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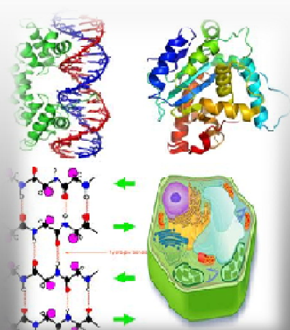

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REVIEW ARTICLE

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Sustainability of Fly Ash Execution for Future Perspectives

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ABSTRACT

One of the interest subjects, in the last time is to develop new applications of Fly ash, produced in escalating quantities by burning coal-fired power stations and other industrial sources. Current annual production of Fly ash, a by-product of coal based thermal power plant is 112million tones. Some of the dilemmas associated with the Fly ash are the large area of land required for disposal and toxicity linked with heavy metal leached to groundwater. Fly ash is an environmental hazard that cause air, water and soil pollution, disrupt ecological cycles. This preview represent different ways of using Fly ash as a potential raw material for the manufacture of Fly ash bricks, mosaic titles, as a adsorbent for uptake of organic compounds from waste effluents. Environmental and occupational health vulnerability associated with Fly ash is also delineated precisely.

Keywords: Geopolymers; Bricks; Fill material; Portland cement; Paving roads; Mosaic titles; Flowable fill; Asphalt concrete Mycorrhizal fungi; Pulverised coal; Pozzolanic properties; Exposure concerns

INTRODUCTION

Fly ash closely resembles volcanic ashes used in production of the earliest known hydraulic cements about 2,300 years ago. Those cements were made near the small Italian town of Pozzuoli - which later gave its name to the term "pozzolan." A pozzolan is a siliceous or siliceous / aluminous material that, 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. 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. Fly ash closely resembles volcanic ashes used in production of the earliest known hydraulic cements about 2,300 years ago. Those cements were made near the small Italian town of Pozzuoli - which later gave its name to the term "pozzolan." A pozzolan is a siliceous or siliceous / aluminous material that, 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. Instead of volcanoes, today's fly ash comes primarily from coal-fired electricity generating power plants. These power plants grind coal to a 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 (Fig. 1).

Fig. 1 Fly Ash from Thermal Power Plant

Fly ash is an environmental peril, which has somehow escaped the attention of the environmentalists. Fly ash utilization in the country is gaining momentum owing to the stringent regulations that the Ministry of Environment and Forests (MoEF) has stipulated, as also to increase awareness about the benefits of using Fly ash for various products. India has about 70 thermal power plants and 70 per cent of them burn coal to generate power. Scattered Electron Micrograph of coal fly ash is shown in figure 2.

Various Indian collieries supply the coal, which is known to have a very high ash content of almost 40-45 per cent. India's thermal power plants produce an estimated 100 million tonnes of Fly ash per annum.

India utilise only 3-4 per cent of the fly ash generated as compared to more than 40 per cent utilization in Europe, China and US. The government has indicated a clear willingness to achieve 50 per cent fly ash utilization by the turn of the century at its enlarged level of 90 million tonnes per annum. A variety of experiences are now available to us on the scenario at different levels of Fly ash utilization. The World Bank has cautioned India that by 2015, disposal of coal ash would require 1000 Km^2 or $1M^2$ of land per person. Since coal currently accounts for 70 per cent of power production in the country, the bank has highlighted the need for new and innovative methods for reducing impacts on the environment.

Fly ash, also known as flue-ash, is one of the residues generated in combustion, and comprises the fine particles that rise with the flue gases. Fly ash which does not rise is termed bottom ash. In an industrial context, fly ash usually refers to ash produced during combustion of coal. Fly ash is generally captured by electrostatic precipitators or other particle filtration equipment before the flue gases reach the chimneys of coal-fired power plants, and together with bottom ash removed from the bottom of the furnace is in this case jointly known as coal ash. Depending upon the source and makeup of the coal being burned, the components of fly ash vary considerably, but all fly ash includes substantial amounts of silicon dioxide (SiO_2) [both amorphous & crystalline] and calcium oxide (CaO), both being endemic ingredients in many coal-bearing rock strata.

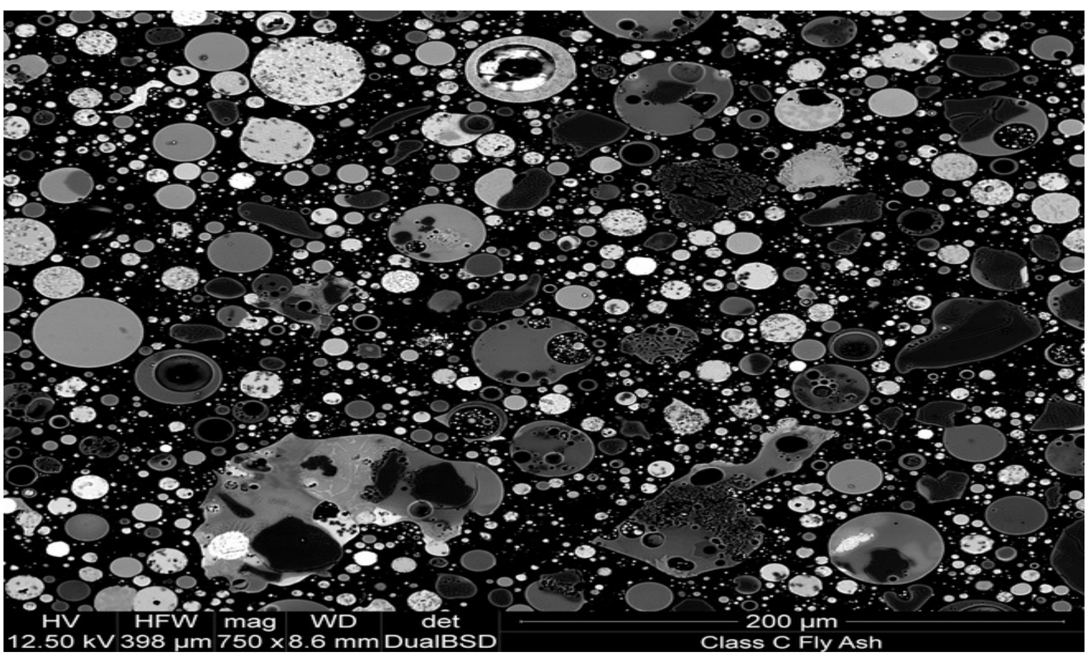

Fig. 2 Scattered Electron Micrograph of Coal Fly Ash

In the past, fly ash was generally released into the atmosphere, but pollution control equipment mandated in recent decades now requires that it be captured prior to release. Fly ash is generally stored at coal power plants or placed in landfills. About 43% is recycled, often used to supplement Portland cement in concrete production. Some have expressed health concerns about this. In some cases, such as the burning of solid waste to create electricity ("resource recovery" facilities a.k.a. waste-to-energy facilities), the fly ash may contain higher levels of contaminants than the bottom ash and mixing the fly and bottom ash together brings the proportional levels of contaminants within the range to qualify as nonhazardous waste in a given state, whereas, unmixed, the fly ash would be within the range to qualify as hazardous waste.

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 only few minerals will have time to crystallize and that mainly amorphous, quenched glass remains. Nevertheless, some refractory phases in the pulverized coal will not melt (entirely) and remain crystalline. In consequence, 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, magnetite and/or maghemite. Other phases often identified are cristobalite, anhydrite, free lime, periclase, calcite, sylvite, halite, portlandite, rutile and anatase. The Ca-bearing minerals anorthite, gehlenite, akermanite and various calcium silicates and calcium aluminates identical to those found in Portland cement can be identified in Ca-rich fly ash. The above concentrations of trace elements vary according to the kind of coal combusted to form it. In fact, in the case of bituminous coal, with the notable exception of boron, trace element concentrations are generally similar to trace element concentrations in unpolluted soils.

CHEMICAL COMPOSITION AND CLASSIFICATION

Component (%)	**Bituminous**	**Subbituminious**	**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

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, magnetite and/or maghemite. Other phases often identified are cristobalite, anhydrite, free lime, periclase, calcite, sylvite, halite, portlandite, rutile and anatase. The Ca-bearing minerals anorthite, gehlenite, akermanite and various calcium silicates and calcium aluminates identical to those found in Portland cement can be identified in Ca-rich fly ashes.

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EXPOSURE CONCERNS

Crystalline silica and lime along with toxic chemicals are among the exposure concerns. Although industry has claimed that fly ash is "neither toxic nor poisonous," this is disputed. Exposure to fly ash through skin contact, inhalation of fine particle dust and drinking water may well present health risks. The National Academy of Sciences noted in 2007 that "the presence of high contaminant levels in many CCR (coal combustion residue) leachates may create human health and ecological concerns". Fine crystalline silica present in fly ash has been linked with lung damage, in particular silicosis. OSHA allows 0.10 mg/m^3, (one ten-thousandth of a gram per cubic meter of air).Another fly ash component of some concern is lime (CaO). This chemical reacts with water (H_2O) to form calcium hydroxide [$Ca(OH)_2$], giving fly ash a pH somewhere between 10 and 12, a medium to strong base. This can also cause lung damage if present in sufficient quantities. Fly ash contains trace concentrations of heavy metals and other substances that are known to be detrimental to health in sufficient quantities. Toxic constituents depend upon the specific coal bed makeup, but may include one or more of the following elements or substances in quantities from trace amounts to several per cent: arsenic (AS), beryllium (Be), boron (B), hexavalent chromium Cr[(VI)] , cobalt (Co), lead (Pb), manganese (Mn), mercury (Hg), molybdenum (Mb), selenium (Se), strontium (Sr), thallium (Tl), and vanadium (V), along with dioxins and PAH compounds.

FLY ASH: RISKS & CONSTERNATION

The high temperature of burning of coal turns the clay minerals present in the coal powder into fused fine particles mainly comprising aluminium silicates. When pulverised coal is burnt to generate heat, the residue contains 80 per cent fly ash and 20 per cent bottom ash. The fly ash is carried away by flue gas collected at economiser, air pre-heater and hoppers. Clinker type ash collected in the water-impounded hopper below the boilers is called bottom ash. Fly ash, which consists of silica, alumina and oxides of iron, calcium and magnesium, is the waste generated by thermal power plants. Fly ash produced thus possesses both ceramic and pozzolanic properties. It is the most undesirable part of coal, which causes erosion, corrosion and creates environmental pollution. Fly ash is a serious source of pollution in the air since it can be air borne for a very long period. Fly ash is a very fine powder and tends to travel far in the air. When not properly disposed, it is known to pollute air and water, and causes solemn health hazards in the form of throat and respiratory troubles and a burning sensation in the eyes. It reduces the longevity of human life. When it settles on leaves and crops in field around the power plant, it lowers the yield.

DISPOSAL CRISIS

Primarily, the Fly ash is disposed of using either dry or wet disposal scheme. In dry disposal, the Fly ash is transported by truck, chute or conveyor at the site and disposed of by constructing a dry embankment (dyke). The conventional method used to dispose of both fly ash and bottom ash is to convert them into slurry for impounding in ash ponds around the thermal plants. In wet disposal, the fly ash is transported as slurry through pipe and disposed of in impoundments called “ash pond”. Most of the power plant in India use wet disposal system, and when the lagoons are full, four basic options are available:

- Constructing new lagoons using conventional construction material
- Hauling of ash from the exciting lagoons to another disposal site
- Raising the existing dyke using conventional constructional material
- Raising the dyke using fly ash excavated from the lagoon (ash dyke)

This method entails long-term problems. The severe problems that arise from such dumping site are:

- The construction of ash ponds requires vast tracts of land. This depletes land available for agriculture over a period of time.
- When one ash pond fills up, another has to be built, at great cost and further loss of agricultural land
- Huge quantities of water are required to convert ash in slurry
- It contributes a great degree in reducing the fertility of land and contaminating the surface and sub-surface water
- It silts up the natural draining system by flowing in wet form, and also reduces the pH balance and portability of water

  During rains, numerous salts and metallic content in the slurry can leach down to the groundwater and contaminate it. To keep this haze at bay, thermal poor plants in India spend crores of rupees annually to maintain the dumping sites.

UTILIZATION - A VIABLE ALTERNATIVE TO DUMPING

Coal-based thermal power stations have been operational for more than 50 years but the concept of developing environment friendly solutions for fly ash utilization is only about 15 years old. Among numerous factors that account for the low level of utilization, the chief factors are:

- Poor understanding of the chemistry of fly ash and its derivatives for proper end applications
- Absence of standards and specifications for Fly ash products
- Lack of reliable quantity assurance for Fly ash products
- Poor public awareness about the products and their performance
- Non-availability of dry Fly ash collection facilities
- Easy availability of land with top soil at cheap rates for manufacturing conventional bricks
- Lack of proper coordination between thermal plants and ash users

Fly ash from coal-fired thermal power stations is an excellent potential raw material for the manufacture of construction materials like blended cement.

Fly ash bricks, mosaic titles and hollow blocks/ it also has other, high volume applications and can used for paving roads, building , and mine fills. Fly ash products have several advantages over conventional products. The use of cement in the manufacture of construction products can be reduced by substitution with fly ash. While the use of cement cannot be completely avoided, for certain products like tiles, the substitution can go up to 50 per cent. These products are known to be stronger and more cost-effective because of substantial savings on raw material. Fly ash products are also environment friendly. A case in point is fly ash bricks. The manufacture of conventional clay bricks involves the consumption of large amount of clay. This depletes top soil and degradation of agricultural land. Fly ash bricks don't require clay and serve two purposes; preservation of top soil and constructive utilization of fly ash.

Soil stabilization is the permanent physical and chemical alteration of soils to enhance their physical properties. Stabilization can increase the shear strength of a soil and/or control the shrink-swell properties of a soil, thus improving the load-bearing capacity of a sub-grade to support pavements and foundations. Stabilization can be used to treat a wide range of sub-grade materials from expansive clays to granular materials. Stabilization can be achieved with a variety of chemical additives including lime, fly ash, and Portland cement, as well as by-products such as lime-kiln dust (LKD) and cement-kiln dust (CKD). Proper design and testing is an important component of any stabilization project. This allows for the establishment of design criteria as well as the determination of the proper chemical additive and admixture rate to be used to achieve the desired engineering properties. Benefits of the stabilization process can include: Higher resistance (R) values, Reduction in plasticity, Lower permeability, Reduction of pavement thickness, Elimination of excavation - material hauling/handling - and base importation, Aids compaction, Provides "all-weather" access onto and within projects sites. Another form of soil treatment closely related to soil stabilization is soil modification, sometimes referred to as "mud drying" or soil conditioning. Although some stabilization inherently occurs in soil modification, the distinction is that soil modification is merely a means to reduce the moisture content of a soil to expedite construction, whereas stabilization can substantially increase the shear strength of a material such that it can be incorporated into the project's structural design. The determining factors associated with soil modification *vs* soil stabilization may be the existing moisture content, the end use of the soil structure and ultimately the cost benefit provided. Equipment for the stabilization and modification processes include: chemical additive spreaders, soil mixers (reclaimers), portable pneumatic storage containers, water trucks, deep lift compactors, motor graders.

FLOWABLE FILL

Fly ash is also used as a component in the production of flowable fill [also called controlled low strength material (CLSM)], which is used as self-leveling, self-compacting backfill material in lieu of compacted earth or granular fill. The strength of flowable fill mixes can range from 50 to 1,200 lbf/in^2 (0.3 to 8.3 MPa), depending on the design requirements of the project in question. Flowable fill includes mixtures of Portland cement and filler material, and can contain mineral admixtures.

Fly ash can replace either the Portland cement or fine aggregate (in most cases, river sand) as a filler material. High fly ash content mixes contain nearly all fly ash, with a small percentage of Portland cement and enough water to make the mix flowable. Low fly ash content mixes contain a high percentage of filler material, and a low percentage of fly ash, Portland cement, and water. Class F fly ash is best suited for high fly ash content mixes, whereas Class C fly ash is almost always used in low fly ash content mixes.

GEOPOLYMERS

More recently, fly ash has been used as a component in geopolymers, where the reactivity of the fly ash glasses is used to generate a binder comparable to a hydrated Portland cement in appearance and properties, but with possibly reduced CO_2 emissions. It should be noted that when the total carbon footprint of the alkali required forming geopolymer cement is considered, including the calcining of limestone as an intermediate to the formation of alkali, the net reduction in total CO_2 emissions may be negligible. Moreover, handling of alkali can be problematic and setting of some geopolymer cements is very rapid (minutes versus hours) as compared to Portland cements, making widespread use of geopolymer cements impractical at the ready mix level (Fig. 3a & 3b).

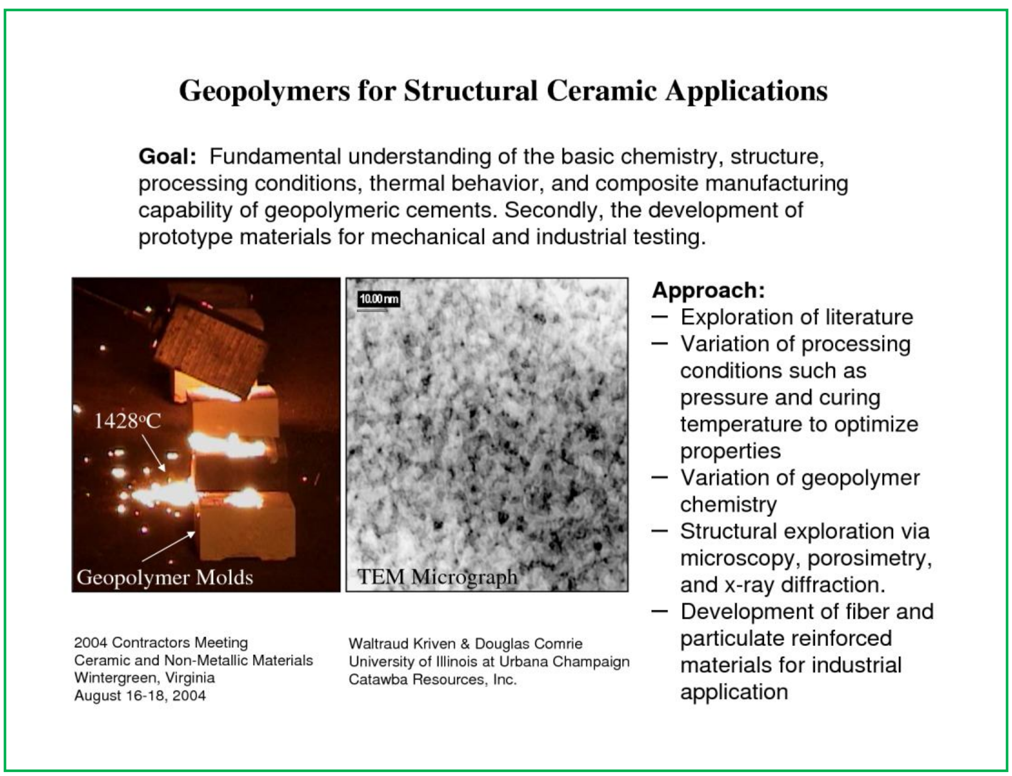

Fig. 3a & 3 b Geopolymer Cement

Fig. 4a Designs of Various Types of Fly Ash Bars

FLY ASH BRICKS AND BARS

There are several techniques for manufacturing construction bricks and bars from fly ash, producing a wide variety of products. One type of fly ash brick is manufactured by mixing fly ash with an equal amount of clay, then firing in a kiln at about 1000°C. This approach has the principal benefit of reducing the amount of clay required. Another type of fly ash brick is made by mixing soil, plaster of Paris, fly ash and water, and allowing the mixture to dry. Because no heat is required, this technique reduces air pollution. More modern manufacturing processes use a greater proportion of fly ash, and a high pressure manufacturing technique, which produces high strength bricks with environmental benefits (Fig. 4a & 4b).

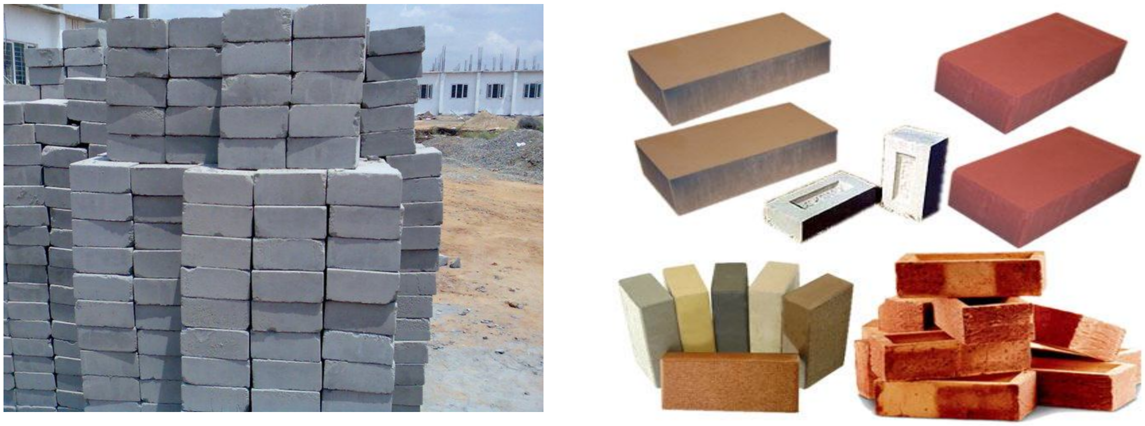

Fig. 4b Fly Ash Bricks

Fig. 5a. Fly Ash in Portland Cement

AGRICULTURAL UTILITY OF FLY ASH

A bio-technological intervention from The Energy Research Institute (TERI) has been provided by introducing a mycorrhizal fungi-based organo-bio-fertilizer.

Mycorrhizal fungi renewed the biological activity in the Fly ash-infected wastelands at the demonstration site of BTPS. Merigolds, tuber rose, gladiolus, carnations and sunflowers, and a variety of trees like popler, sheesham, and eucalyptus now are grown successfully. The successfully growth of economically viable plants was made possible only by introducing mycorrhizae to the plants. As the fungus germinates, drawing sustenance from partner plant, it quickly spreads to the roots and beyond. It improves the plant's water and nutrient uptake, helps in the development of roots and soil-binding, stores carbohydrates and oils for the use when needed, protects the plants from soil-borne diseases, and detoxify contaminated soils.

FLY ASH IN PORTLAND CEMENT CONCRETE

Fly ash can be used in Portland cement concrete to enhance the performances of the concrete (Fig. 5). Portland cement is manufactured with calcium oxide (CaO), some of which is released in a free state during hydration. As much as 20 pounds of free lime is released during hydration of 100 pounds of cement. This librated lime forms the necessary ingredient for reaction with fly ash silicates to form strong and durable cementing compounds, thus improves many of the properties of the concrete. Some of the resulting benefits are:

- ✓ Higher ultimate strength
- ✓ Increased durability
- ✓ Improved workability
- ✓ Reducing bleeding
- ✓ Increase resistance to sulphate attack
- ✓ Increase resistance to alkali-silica reactivity
- ✓ Reduced shrinkage

Fly ash utilization, especially in concrete, has significant benefits including:

(a) Increasing the life of concrete roads and structures by improving concrete durability.

(b) Net reduction in energy use and greenhouse gas (GHG) and other adverse air emissions when fly ash is used to replace or displace manufactured cement.

(c) Reduction in amount of coal combustion products that must be disposed in landfills.

(d) Conservation of other natural resources and materials

Typically, 15 to 30 per cent of the Portland cement is replaced with fly ash.

Fig. 5b. Machinery of Mixing Fly Ash with Portland Cement Concrete

MANUFACTURING PROCESS OF A TYPICAL FLY ASH PRODUCT
Mosaic tile manufacture involves preparing the mix for two layers: the wearing layer and the base layer. The wearing layer consists of a plastic mix of mosaic chips, cement, and fly ash and dolomite powder. The base layer consists of a semi-dry mix of fly ash, cement, and quarry dust. The tiles are pressed in the tile-making machine and air-dried for 12 hours or more.

ADSORPPTION OF WATER POLLUTANTS
The chemical characteristic of fly ash depends strongly on the geological origin of the coal, method and condition of combustion. Adsorption, which is a surface phenomenon, that depends on the higher specific surface area, narrow particle size distribution and the porosity of an adsorbent were investigated for fly ash. It was observed that the larger the specific surface area, the higher the carbon content and the finer the particle size of the fly ash the greater its adsorption capacity will be. It has been confirmed that the utilization of fly ash would solve both disposal problem and a cheaper material for adsorption of water pollutants. The knowledge of fly ash mineralogy, the degree of the unburned carbon in fly ash and the quality need in the market-place are supreme in creating an opportunities for research into the modification and exploitation of the unique chemistry of fly ash. Therefore, the study on the importance of beneficiation of fly ash had lead to comprehensive information regarding the feasibility of fly ash for adsorption process.

FLY ASH DRAWBACKS
Fly ash has been gaining acceptance by several institutions, however, smaller builders and housing contractors are not that familiar with fly ash products. Fly ash could have different properties depending on where it was obtained or how it was obtained. For this reason, fly ash applications are encountering resistance on traditional builders due to tendency to effloresce and major concerns about freeze/thaw performance.

Other major concerns about using fly ash concrete are:

- Slower strength gain
- Seasonal Limitation, and
- Increase in air entraining admixtures.
- Higher fly ash contents can produce an increase of salt scaling.

CONCLUSION
Fly ash is an environmental hazard, which has somehow escaped the attention of the environmentalists. Fly ash from coal-fired thermal power stations is an excellent potential raw material for the manufacture of construction materials like blended cement, fly ash bricks, mosaic titles and hollow blocks. It also has other, high volume applications and can be used for paving roads, building, and mine fills. Fly ash products have several advantages over conventional products. The use of cement in the manufacture of construction products can be reduced by substitution with fly ash.

While the use of cement cannot be completely avoided, for certain products like tiles, the substitution can go up to 50 per cent. These products are known to be stronger and more cost-effective because of substantial savings on raw material. A bio-technological intervention from TERI has been provided by introducing a mycorrhizal fungi-based organo-bio-fertilizer. Fills can be constructed as structural fills where the city fly ash is placed in thin lifts and compacted. Fly ash can be used in Portland cement concrete to enhance the performances of the concrete. Fly ash can be used for construction of road and embankment. It was observed that the larger the specific surface area, the higher the carbon content and the finer the particle size of the fly ash the greater its adsorption capacity will be. It has been confirmed that the utilization of fly ash would solve both disposal problem and a cheaper material for adsorption of water pollutants.

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