A study on components of fly ash of different locations and its utilization for production of improved quality materials: A Review

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Abstract: During the combustion of coal for energy production an industrial by-product is generated known as Fly Ash, is recognized as a hazardous environmental pollutant. Globally, a lot of considerable research has been undertaken by the researchers and scientists on this subject because of various environmental problems caused by Fly Ash. In recent past it is only being treated as waste and a source of air and water pollution but is in fact a resource material and has also proven its worth over a period of time. The present paper reviews on the potential applications for coal Fly Ash as a eco-friendly raw material: in construction of building materials like bricks and Portland cement, in painting application, application in TL Dosimetries, as a soil amelioration agent in agriculture, in the synthesis of zeolite, in the synthesis of geo-polymers, as an adsorbent for flue gases, as a removal agent for toxic metals, dyes, organic & inorganic compounds from waste water and for the extraction of the metals. Since at different locations the property of Fly Ash varies; thus we required analyzing its variability parameter for utilizing it effectively. Hence, before the utilization of Fly Ash as a eco-friendly resource material, it is necessary to study properties of Fly Ash from different sources, so that it can be used beneficially. Thus Fly Ash management is a cause of concern for the future. This article attempts to highlight the management of waste Fly Ash to make use of this solid waste, in order to save our environment.

Keywords: Eco-friendly, Fly Ash, TLD badges, Construction Materials, Waste Management.
1. Introduction

In present era fly ashes are generated from combustion of coal at thermal power generating plants. The production of fly ash has rapidly increased due to vastly growing industrialization. In the power plants before the combustion of coal it is been grind and converted into fine powder to utilize most from it. The safe disposal and waste management is the most important threat in the whole process of fly ash production. In order to maintain the ecological balance of the nature we need to properly dispose the toxic and complex characterized waste produced from various industries so that it will not impose any sort of harmful effect on our environment and social life. [1].

The amount of coal waste (fly ash), released by factories and thermal power plants has been increasing throughout the world, and its disposal has become a serious environmental problem. The present day utilization of ash on worldwide basis varied widely from a minimum of 3% to a maximum of 57%, yet the world average only amounts to 16% of the total ash [2]. (Table 1) simply shows that India is the world largest producer of fly ash but only 38 % of produced ash is being utilized in various applications as shown in (Table 2) from year 1993 to 2012 and futuristic utilization during 2031-32. On the other hand countries like Denmark, Italy, and Netherlands were utilizing all produced fly ash from their power plants.

Now, we will look after a comparison of 18 Indian states during the year 2016-17 of their power plant installation capacity, fly ash generation and fly ash utilization in million tons.

| Countries | Production of FA (MT/year) | Utilization % of produced |
|-----------|---------------------------|---------------------------|
| INDIA     | 112                       | 38                        |
| CHINA     | 100                       | 45                        |
| USA       | 75                        | 65                        |
| GERMANY   | 40                        | 85                        |
| UK        | 18                        | 50                        |
| AUSTRALIA |                            |                           |
| CANADA    |                            |                           |
| FRANCE    |                            |                           |
| DENMARK   | 2                         | 100                       |
| ITALY     | 2                         | 100                       |
| NETHERLANDS |                         |                           |

| Year       | Generation (MT) | Utilization |
|------------|-----------------|-------------|
| 1993-94    | 40              | 1.2         |
| 2004-05    | 112             | 42          |
| 2006-07    | 130             | 60          |
| 2011-12    | 170             | 170         |
| 2031-32    | 600             | ---         |

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Graph 1: State wise Fly Ash generation and its utilization during year 2016-17 [4].

Table 1: Country wise production and utilization of FA as on 2014 [3].

Table 2: Fly Ash Generation and Utilization in India [5].
About 75% of power generation capacity of India is based on thermal energy and it is mainly dependent on coal based power generation. It is around 90% of whole thermal power generation which is based on combustion of coal and rest others are merely 10%. The main reason behind the large amount of fly ash generation is the presence of high ash content in the Indian coal of about 30-50 percent. Fly ash management would remain an important area of national concern just because from past to present and also in future coal will be a major source of energy generation.

The most shocking stats for the two states of Uttar Pradesh and Chhattisgarh since these two were the largest producers of fly ash while both of these states were below 50% line in utilizing the fly ash in various fields. In the state of Chhattisgarh there are some major thermal power plants are situated at Korba district which generates about 24000 metric tons per day or 8.7 million tons of fly ash annually that is approximately 9/10th part of the total fly ash produced in the Chhattisgarh State.

2. Types of fly ash and its classification

Fly ash is the residue of coal being burnt and obtained from combustion process involved in the thermal power plants. Due to the combustion of coal in thermal power plants some different varieties of ashes are produced. They are:

i. Fly Ash: This kind of ash is extracted from flue gases through electrostatic precipitator in dry form. This ash is fine materials and possesses good pozzolanic property.

ii. Bottom Ash: This kind of ash is collected in the bottom of the boiler furnace. It is comparatively coarse materials and contains higher unburned carbon. It possesses zero or little pozzolanic property.

iii. Pond Ash: Both fly ash and bottom ash with a large quantity of water to make it in slurry form and deposited in ponds wherein water gets drained away.

iv. Mound ash: - Fly ash and bottom ash or both mixed in any proportion and deposited in dry form in the shape of a mound is termed as mound ash.

1/5th of the total fly ash generated is bottom fly ash while 4/5th part is the fly ash generated from power plants. Both bottom and fly ash are together dumped into the ash ponds.

| Compounds | Fly Ash % |
|-----------|-----------|
| SiO₂      | 38.63     |
| Al₂O₃     | 27.44     |
| Fe₂O₃     | 9.4-1.8   |
| Fe₂O₃+3   | 3.3-4.4   |
| MnO       | 0-0.5     |
| Fe₂O₃     | 0.01-0.5  |
| CaO       | 0.2-8     |
| K₂O       | 0.04-0.5  |
| Na₂O      | 0.07-0.45 |
| LOI       | 0.2-3.4   |

(Table 3) and (Table 4) shows the percentage of components in fly ash, percentage of components as per the type of coal. Depending on the concentration of calcium oxide, silica, alumina and iron oxide there are two grades of Fly Ash.

a. Grade I fly ash, having fractions SiO₂+Al₂O₃+Fe₂O₃ greater than 70% and which are derived from bituminous coal.
b. Grade II Fly ash, having fractions $\text{SiO}_2+\text{Al}_2\text{O}_3+\text{Fe}_2\text{O}_3$ greater than 50% and which are derived from lignite coal.

ASTM C618 specified two categories of fly ash, Class C and Class F depending on the type of coal and the resultant chemical analysis [7]. The Fly Ash mainly consists of micro sized particles of silica, alumina and iron. It is easy to form mixture of fly ash with any other component as the particle of fly ash is spherical in nature. The capillarity is one of the best properties for fly ashes to be utilized during the preparation of concrete [1]. The Quality requirements for fly ash varied with respect to the kind of use made out of it. Fly ash quality is mainly affected by types of coal and combustion process. The four most relevant characteristics of fly ash which affects the quality for use in various applications are loss on ignition (LOI), fineness, chemical composition and uniformity. 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) [3]. In Class C fly ash the amount of alkali and sulphate ($\text{SO}_4$) present is higher than Class F fly ash.

It is found that all the Indian coal ashes possess pozzolanic activity. ASTM defines a pozzolan as "a siliceous and aluminous materials which possess very little or no cementious property within it but in finely divisible form and when the moisture is present, react chemically with calcium hydroxides at room temperatures to form compounds possessing cementious properties" [4]. For this reason, it has been chosen for preparing building materials and materials for some other constructive works.

3. Composition of fly ash at different locations

Now we will look after some statistics through graphs regarding the composition of fly ash and the percentage comparison of different locations in India and outside India. In this statistics power plants in 11 different locations in India were shown with the composition of fly ash different at each location. Similarly, 4 locations of Russia (Outside India) were shown in the statistics for composition of fly ash.
4. Utilization of fly ash as eco-friendly source material

Due to large scale production of fly ash and increasing environmental issues originated from it, vital steps toward the management of fly ash is to be taken. Most importantly fly ash has tremendous qualities and potential to be utilized as initial material. Keeping in view this versatility of fly ash, several Government and Non Government Organizations are involved in fly ash utilization and its safe disposal. It is now being used as a source material in various applications and is been replacing various natural materials in order to save it. Some of the applications are discussed below:

4.1 Use of Fly Ash in manufacturing of eco-friendly Bricks

A better replacement of fired clay bricks is fly ash based bricks as a construction material as it can be utilized as an eco-friendly source. It is eco-friendly in the sense that it will stop the depletion of top layered soil as clay bricks required a lot of soil mass where as fly ash is produced using ash produced during the combustion of coal and some other components like sand, cement and many more. Apart from that we need very high temperature in order to produce clay bricks where as different compositions of fly ash bricks can be produced at room or normal temperature. The different compositions of fly ash brick sets and gain a shape in the presence of moisture. With the time passes this fly ash based bricks became more durable due to its moisture absorbing capacity and thus gain strength.

According to some statistics only 5 million tones fly ash is utilized in preparation of fly ash bricks which saves around 20 crores INR out of 5770 crores INR which is quite less in comparison to other applications. So the use of fly ash in bricks preparation needs to increase for the betterment of environment and to maintain socio-economic condition [10].

In such a way we can have many different mixtures for fly ash bricks to make it eco-friendly and low cost. Now a day various attempts were made by researchers and scholars to study new properties of bricks prepared by inclusion of waste materials such as fly ash, lime and gypsum. So that these bricks can be used as a replacement to burnt clay bricks. Fly ash bricks can be economical and having good compressive strength compared to fired clay bricks [3].
Since we know that fly ash bricks does not require soil but the inclusion of some medicinal plants content can make it more eco-friendly. The dry leafs of neem, tulsi, bhuineem (Kalmegh) etc. can be mixed with fly ash in a proper ratio in powder form for maintaining the ecological balance. Along with that bio-waste like rice husk and egg shell can be mixed with fly ash as rice husk contains silica where as egg shell can be a source of CaO which are constituents of fly ash chemically.

4.2 Use of Fly Ash in manufacturing of eco-friendly concrete

On economic grounds the utilization of fly ash is quite unique as it replaces cement in preparation of concrete mixtures and it also possess some positive benefits as it demands less water for similar workability, reduces the bleeding mechanism and does not require large amount of heat. Its application lies particularly in mass concrete production [2]. Since mix concrete is very popular in western countries but in countries like India merely 5 % of cement is replaced by fly ash (Cement like material) in concrete production. In ready mix concrete we need to control the ration of ingredients and quality parameters but in concrete prepare at sites it impossible to attain exact accuracy which consumes higher amount of fly ash and quality factor may go down [11]. It provides natural protective sheet against natural weathering action. To understand the complex aggregate action and sulphate resistance fly ash is utilized in concrete. An agricultural residue Rice husk which accounts for 20% of the 649.7 million tons of rice produced in the world per annum. When this residue is burnt partially in the rice milling plants and when used as fuel produces pollution up to great extent. One more natural waste Chicken eggshell is a by-product in food processing and several tons of eggshells are sent to landfills on daily basis without further processing. So it is generous to apply eggshell bio-waste which is of very low cost as a commercial product for increasing its value. Thus (Table 5) gives a comparative idea of Rice Husk and Egg Shell.

| Composition (% by mass) | RHA | Egg Shell |
|------------------------|-----|-----------|
| SiO₂                  | 88.32 | 0.09 |
| Al₂O₃                  | 0.46 | 0.03 |
| Fe₂O₃                  | 0.67 | 0.02 |
| CaO                   | 0.67 | 58.7 |
| MgO                   | 0.44 | 0.01 |
| Na₂O₃                 | 0.12 | - |
| K₂O                   | 2.91 | - |
| Na₂O                  | - | 0.19 |
| P₂O₅                  | - | 0.24 |
| SeO₅                  | - | 0.13 |
| NiO                   | - | 0.001 |
| Cl                    | - | 0.08 |
| SO₄                   | - | 0.57 |
| LOI                   | 5.81 | 47.8 |
| Specific gravity       | 2.11 | - |
So utilizing this agricultural residue with fly ash as a supplementary cementing material gives a remedy for pollution generated by its burning and also it provides an eco-friendly and economical option for concrete production. The compressive strength of RHA was investigated with replacing the percentage of cement in the mixture of concrete and variable grinding period for different period; 1, 3, 7, 28 days [12].

Graph 18: Compressive strength of Concrete mixtures with RHA with variable grinding period [12].

![Graph 18: Compressive strength of Concrete mixtures with RHA with variable grinding period](image)

It basically possess 10 % overall weight of hen egg and contains 94 % weight of calcium carbonate as calcite along with magnesium carbonate, calcium phosphate and organic. It was used for adsorbing heavy metal ions such as Cu, Cr, Cg, Ag and Zn from solution [13-17] and removing dry effluents. It can also be used as fertilizers, soil conditioner and additives for animal feeding as it contains nutrients like calcium, magnesium and phosphorous [18].

4.3 In Thermo Luminescence Dosimeter applications

For the identification of radiation level in any body or material Thermoluminescence Dosimetry are used. It is helpful in determination of dose absorbed by the material irradiated by ionizing radiation source. Since some elements of the procedures have broader application, the specific area of concern is radiation level testing of electronic devices using phosphor based Dosimetry with the inclusion of waste fly ash as a source material [20]. By using acid evaporation in open system Dysprosium doped Calcium Sulfate (CaSO$_4$;Dy) has been prepared by Yamashita in 1968 which faces some problems related to health issues, corrosion and pollution to the environment due to sulfuric acid vapor. A linear response obtained at 0.25 mol % with higher sensitivity level from 5µGy to 10 µGy and at 75 µm grain size optimum sensitivity is achieved [21]. The TL response is studied when exposed to gamma radiation through a curve between temperature (T) and TL intensity in arbitrary units.

![Figure 6: Glow curve for temperature (T) in °C vs TL Intensity in arbitrary units when exposed to gamma dose for (CaSO$_4$;Dy)](image)

![Figure 7: Glow curve of T (°C) vs TL Intensity for Fly Ash when exposed to gamma radiation](image)
In a $^{60}$Co gamma field the behavior of fly ash in powder was tested whether it can be used as a material for dosimeter. Fly ash is irradiated to different doses of gamma rays varying from 10-60 kGy and linear response was obtained at 40 kGy of irradiation. $T_{m}-T_{\text{stop}}$ method is used to estimate the possible number of TL peaks present in the glow curve and the TL response of fly ash is found to be satisfactory in high dose Dosimetry applications [22].

4.4 As a Soil amelioration agent in agriculture

Recent agricultural investigations suggests that fly ash when combined with organic materials like cow dung, mud, paper factory sludge, farmyard manure, sewage, residue of crops and with degraded soil gives very positive applications toward eco-friendly and balancing ecosystem.

Its utilizes ‘slash’ which is a mixture of sewage, sludge and lime as a soil ameliorating agent which also shows positive impact on soil pH and elemental contents in it. Thus we can say that amendment of fly ash in the agriculture field will be beneficial for the crop production as shown in (Graph 19).

Sao et.al; investigated the effect of varying levels of fly ash and growth hormones on the determination of chlorophylls. For fresh leaf, chlorophylls content varies in the plain soil from 0.29 to 0.64 mg g$^{-1}$, which is less for photosynthetic activities [24].

The inclusion of fly ash in soil also improves permeability status of soil, fertility of crop yield, improves porosity, reduces crust formation, provides micro nutrients like Fe, Zn, Cu, Mo, B, Mn, etc. and macro nutrients as K, P, Ca, Mg, S etc., as a substitute of gypsum for reclamtion of saline alkali soil and lime for reclamation of acidic soils, provides ash pond as a place for the nutritional growth of plants, and in improving the socio-economic condition of the inhabitants around the area [14].

5. Conclusions

In this paper we studied about the different locations of fly ash generation and the composition difference at various locations some in India and some outside India. Overall we can see that the percentage of $\text{SiO}_2$, $\text{Al}_2\text{O}_3$, $\text{Fe}_2\text{O}_3$ and $\text{CaO}$ is quite higher in comparison to other components of fly ash in all the locations examined in the paper. The utilization of fly ash as brick and concrete manufacturing material is been done earlier but now we are trying to make it eco-friendly and low cost by inclusion of some part of medicinal plants leafs and also waste materials like egg shell, rice husk, banana bark, etc. From several studies in the agriculture field we came to know that it is perfect candidate for enhancing the

![Graph 19: pH value and Specific Conductivity of Mixture of soil and FA in different incubation periods [23.]](image)
fertility of soil. Fly ash also can be utilized as source material for the preparation of radiation absorbing discs as it mixed with phosphor material. Thermoluminescence Dosimetry is useful for radiation workers to take care of exposure from radiation in radiation areas.

Finally, we can conclude that fly ash is a resource which can be utilized in such a way that it will definitely replace many high cost ingredients in various applications discussed above. Its utilization itself solves the problem of environment pollution either it is air, soil or land pollution. Fly ash consumption allows us to get free landmass for agriculture purpose.

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