A Review on the Utilization of Fly Ash in the Construction Industry of India

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Abstract

Coal-based thermal power stations producing fly ash have been operated for more than 50 years in India, but the concept of developing environment-friendly solutions for fly ash utilization is major concern now a days. In the past, vast majority of the material generated each year was held in ash dams or similar dumps but in recent years a number of technologies have been developed for the beneficial utilization of fly ash in different fields. The utilization of fly ash in construction industry such as mine back fill, paints, wood substitute composites etc. is reviewed in this article. From the review of various applications of fly ash in the construction industry it can be concluded that fly ash is very good alternative to conventional activated carbon and can replace activated carbon in many processes in order to minimize the cost and reduce the industrial waste leading to environmental problems when released into the atmosphere.

Keywords: Fly Ash; Construction; Waste management; Thermal Power Plant

1. Introduction

Thermal power plants, cement, steel and paper industries all over the world contribute enormous quantity of fly ash every year in India. From a recent report published by the Ministry of Environment and Forests, Govt. of India, it was found that in the year 2015-2016 the status of fly ash generation from 151 thermal power stations in India is about 176.74 million tonnes [18]. The Ministry of Power, Government of India estimates that 1800 million tonnes of coal used annually leading to generation of 600 million tonnes of fly ash by 2030-2031. However, the disposal of large amount of ash involves occupancy of huge land, toxicity associated with heavy metal, leached to ground water and further generates the problem of leaching and dusting in wet and dry conditions, respectively. Consequently, give

rise to many health and environmental hazards. Therefore, it is very important to develop some suitable scientific, technical and economic solutions for fly ash utilization in order to dispose and reuse the fly ash safely [5].

Henceforth, environmentally safe disposal of fly ash has necessitated the exploration of innovative and cost-effective methods of utilizing the fly ash in many fields. The best way of disposing fly ash is to utilize it with some additives and converting it into a non-hazardous material and apply them in eco-friendly way.

In field of civil engineering, fly ash is used in abundance and has become an important raw material for various industrial and construction applications. Fly ash is often a component in concrete mixtures, but it is also used in stabilized road bases, landfill linear and waste stabilizations [17]. The waste generate from thermal power plant has proven its suitability for variety of applications as admixture in cement/concrete/mortar, lime pozzolana mixture (bricks/blocks) etc. Cement and Concrete Industry accounts for 50% Fly Ash utilization, the total utilization of which at present stands at 30MT (28%). The other areas of application are Low lying area fill (17%), Roads & Embankments (15%), Dyke Raising (4%), Brick manufacturing (2%) and other new areas for safe disposal of fly ash is in paint industry, agriculture etc.

2. Fly-Ash and its Properties

Fly ash can be defined as a waste residue that is released from coal combustion process in electric power stations [19]. It is extracted by the precipitators in the smokestacks of coal-burning power plants to reduce pollution [2]. Fly ash have fine, powdery particles predominantly spherical in shape, either solid or hollow, and mostly glassy (amorphous) in nature. The particle size ranges from 0.5μm to 100μm. This micron sized particle consists mostly of silica, alumina, calcium and iron oxide. Previous investigations carried out on Indian fly ashes showed that the silica content present in it is between 38- 63%, alumina content ranges between 27 - 44%, calcium oxide and iron oxides are in the range of 0 - 8% and 3.3 - 6.4% respectively [12]. Besides, minor amounts of magnesium, sulphur, sodium, potassium, and carbon are also present in it. The colour of fly ash can vary from tan to grey to black, depending on the amount of unburned carbon in the ash. [7]

Further, depending on the concentration of calcium oxide, silica, alumina and iron oxide, as per ASTM C-618, fly ash are commonly two types of Fly ash: (i) Class F and (ii) Class C fly ash [4]. Fly ash produced from the burning of anthracite and bituminous coal produces Class F fly ash whereas combustion of lignite or sub-bituminous coal produces Class C fly ash. Class C fly ash generally contains more than 20% lime (CaO) and has both pozzolanic and self-cementing characteristics whereas class F contains less than 10% lime (CaO) and only possess pozzolanic properties and requires a cementing agent, such as Portland cement, quicklime, or hydrated lime to produce cementitious compounds [1]. For this reason, it has been chosen for preparing building materials and materials for some other constructive works. However, in Class C fly ash the amount of alkali and sulphate (SO4) present is higher than Class F fly ash [3].

3. Uses of Fly ash

According to statistics, fly ash rate of production is clearly far outweighs consumption due to increased amounts of energy being generated by coal-fired power plants and widely available across the globe as shown in Table 1 [17].

Table 1: Production of Fly ash in different countries

Country	Amount of Production (million tons/year)	Country	Amount of Production (million tons/year)
India	112	Malaysia	6.8
China	100	Canada	6
USA	75	France	3
Germany	40	Denmark	2
UK	15	Italy	2
Australia	10	Netherland	2

The generation of fly ash in India has increased from 68.88 million tonnes in 1996–97 to 163.56 million tonnes in 2012–13, of which only 100.37 million tonnes was utilized. India has achieved a tremendous increase in its utilization from 9.63% in 1996–97 to 61.37% in 2012–2013. However, nearly 40% of the ash is still unused. The government of India launched several programs and established many agencies regarding better understanding of fly ash for its greater usage in different sectors. According to the CEA annual report on fly-

ash generation –utilization in 2011–2012, as presented in the form of pie-chart in Fig. 1. The maximum utilization of fly ash to the extent of 44.76% has been in the cement sector, followed by the reclamation of low lying areas (16.71%), mine filling (9.1%), ash dyke raising (6.89%), bricks and tiles (6.86%), roads and embankments (6.51%), and agriculture (1.03%). Even after application in these sectors, only 55.79% of the total ash is utilized. Therefore, there exist a wide scope and an imperative need to increase the quantum of fly ash use in each sector. Especially there is a wide scope for brick and title, roads and embankments, mine filling, and soil amendment as the present utilization in these sectors are relatively little.

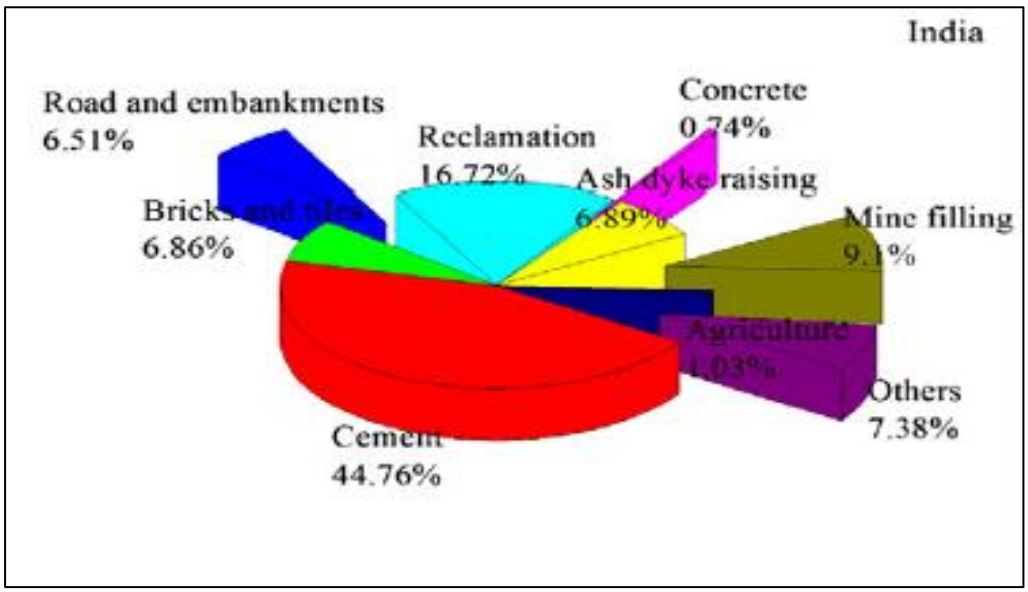

Fig. 1: Fly ash generation –utilization in 2011–12, India

From the recent report published by the Central Electricity Authority, New Delhi in the year 2015-2016 it can be observed that in the Year 2015-2016, 60.97 % of the total fly ash were utilized. The State of Delhi has achieved maximum level of fly ash utilization level and the States of Gujarat, Haryana, Jharkhand, Punjab, Rajasthan, Tamil Nadu and West Bengal have also achieved the fly ash utilization level of more than 75% [14].

4. Fly ash in construction industry

Fly ash, generated during the combustion of coal for energy production, is an industrial by-product which is recognized as an environmental pollutant. Because of the environmental problems presented by the fly ash, considerable research has been undertaken on the subject worldwide.

In order to reduce its impact on environment, fly ash has predominantly been used as a substitute for material in the construction industry, especially either as a raw material or as an additive in the cement industry. Some of the innovative and commonly manufactured eco-friendly building material utilizing fly ash is covered below:

4.1. Fly ash in Concrete:

Fly ash in concrete has significant benefits such as: increasing the life of concrete, roads and structures by improving concrete durability, net reduction in energy use. Further, its use in concrete is beneficial for its pozzolonic property which enhances the durability of concrete. It is used in Portland cement concrete to improve the concrete performance. When fly ash particles combines with water and free lime present in the cement matrix, produce additional cementitious materials (pozzolanic activity of fly ash) which results in denser and higher strength concrete. It also minimizes water demand and reduces bleed channels which increase concrete density. These factors produce concrete of low permeability with low internal voids and hence its durability is also increased. The reduction of permeability also helps to prevent sulphate penetration through the concrete and increases the resistance to corrosion. The pozzolanic reaction between fly ash and lime produces less heat and therefore reduces the possibility of thermal cracking when fly ash is used to replace Portland cement. Previous investigation reported that replacement of cement by 15% to 25% by fly ash results in lower porosity of concrete and plain cement mortars [6].

4.2. Fly ash Bricks:

Fly ash bricks can be used as building material in place of clay bricks, since it is environment friendly. Production of clay bricks requires large amount of clay which depletes top-soil but fly ash bricks are prepared from fly ash, sand and cement. Furthermore, higher temperature is required to fire the kilns to produce clay bricks, whereas fly ash bricks are manufactured at room temperature. Another type of fly ash brick is FAL-G brick (mixture of fly ash-lime-

gypsum or fly ash-cement-gypsum) which is also manufactured without using thermal energy, sets and hardens in the presence of moisture. With aging this brick becomes more durable. NTPC has manufactured more than 54 crores fly ash bricks in its various thermal power stations and utilized in construction activities. NTPC township at Faridabad (Haryana), Sipat (Chhattisgarh), Simhadri (Andhra Pradesh), and Talchar (Orissa) have been constructed with fly ash bricks. Fly ash bricks were used in NTPC's power plant construction works at Rihand, Dadri (Uttar Pradesh), Talchar- Kaniha (Orissa), and Ramagundam (Tamilnadu). NTPC has installed thirteen pilot plants for manufacturing of ash based bricks at its various power stations. More than 1500 lakhs ash bricks have been produced so far and utilized in various construction activities in power plants [14].

A further advantage of using fly ash bricks is that it can be produced in a variety of strengths and sizes. This means that apart from their conventional use in building walls etc. fly ash bricks can also be used for the construction of a variety of infrastructure projects such as roads and pavements, dams and bridges.

4.3 Cellular Light Weight Concrete (CLC) Blocks:

These are substitute to bricks and conventional concrete blocks in building with density varying from 800 kg/m3 to 1800 kg/m3. The normal constituents of this Foaming Agent based technology from Germany are cement, Fly Ash (to the extent 1/4th to 1/3rd of total materials constituent), sand, water and foam (generated from biodegradable foaming agent). Using CLC walling & roofing panels can also be manufacture. Foaming agent and the Foam generator, if used for production of CLC with over 25% fly ash content invites concession on import duty by Govt. of India [16].

4.4 Portland Pozzolana Cement (PCC):

Up to 35% of suitable fly ash can directly be substituted for cement as blending material. Addition of fly ash significantly improves the quality & durability characteristics of resulting concrete. In India, present cement production per annum is comparable to the production of Fly Ash. Hence even without enhancing the production capacity of cement availability of the cement (fly ash based PPC) can be significantly increased [9].

Fly ash can be used in Portland cement concrete to enhance the performance of the concrete. 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 liberated 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: be disposed in landfills, and conservation of other natural resources and materials. Typically, 15 to 30 % of the Portland cement is replaced with fly ash.

4.5 Ready mixed Fly Ash concrete:

Though Ready Mix concrete is quite popular in developed countries but in India it consumes less than 5 percent of total cement consumption. Only recently its application has started growing at a fast rate. On an average 20% fly ash (of cementitious material) in the country is being used which can easily go very high. In ready mix concrete various ingredients and quality parameters are strictly maintained/controlled which is not possible in the concrete produced at site and hence it can accommodate still higher quantity of fly ash [15].

4.6 Fly Ash in Road Construction:

Fly ash can be used for construction of road and embankment. This utilization has many advantages over conventional methods. Saves topsoil which otherwise is conventionally used, avoids creation of low lying areas (by excavation of soil to be used for construction of embankments). Avoids recurring expenditure on excavation of soil from one place for construction and filling up of low-lying areas thus created. Fly Ash may be used in road construction for:

(i) Stabilizing and constructing sub-base or base;
(ii) Upper layers of pavements;
(iii) Filling purposes. Concrete with fly ash (10-20% by wt.) is cost effective and improves performance of rigid pavement;
(iv) Soil mixed with fly ash and lime increases California Bearing Ratio (CBR), increased (84.6%) on addition of only fly ash to soil. Addition of fly ash has not shown any adverse effects on the ground water quality in the vicinity of experimental plots;
(v) National Highway Authority of India (NHAI) is currently using 60 lakh m^3 of fly ash and proposed to use another 67 lakh m^3 in future projects.

4.7 Embankment:

Fly ash properties are somewhat unique as an engineering material. Unlike typical soils used for embankment construction, fly ash has a large uniformity coefficient consisting of clay-sized particles. Engineering properties that will affect fly ash use in embankments include grain size distribution, compaction characteristics, shear strength, compressibility, permeability, and frost susceptibility. Nearly all fly ash used in embankments are Class F fly ashes.

Embankment fill is typically an earthen material to use to create a strong stable base. Embankment fills are usually constructed by compacting earthen materials. Therefore, compaction and permeability properties are very important to good performance of the embankment. The shear strength and compressibility is also important measures of the compacted material. The use of fly ash in highway embankments and fills is the second highest use of this material since it behaves like a fine sand material but has a lower density [11].

4.8 Use of Fly Ash in Mine Back Filling:

Large underground voids that are left out because of the mining operations have been creating various types of ground stability problems in many mining areas in India. Subsidence is a very common phenomenon in many coal mining areas. Backfilling or sand stowing technique has been followed for decades to counter the ground subsidence problem as well as to improve pillar recovery. Mill tailings and river sand have been used largely as mine back filling materials. However strict regulation and unavailability of river sand has created a huge problem for mining industry in India. Therefore, easily available fly ash can be an attractive option for a filling material for reclamation of abandoned mines which results saving of top fertile soil and river sand. It may be seen that 0.65 million-ton of fly ash was used for backfilling/stowing of open cast and underground mines during 1998-99 which increased to 10.33 million-ton in 2015-16 constituting 5.85 % of total fly ash utilization in the aforesaid year and the trend is on increasing side [14]. Mine void filling using fly ash will not only help in reducing huge land requirement, but also help to increase the production of crops.

4.9 Fly Ash in Paints and Enamels

White cement is commonly used as a base material for the preparation of distemper. Fly ash is utilised to replace white cement for the preparation of distemper. The distemper manufactured from fly ash has been utilised in many buildings and the performance is satisfactory. Paints based on fly ash have better resistance to abrasion and corrosion. It has no adverse effect on film properties, such as drying time, thickness, brush ability and gloss. It exhibits better extending properties (less oil absorption). In paints fly ash percentage is about 30-40 % (in paints) and in enamel the percentage is 18- 22% [8].

4.10 Fly Ash as Wood Substitute Composites

The main objective for using fly ash as wood substitute composites (i.e. fly ash polymer composites) is that by using alternative to timber products deforestation can be reduced which is very much required to save our environment. Development of fly ash based composites needs fly ash as filler and jute cloth as reinforcement. This technology can be applied in many applications like door shutters, partition panels, wall panelling, ceiling, etc. Such types of doors have some useful properties, such as these are resistant to weather, termite, fungus and fire. Regional Research Laboratory, Bhopal in collaboration with Building Materials & Technology Promotion Council (BMTPC) and TIFAC has been working on this technology. Near Chennai, one commercial plant has also been set up based on this technology [10].

4.11 Floor Tiles and Wall Tiles

Fly ash is also used to manufacture floor tiles and wall tiles with fly ash content not exceeding 50%. Fly ash based blocks/tiles are as good as clay based conventional building products. These types of tiles can also be used in the exterior part of the building to give a longer life, even in coastal areas. This technology has been developed by Central Power Research Institute, Bangalore [14, 10].

Mosaic tile are manufactured utilizing the fly ash. The process 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. They then undergo curing in water tanks for 15 days. The tiles are then polished and stacked for supply [14].

5. Conclusions

The disposal of fly ash from coal-fired power stations causes significant economic and environmental problems. Although, fly ash causes environmental pollution, it is an important raw material for various applications. Poor understanding of the chemistry of fly ash and its derivatives for proper end applications, poor public awareness about the products, lack of proper coordination between thermal plants and ash users etc. are the cause of low level utilization of fly ash. But now-a-days the utilization of fly ash has been increasing. Central Electricity Authority, New Delhi in the year 2015-16 published a report which stated that the highest level of fly ash utilization of about 60.97% was achieved in the year 2015-16. The utilization of fly ash in different field such as: in construction, agricultural field, mine back filling, organic dye and heavy metals removal is reviewed here which clearly shows that a waste material can be used as a potential resource material in various fields.

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