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Review Article

A Statistical Review on the Current Scenario of Generation and Utilization of Fly-Ash in India

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Abstract

In this paper we focused upon the nature of Indian fly-ash and its various utilizations. In the past decade, there has been tremendous increase in the generation of fly-ash since more than 70% of country's demand for electricity is met by coal-based thermal power plants. At present scenario, around 160 million-tons of fly-ash is produced which is nearly twice over the last decade. The disposal of such huge quantity of ash is a serious issue. With detailed knowledge, it could be gainfully exploited in different sectors, thereby conserving soil and other resources by acting as their substitute material. Many governmental agencies have been made responsible for the comprehensive exploration of associated hazards and potential applications of fly-ash for its better and increased consumption. Fly-ash is used in numerous sectors with majority application in construction and related activities. Various mitigation measures have been discussed in this paper viz. brick making, roads & embankments construction, cement manufacturing and agricultural uses.

Keywords: *coal, fly-ash, thermal power plants, generation, utilization, fly-ash bricks*

1. Introduction

Fly-ash is micron-sized glass powder, produced due to the combustion of powdered coal in thermal power plants. These micron-sized particles consist mainly of silica, alumina and iron oxide. Fly-ash is defined in Cement and Concrete terminology (ACI committee 116) as the 'finely divided residue resulting from the combustion of ground or powdered coal, which is transported from the fire box through the boiler by flue gases'.

The thermal power plants in India consume more than 300 million-tons of coal and generate nearly 100,000 MW power. This produces fly-ash around 163.56 million-tons out of which only 61.37% is being utilized for construction of roads and embankments, production of cement, mine-filling, reclamation of low-lying areas, agriculture, making bricks and tiles and others (CEA Annual Reports, 2012-13). The remaining ash causes many environmental problems such as land degradation and degradation of quality of air and water. Also, the problem of storing the fly-ash creates considerable demand for land, which may even contaminate surrounding water body or agricultural land due to overflow from fly-ash ponds during heavy precipitation. Thus, realizing the problems caused due to the unused fly-ash, Government of India established Fly-ash Mission (FAM), Technology Information, Forecasting & Assessment Council (TIFAC), Department of Science and Technology (DST) and other stake holder agencies for gainful utilization and proper disposal of fly-ash.

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Some of the fly-ash contains deadliest toxic metals like arsenic, mercury, cadmium, chromium and selenium. These toxic metals along with other toxicants can cause cancer and neurological damages in humans. They can also harm and kill wildlife, especially fish and other water-dwelling species. However, Indian fly-ashes are found to be very low on radioactivity and heavy metal counts on the basis of tests conducted by Bhabha Atomic Research Center (BARC) and Institute of Physics, Bhubaneshwar, Department of Atomic Energy, Govt. of India (Vimal Kumar *et al*, 2005) .All investigations certify that radioactivity in Indian fly-ashes is almost in the same range as radioactivity in other building materials available in India.

2. Characteristics of fly-ash

2.1 Physical Characteristics

Generally, fly-ash particles are spherical in shape and its size ranges from 0.5 to 100 µm. It contains large carbonaceous and porous particles which cause high surface area and light texture of the fly-ash. On adding it to the soil, it changes the bulk density, texture, water-holding capacity, hydraulic conductivity and particle size distribution of the soil (Chang *et al, 1977*), (Sharma *et al, 2002*). The color of fly-ash may vary from tan to gray to black, depending upon the amount of unburned carbon in the ash. The lighter the color of fly-ash, more are the chances of the lower carbon content (Carlson and Adriano, 1993).

Table 1 Physical properties of Indian fly-ash

(Source: Effects of pulverized coal fly-ash addition as a wet-end filler in paper making, Akhouri Sanjay Kumar Sinha)

Fly-ash Properties	Average Values
Mean particle size, µm	30
Bulk density, Kg/m^3	0.897
Brightness, % ISO	28.5
pH	8.5
Specific surface area, m^2/g	1.45
Refractive index	1.7
Color	grey-brown

2.2 Chemical Characteristics

Major elements in fly-ash are Si, Al, Fe, Ca, C, Mg, K, Na, S, Ti, P and Mn (Page *et al*, 1979). All these elements exist in their oxidized state. Table 2 shows the normal ranges of chemical composition of Indian fly-ash.

Table 2 Normal range of chemical composition of Indian fly-ash produced from different coal types (expressed as percent by weight). *(Source: www.coalnic.in)*

S. No.	Component	Bituminous	Sub-bituminous	Lignite
1.	SiO_2	20-60	40-60	15-45
2.	Al_2O_3	5-35	20-30	10-25
3.	Fe_2O_3	10-40	4-10	4-15
4.	CaO	1-12	5-30	15-40
5.	MgO	0-5	1-6	3-10
6.	SO_3	0-4	0-2	0-10
7.	Na_2O	0-4	0-2	0-6
8.	K_2O	0-3	0-4	0-4
9.	LOI	0-15	0-3	0-5

A considerable amount of macro- as well as micro-nutrients are present in fly-ash for plants. Several other minerals such as quartz, mullite, hematite, magnetite, calcite and borax were also found in fly-ash and their quantity is reduced upon oxidation of carbon and nitrogen during combustion.

3. Utilization of fly-ash

The generation of fly-ash from thermal power plants in India has increased from 68.88 million-tons in 1996-97 to 163.56 million-tons in 2012-13 of which only 100.37 million-tons are utilized. India achieved a tremendous increase in its utilization from 9.63% in 1996-97 to 61.37% in 2012-13 (CEA Annual Reports, 2012-13). Nearly 40% of fly-ash is still unused which is a serious issue. Government of India launched several programs and established many agencies regarding better understanding of fly-ash for its greater usage in different sectors. Fig.1 shows generation and utilization of fly-ash for the period from 1996-97 to 2012-13.

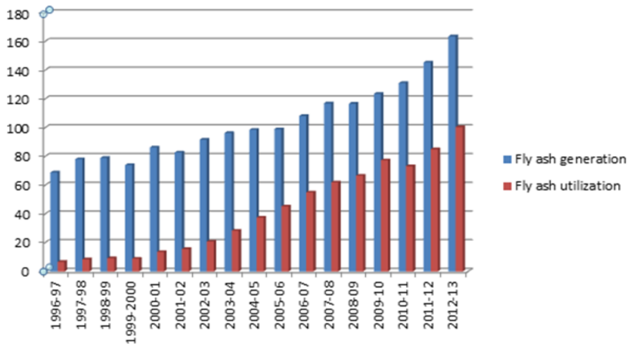

Fig.1 A graph showing fly-ash generation and its utilization (*in million-tons*) for the period from 1996-97 to 201-13.*(Source: Central Electricity Authority, Annual Report on fly-ash generation and utilization 2011-12 and 2012-13)*

Table 3 Fly-ash utilization in India during the year 2011-12 and 2012-2013 *(Source: Central Electricity Authority Annual Report on fly-ash generation and utilization 2011-12 and 2012-13)*

S.No	Mode of utilization	Quantity of Fly-ash used in the mode of utilization			
		2011-12		2012-13	
		Million-ton	Percentage	Million-ton	Percentage
1	Cement	38.08	44.74	41.33	41.18
2	Reclamation of low-lying areas	14.21	16.71	11.83	11.78
3	Roads and Embankments	5.54	6.51	6.02	6.00
4	Concrete	0.63	0.74	1.03	1.03
5	Ash Dyke Raising	5.86	6.89	10.93	10.89
6	Mine filling	7.74	9.10	10.34	10.30
7	Bricks and Tiles	5.83	6.86	9.98	9.94
8	Agriculture	0.88	1.03	2.50	2.49
9	Others	6.28	7.38	6.41	6.39
Total		85.05	100	100.37	100

Fig.2 Graphs showing the percentage of utilization of fly-ash in different sectors for the years 2011-12 and 2012-13.

3.1 Fly-ash in cement industry

In India, the maximum consumption of fly-ash is in cement manufacturing industries. About 41% of generated fly-ash is used as a replacement for some of the Portland cement content of concrete. Only class F fly-ash is used as a partial replacement since it is pozzolanic in nature and contains less than 20% lime.

In the presence of moisture, fly-ash reacts chemically with calcium hydroxide and CO_2 present in the atmosphere and produces a binder that strengthens the concrete mass. When fly-ash is used as a cementitious material, the temperature rise and heat liberated becomes low, thus reducing thermal stresses which minimizes micro-cracking. Also, fly-ash improves workability of concrete, increases resistance to alkali-silica reactivity and sulfate attack.

The fly-ash utilization in cement industry has increased from 2.45 million-tons in 1998-99 to 41.33 million-tons in 2012-13, constituting 41.18% of total use. The details regarding fly-ash production and its utilization in cement industry for the period 1998-99 to 2012-13 has been shown in figure 3.

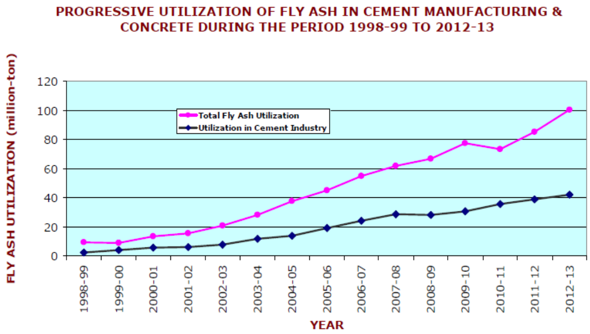

Fig.3 Progressive utilization of fly-ash in cement manufacturing and concrete during the period 1998-99 to 2012-13 *(Source: Central Electricity Authority, annual report, 2012-13).*

It is expected to absorb more than 50% of fly-ash in Indian cement industries since the country's cement production will grow at a compound annual growth rate (CAGR) of around 12 percent during 2011-12 - 2013-14 to reach 303 MMT, (according to a report titled 'Indian Cement Industry Forecast to 2012', by research firm RNCOS). Figure 4 shows the expected fly-ash absorption in cement industry for the coming decades.

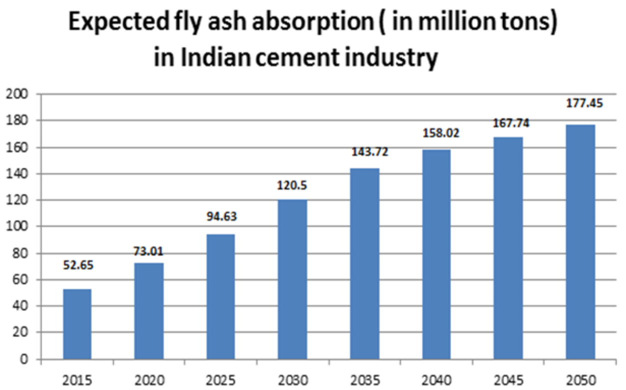

Fig.4 Expected Fly-ash absorption in cement (million tons per annum) *(Data Source: WBCSD/CSI/LOW Carbon technology road map for Indian cement industry)*

3.2 Fly-ash in building materials like bricks, blocks and tiles

Fly-ash is being used in manufacturing of building products like bricks, blocks, tiles etc which results in saving of fertile top soil. These bricks are uniform in shape and size, therefore, require less mortar. They have low water absorption (6-12%) and high compressive strength that can be engineered by varying compositions of fly-ash, additives and filler materials.
They are less porous and have a thermal conductivity of 0.90-1.05 W/m^{2o}C.

Brick making has substantial potential of fly-ash utilization especially for thermal power stations located near load centers (CEA Annual Reports, 2012-13). Bureau of Indian Standards have issued code IS: 12894-2002 for ash bricks (NTPC). Unglazed tiles for use on footpaths can also be made from it. Awareness among the people is required and the Government has to provide special incentives for this purpose (Ahmad *et al*, 2014).

Fig.5 Fly-ash bricks

The Central Fuel Research Institute, Dhanbad has developed a technology for the utilization of fly-ash for the manufacture of building bricks. Fly-ash bricks are also being used in NTPC's power plant construction works at Rihand, Unchahar and Dadri (Uttar Pradesh), Talcher-Kaniha in Odisha and Ramagundam (Andhra Pradesh). NTPC has manufactured more than 54 crores ash bricks in its various thermal power stations and utilized in construction activities (NTPC). In the year 1998-99, 0.70 million-tons of total fly-ash generated in India was used for making of fly-ash based bricks/blocks/tiles etc which increased to 9.98 million-tons in the year 2012-13 (CEA Annual Report, 2012-13).

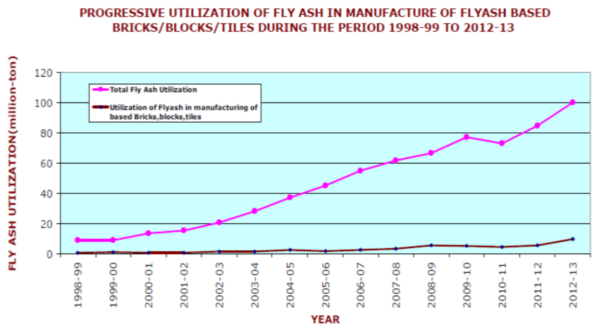

Fig.6 Progressive utilization of fly-ash in manufacture of bricks/tiles/blocks during the period 1998-99 to 2012-13 *(Source: Central Electricity Authority, annual report, 2012-13)*

A progressive utilization of fly-ash in making of fly-ash based building products for the period from 1998-99 to 2012-13 is given in Figure-6.

3.3 Fly-ash in the construction of roads, embankments, pavements, flyovers etc

Fly-ash can be used for the construction of roads and embankments. It is used for stabilizing roads due to its high content of calcium and silicate oxides which gives pozzolanic properties and thus high compression strength (Lahtinen, 2001), (Mulder, 1996). It saves top soil which otherwise is conventionally used and also avoids creation of low-lying areas (by excavation of soil to be used for construction of embankment). Other properties of fly-ash like high shear strength, high permeability, grain size distribution, ease of compaction and faster rate of consolidation makes it suitable to be used as a constituent material in making roads and pavements. The permeability of a fly-ash fill material is the most important property that affects the embankment construction and its performance quality. The permeability of well compacted fly-ash has been found to range from 10^{-4} to 10^{-6} cm/sec (Di Gioia *et al*, 1979). Some of the other engineering properties when fly-ash is used as fill material are its moisture-density relationship, particle size distribution and shear strength, are also significant. Fly-ash has proved to be versatile material with many possible applications in highway embankment filling.

In the recent past, the projects at New Delhi, Dadri (U.P.) and Raichur (Karnataka) have been successfully completed for use of fly-ash in road / flyover embankments. Some of the other fly-ash based projects are:

- Construction of plant roads at Budge-Budge thermal power plant using fly-ash based pavement (Collaboration with CESC Ltd, Kolkata)
- Construction of one km long rural road near Raichur in Karnataka with fly-ash based flexible/semi-rigid pavement composition (Collaboration with Karnataka PWD and Raichur thermal power station – executed as Fly-ash Mission demonstration project)
- Construction of 1.9 km long, 6 to 9 m high road embankment forming eastern approach of the second Nizamuddin Bridge in Delhi using fly-ash (Collaboration with Delhi PWD and Indraprastha thermal power station, Delhi)
- Construction of plant road and two rural roads using fly-ash (collaboration with National Capital Power Station, NTPC, Dadri, U.P)

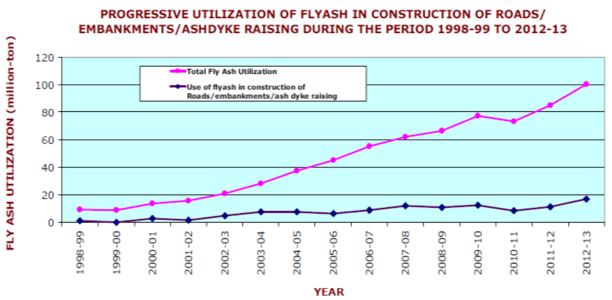

Fig.7 A graph showing progressive utilization of fly-ash in construction of fly-ash based roads, embankments, ashdyke raising for the period from 1998-99 to 2012-13. *(Source: Central Electricity Authority, annual report, 2012-13)*

In the year 1998-99, 1.055 million-tons of total fly-ash generated in India was used for the construction of roads/embankments/flyovers and raising of ash dykes which increased to 6.02 million-tons in the year 2012-13 (CEA Annual Report, 2012-13).

3.4 Fly-ash in agriculture

Fly-ash is being used as manure in agricultural sector as it has many micronutrients. It acts as a soil modifier by enhancing moisture retaining capacity and fertility of the soil. The concentration of Al, Si, Ca, Fe, Mg, Na, K, S and P are higher in fly-ash than in soil. Therefore, fly-ash as an amendment for agricultural soils can improve the physical and chemical properties of the deficient soil, thereby increasing soil fertility and crop yield. It improves the plant's water and nutrient uptake, helps in the development of roots and soil binding, stores carbohydrates and oils for use when needed, protects the plant from soil-borne diseases and detoxifies contaminated soils. It also provides micro nutrients like Fe, Zn, Cu, Mo, Bi, Mn etc and macro nutrients like K, P, Ca, Mg, S etc. Crops grown on fly-ash amended soil are safe for human consumption and groundwater quality is also not affected (Ahmad *et al*, 2014).

Fly-ash addition generally decreases the bulk density of the soil, which in turn improves soil porosity and enhances water retaining capacity. The soluble Ca of the fly-ash provides protective action to stabilize the physical environment of the soil. On adding fly-ash to the soil (8% by weight) increases pH (5.4-9.9) of the calcareous soil (Page *et al*, 1979). The pH of the soil was significantly influenced with ash application and there was a marked reduction in the pH with increase in percentage of fly-ash and the values being minimum under 30% fly-ash application and maximum under the control (Singh *et al*, 1986).

Table 4 Effect of fly-ash on yield of crops (S*ource: Fly-ash India 2005, New Delhi*)

Crop	Percentage Increase
Groundnut	40.2
Sunflower	25
Safflower	15.2
Maize	12
Paddy	10.5-18

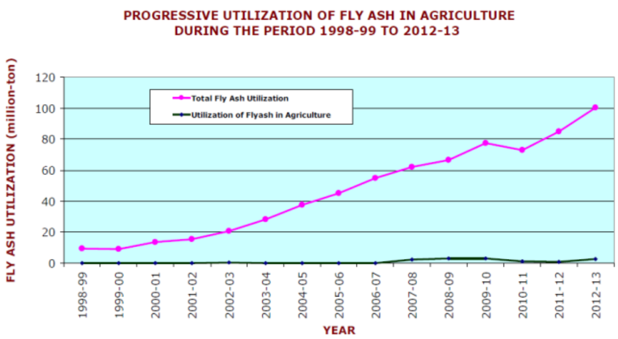

Fig.8 A graph showing progressive utilization of fly-ash in agriculture for the period from 1998-99 to 2012-13. *(Source: Central Electricity Authority, annual report, 2012-13)*

It may be seen from Figure-8 that 0.126 million ton of fly-ash was used in agricultural sector during 1998-99 which increased to 0.88 million ton in 2011-12 and constituted about 1.03% of total fly-ash utilization in the aforesaid year. In 2012-13, it was 2.50 million ton and constituted 2.49% of total fly-ash utilization in the aforesaid year

3.5 Fly-ash for paper-making

Fly-ash can also be used as a component in paper making. Fillers which are finest particles of fly-ash having average particle size of 19 micrometers mixed with kaolin clay are used in papermaking. These fillers are inert material and they adversely affect most of the mechanical strength properties by interfering directly with inter-fiber bonding. Addition of fly-ash causes lesser decrease in mechanical strength properties because of its larger particle size and irregular shape compared with kaolin clay. The constituents of both fly-ash and kaolin clay are silica (SiO_2) and alumina (Al_2O_3). However, fly-ash also contains other oxides such as titanium dioxide, magnesium dioxide, calcium oxide and iron oxide, which provides higher opacity and lower brightness in paper (Ahmad *et al*, 2014).

Conclusion

In this paper, attempt has been made to provide remedial information against the problems associated with fly-ash management and disposal. Even though fly-ash is an environmental pollutant, it holds numerous beneficial characteristics. Its physical and chemical properties are best suited for constructional and agricultural works. The inherent low permeability and pozzolanic binding capacity make fly-ash ideal for a wide range of environmental applications including ground remediation, landfill liners, etc. as well as road construction. It is advisable to fully exploit fly-ash like materials in order to be sustainable for the future.

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