area than larger aggregates and therefore requires more

9. Environmental benefits of fly ash use in concrete

Use of fly ash in concrete imparts several environmental benefits and thus it is ecofriendly. It saves the cement requirement for the same strength thus saving of raw materials such as limestone, coal etc required for manufacture of cement. Manufacture of cement is high-energy intensive industry. In the manufacturing of one tonne of cement, about 1 tonne of CO_2 is emitted and goes to atmosphere. Less requirement of cement means less emission of result in reduction in greenhouse gas emission. 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 acquire large CO_2 Salient advantage of using fly ash in cement concrete

- Reduction in heat of hydration and thus reduction of thermal cracks and improves soundness of concrete mass.
- Improved workability / pumpabilty of concrete
- Improved impermeability of concrete mass increases resistance against ingress of moisture and harmful gases result in increased durability.
- Reduced requirement of cement for same strength thus reduced cost of concrete.

10. Conclusions

In India, about 120 coals based thermal power plants are producing nearly about 112 million tons of coal fly ash per annum. Indian thermal power plants generate both class F and class C fly ash and are disposed in ash ponds. Fly ash is a potential source of pollution not only for the atmosphere but also for the other components of the environment. Its safe disposal is a great problem. At present Fly Ash is dumped in ponds. Use of Fly Ash in civil engineering construction and others have been taken up. Some new materials viz., fiber glass reinforced plastics and glass reinforced gypsum have also been discussed. Fly Ash has become an important material for various industrial and construction applications. Fly ash is now recognized as valuable substances which confer certain desirable characteristics in its many applications. Utilization of fly ash is already well established in various construction and waste solidification and stabilization processes. It can also be used in reinforced concrete construction since the alkaline nature will not corrode steel. Utilization of Fly Ash also creates significant benefits in terms of energy saving as well as environment.

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BIOGRAPHY

Publications

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National Journals: 5
National & International Conference Proceedings: 28

PhD (2013) in Chemistry, Assistant Professor of Chemistry, almost 14 Years of research and academic experiences , 20 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 bord member of many international and national journals.

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- Development of innovative methods for synthesis of green catalysts
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- 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