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A Brief Review on Fly Ash Utilization

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ABSTRACT

This article addresses the quantity, characteristics, recycling potential and effective management of fly ash with specific reference to the processes and technologies developed in India. In India major source of electrical energy is fulfilled through coal based thermal power plants resulting in the generation of approx 175 million tons of fly ash as solid waste annually. Considerable efforts have been made in the country to utilize the fly ash in huge quantity for road construction, land filling and producing building materials e.g. bricks, block, cement and clinkers etc. No one would have imagined about two decades back that fly ash will generate revenue. Today, fly ash has become an essential ingredient for many of the industries like cement manufacturers, ready mix concrete plant, asbestos industries, construction industries etc. These segments are now ready to pay the price for the quality. Fly ash utilization has increased from approx 5% in the nineties to 50% during the last few decades in various applications such as cement and asbestos industries, bricks, blocks, lightweight concrete blocks, binder in concrete, embankments, road construction, land reclamation, agriculture, and reclamation of abandoned mines. Indeed fly ash is considered to be a resource material rather as waste which may contribute to saving the natural resources leading to a reduction in carbon dioxide sequestration and global warming resulting to sustain the clean and green environment.

Keywords: Fly Ash, Cement, Bricks, Coal, Concrete, Lightweight Aggregate, Composites

I. INTRODUCTION

India has a coal reserve of 211 billion tonnes making coal one of the most extensively used fossil fuel for generating power. About 240 million tonnes of coal is being used every year to generate electricity. It is estimated that coal ash production in the country has been reached approx 175 MT by 2012 and will 600 MT by 2030 as coal will remain a major source for power generation for many more coming years because of its huge reserves. Indian coals, however, are low in sulphur, radioactive elements and overwhelming heavy metals, yet are rich in incombustible siliceous material and another inorganic issue which turns out as ash on combustion.

As a result of the efforts of the Fly Ash Mission and some other agencies in India, the utilization of fly ash as improved from 3% in 1994 to 27% in 2003. Further, fly ash utilization increased to 60 million tonnes per year in 2006-2007 as against a generation of 130 million tonnes per year. Some of these include the use of fly ash in mine filling, construction of roads/flyover, embankments, hydraulic structures, rising of dykes, manufacture of building components like bricks, blocks, tiles and use in agriculture. Their focus was on the demonstration of coal ash related technologies for infusing confidence and thus ensuring large scale adoption. While there has been a constant increase in the utilization of fly ash yet the unutilized fraction is also growing considerably. The extensive R&D and sincere and dedicated efforts have enhanced the level of fly ash utilization in India to about 50% [1] [2]. Today, fly ash has become a commodity for many of the industries like cement manufacturers, ready mixed concrete plants, asbestos industry etc. These segments are now ready to pay the price for the quality. In NTPC, there is a continuously increasing trend of ash utilization through the increase of ash production due to capacity addition. The major areas of ash utilization are an issue to industries for the manufacture of cement/asbestos products/RMC plants, low lying area development, ash dyke raising, road embankment construction, mine filling, bricks etc [2]. The present paper describes the contribution of many research organizations, agencies and investigators on the development of processes and technologies on use of fly ash in different sectors.

II. FLY ASH UTILIZATION

A. Utilization of Fly Ash in Building Construction Materials

1. Fly Ash Blocks

Fly Ash can be used in hollow blocks as a replacement for cement. Considering total cost of construction, hollow blocks masonry is cheaper than bricks, Walls of lesser width (in comparison with bricks) are constructed and increases effective area. More crushing strength is reported than bricks, all engineering properties of pozzolana are achieved in construction. Concrete blocks were developed from stone dust waste with 50% CCRs. The compressive strength of block is 80-130 Kg/cm^2; water absorption is 5-10% [3]. The combined effect of particle shape, grading and particle density of CCRs causes a substantial reduction in the water demand of concrete mix. Such concrete gives much higher long-term strength, lower permeability and increased resistance to chemical attack. Ashes are used as major filler and binder materials due to the pozzolanic properties and meet the IS 456 specification. But studies carried out by National Council for Cement & Building Material, India showed that use of CCRs from 15% to 25% in normal concrete and even more for mass concrete works resulted in impairing the total compressive strength.

Cellular lightweight concrete blocks are used as a substitute for bricks and conventional concrete blocks. This is a foaming agent based technology from Germany using fly ash, sand, water and foam manufactured from biodegradable foaming agents. The blocks have a better strength to weight ratio and reduce dead load resulting in a saving of steel and cement costs and in a reduction in foundation size. It has better acoustics and thermal insulation (Air conditioning requirements are considerably reduced). There is a saving in a mortar and it has a higher fire rating.

2. Cement and Asbestos Industries

Kamal [4] studied that fly ash based blended cement is much superior to ordinary portland cement on account of its higher resistance to lime leaching, alkali aggregate reactions, higher resistance to carbonation, smoother surface, lower water permeability and penetration by chloride and sulphate ions. Roongta [5] experimentally investigated that in cement industry up to 25% of dry fly ash is being used as major raw materials for the production of CCRs blended cement. The presence of SiO_2 + Al_2O_3 (70%), SiO_2 (35%), MgO (5%), SiO_3 (2.75%) and Na_2O (1.5%) in CCRs are the requisite properties for making pozzolana cement. Fly ash in cement concrete minimizes the carbon dioxide emission problem [1] [6]. Production of CCRs based cement also increases the overall availability of cement production, which is cost effective. In cement manufacture/ substitution, about 49% of the ash generated is being used every year in India. This results in a net reduction in energy use, greenhouse gas and other emissions.

3. CCRs Based Bricks

The CCRs bricks can be broadly categorised into two types namely clay CCRs brick (Sintered bricks) and CCRs sand lime bricks (Calcium silicate bricks). The CCRs sintered brick contributes to replacing the topsoil and thus silica and oxides of iron and aluminium play an important role. The presence of unburned carbon in the CCRs becomes an advantage as it saves the fuel consumption. On the other hand in case of air and water cured calcium silicate bricks, CCRs play an important role as pozzolanic materials and presence of CaO, soluble silica, Al_2O_3 and higher surface area, helps in improving the bricks/ block quality. But the presence of organic carbon hampers the quality of bricks. The compressive strength of clay CCRs brick is as high as 120 kg/cm^2, water absorption is less than 18% and shrinkage is less than 10% [3].

The flux-bonded fly ash is based on the principle of formation of a thin liquid phase layer in the temperature range 900-1000^{0}C around the fly ash particles, which provides excellent binding to the fly ash. Fly ash as high 80% by weight is possible. This novel technique of flux bonding of fly ash at low temperature was tested in the laboratory and experimented on the pilot scale under factory conditions to the level of a few thousand bricks/ blocks/ tiles/ glazed articles [7].

Another fly ash based pozzolana product is FaL-G brick, in which 60-75% of fly ash is being used. The compressive strength of FaL-G brick is varying from 80-160 kg/cm^2 [8].

B. Application of Fly Ash for Hazardous Waste Recycling

An attempt has been made to immobilise the toxic substances present in jarosite by admixing with fly ash and converting into nonhazardous building materials like bricks. Jarosite wastes generated from the hydrometallurgical process contain a significant quantity of compounds of zinc, sulphur, lead, cadmium, manganese etc. The presence of toxic substances and their characteristic nature make these wastes hazardous and possesses serious problem at their disposal. The study revealed that the compressive strength of fly ash - jarosite clay bricks attained 50-81kg/cm^2 and absorbing 13-17% water with 11-32% shrinkage and 1.6-1.8 gm/cm^3 density. The study showed great utilization potentials of fly ash for recycling hazardous jarosite in developing non-hazardous building material followed by achieving the objective of environmental sound Management [9].

C. CCRs Based Binder in Concrete

Conditioned fly ash can be used as a binder and it will find large-scale utilisation for replacement of portland cement and admixture [10]. CCRs can be used and will give equivalent or improved properties as compared to portland cement binder where cementitious binders are required for construction work. Literature illustrates that fly ash-lime-phosphogypsum based binder decreased the strength and loss in weight of binder with an increase in temperature 27-60^{0}C [11]. Presently good quality of fly ash conforming to IS 3812 is available in most of the modern thermal plants in India. Fly ash may be used in concrete as a raw material for cement production, as an ingredient in blended cement, and as a partial replacement for cement in concrete. Sometimes fly ash is also used as a partial replacement of fine aggregate as well as in the production of lightweight aggregate for concrete. The present state of the art includes its usage with respect to the use of fly ash as a cementitious component or mineral admixture in concrete. Fly ash in concrete has been tried with encouraging results on concrete using rice husk ash, silica fume which enhanced the durability of concrete as well as utilizes the industrial by products [12].

D. CCRs as Base Course in Embankments and Roads Construction

Compacted pond ash and bottom ash possess good bearing strength and also meet gradation requirements for use as a sub base material [13]. Pond ash and bottom ash which range in particle size from fine to coarse sand have been used as a granular sub base material for construction of embankment and road [14]. A mixture of local soil and CCRs stabilised with 3-5% lime provides good sub base course. Utilisation of structural fill, back fills for reclamation of undulated land and abandoned mine found the most effective for bulk utilisation [15]. CCRs added to cement concrete mix permits easier placement and finishing in which up to 50% of sand can be replaced with CCRs in road construction. In lime CCRs bound macadam, lime CCRs mix was used as filler in the Water Bound Macadam (WBM) construction to provide additional stability.

E. CCRs in Land Reclamation and Agriculture

Long term studies, on the effect of fly ash on soil fertility and crop yield, carried out by Saxena and Asokan, (2000) [15] revealed that CCRs can be used (up to 1170 t/ha.) as an enriched medium in improving the productivity of wasteland soil and increase the yield of most of the crops, vegetables and cereals without affecting the food quality and soil fertility. These effects are usually observed when CCRs overcome nutrients deficiency in the soil to which it has been introduced. Also, CCRs is known to improve crop growth by neutralising soil acidity [16]. On the contrary few investigations involving the use of CCRs in agriculture show that CCRs produced undesirable effects on crop yield and on the development of plants. The most frequently cited cause of these effects heavy metals and boron toxicity [17]. In some cases, CCRs is shown to induce P deficiency, salt injury, pozzolanic effects and heavy metal toxicity to crops [18].

Use of Fly ash in agriculture can increase the yield of cereals, oil seeds, pulses, cotton and sugarcane by 10-15%, vegetables by about 20-25% and root vegetables by 30-40%. Waste lands, degraded lands, saline alkaline soils, eroded soils etc., can be successfully reclaimed by fly ash.

F. CCRs for Reclamation of Abandoned Mines

Bulk quantities of CCRs have been used to replace the conventionally used sand for reclaiming underground mines. In 1999-2000, NTPC was used about 60,000 tonnes of ash for backfilling underground mines of Singrouli Colliery Company Limited, Southern India in collaboration with Central Mining Research Institute, India [19]. The potential application of CCRs in reclaiming abandoned coal mine is of great practical significance in India. Research and Development are still in progress for commercial use of such huge quantum of CCRs as mine-fill material.

G. Value Added Application of Fly Ash

The main emphasis up to now in our country has been towards the utilization of fly ash for low and medium value applications. Efforts will, therefore, have to be directed to developments of other commercially viable products, which may yield high value addition to its manufacturers. Such applications include metal extraction and use of fly ash as raw material for certain high value products. These kinds of products though consume the very low volume of fly ash in absolute terms; however, have the potential in yielding considerable sales revenues for their end products.

Therefore, the recycling of fly ash in newer areas has become an increasing concern in recent years due to increasing landfill costs and current interest in sustainable development. This unproductive use of land and the associated long-term financial burden of maintenance have led to the realization that alternative uses for fly ash as a value-added product beyond incorporation in construction materials are needed [20].

The applications of fly ash under the category of manufacturing value added products have been broadly classified under two groups i.e.,
(i) its use for extracting various resource materials like alumina, magnetite, carbon, cenospheres, titanium, gallium and various other trace elements and
(ii) its use as raw materials for various specialized applications like ceramics, high temperature and acid resistant bricks, floor and wall tiles, mineral wool, lightweight refractory, fillers, synthetic wood, aggregate, building distempers etc. Other promising areas are ash alloys, foam insulation products and decorative glasses [21].

H. Geo Polymers

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. 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 dramatically reduced CO_2 emissions [22]. Fracture behavior and bond strength of heat-cured geopolymer concrete with reinforcing steel are observed to be superior to those of portland cement concrete [23] [24]. Moreover, handling of alkali can be problematic and setting of geopolymer cement is very rapid as compared to Portland cement, making widespread use of geopolymer cement impractical at the ready mix level. The researchers found out that the fly-ash, in most cases contains the sufficient amount of SiO_2 to be used as the agents for the geo-polymerization [25].

I. Lightweight Aggregates

For converting fly ash from a liability into an asset by manufacturing lightweight aggregate from the ash not only helping to solve the disposal problem but there were a number of good reasons
(i) since fly ash is a by-product, no mining is required
(ii) fly ash is already fine enough for sintering, no crushing or grinding is needed
(iii) fuel is “built-in” in the form of unburned carbon
(iv) power plants are located near metropolitan areas, a principal market for lightweight aggregate.

The market for lightweight aggregate speaks to one of the more appealing open doors for business use of fly fiery debris without occasional issues, as lightweight aggregate can be put away for a boundless time in the outdoors without misfortunes, natural issues or harm. The largest potential outlet for lightweight aggregate manufactured from fly ash is in concrete, concrete products, block and masonry units. Lightweight aggregate offers better thermal and acoustic insulation, high fire resistance, easy cutting, drilling and nailability. The potential certainly exists for disposal of a large amount of fly ash in the form of lightweight aggregate in a constructive and profitable manner.

A systematic study was undertaken to study the relative performance of three binders, viz., cement, lime and bentonite on the properties of sintered fly ash aggregate. The salient observations are (i) the characterization studies on sintered fly ash aggregates show that the properties of aggregates depend on the type of binder and its dosage, (ii) the significant improvement in strength and reduction in water absorption of sintered fly ash aggregate is observed when bentonite is added with fly ash, (iii) the binders used did not alter the chemical composition, while they influence the microstructure of the aggregate, which results in enhancement in the properties of aggregates [26].

J. Zeolites

Fly ash can be utilized for the synthesis of zeolite products due to the presence of silica and alumina in high proportions. It is a process analogous to the formation of natural zeolites from volcanic deposits. Both volcanic ash and fly ash are fine grained and contain a large amount of aluminosilicate. Amorphous aluminosilicates are the major mineral compounds present in Class F fly ash along with other crystalline minerals, including quartz, mullite, hematite, lime, and feldspars. These chemical and mineralogical features make fly ash a good candidate for zeolite synthesis. In natural conditions, these volcanic deposits may be converted into zeolites by the influence of percolating hot groundwater. This process may take tens to thousands of years under natural conditions. Within laboratory conditions, this conversion can be expedited to days.

Ansari et al. [27] synthesized pure zeolite X nanoparticles or a mixture of zeolite X and A using the microwave heating method by control of the crystallization time and temperature from fly. Zhou et al. [28] synthesized and used zeolite NaP1 as adsorbents for volatile organic compounds. Babajide et al. [29] prepared and applied zeolite Na-X in the production of biodiesel as a solid base catalyst. Li et al. [30] prepared and used merlinoite as a slow release K fertilizer for plant growth. Liu et al. [31] prepared Zeolite A and A+X mixtures and simulated the performance of the synthesized materials for CO_2 capture. Zeolites prepared from waste fly ash can be used in commercial processes for CO_2 capture and could be a cheap, viable means of producing large quantities of adsorbent [32].

Zeolite synthesized from fly ash for agricultural application as a controlled release fertilizer is a technology which offers considerable advantages in terms of economic, technical and environmental performance. The hydrothermal process for producing zeolites from coal ash, including the relationship between zeolite types produced and operating conditions, desirable zeolite properties for controlled release fertilizers, optimal production conditions and economic implications are ascertained [33].

K. Composites

1. *Metal Matrix Composites with Fly Ash Particles as Reinforcement*

Nowadays the particulate reinforced aluminium matrix composite are gaining importance because of their low cost with advantages like isotropic properties and the possibility of secondary processing facilitating fabrication of secondary components. Metal Matrix Composites (MMCs) possess significantly improved properties including high specific strength; specific modulus, damping capacity and good wear resistance compared to unreinforced alloys. There has been an increasing interest in composites containing low density and low cost reinforcements. Among various discontinuous dispersoids used, fly ash is one of the most inexpensive and low density reinforcement available in large quantities as solid waste. Hence, composites with fly ash as reinforcement are likely to overcome the cost barrier for wide spread applications in automotive and small engine applications. It is therefore expected that the incorporation of fly ash particles in aluminium alloy will promote yet another use of this low-cost waste by product and at the same time, has the potential for conserving energy intensive aluminium and thereby, reducing the cost of aluminium products.

Further to produce Al matrix cast particle composites, wettability of the ceramic particles by liquid Al is essential. To improve wettability, elements such as Mg and Si are added into Al melt to incorporate the fly ash particles. One of the research studies has been focused on the utilization of abundant available industrial waste fly ash in a useful manner by dispersing it into aluminium/ aluminium-magnesium/ aluminium-silicon matrix to produced composites by liquid metallurgy route. Wide size range (0.1-100 μm) fly ash particles were used. These composites were observed with the help of optical micrography, x ray micro analysis, x ray diffraction, wet chemical analysis and image analysis. The dry sliding wear behavior of the composites in the cast conditions was studied at different loads and different sliding velocities with the help of Pin-On-Disc wear test machine. The worn surfaces and wear debris were analyzed using an optical microscope and scanning electron microscope. The mechanical properties such as hardness and tensile strength have been investigated.

2. Polymer Based Composites

2.1 Polypyrrole - Fly Ash Conducting Polymer Composites

Conducting polymer composites have attracted considerable interest in recent years because of their applications in electric and electronic devices. Polypyrrole has been regarded as one of the most studied conducting polymers. In situ polymerization of pyrrole was carried out in the presence of fly ash to synthesize polypyrrole - fly ash composites by chemical oxidation method. The polypyrrole - fly ash composites have been synthesized with various compositions (10, 20, 30, 40 and 50 wt %) of fly ash in pyrrole. The surface morphology of these composites was studied with Scanning Electron Micrograph (SEM). The polypyrrole- fly ash composites were also characterized by employing X-Ray Diffractometry (XRD) and Infrared Spectroscopy. The AC conductivity behaviors have been investigated in the frequency range 102-106 Hz. The DC conductivity was studied in the temperature range of 10-200^{0}C. The measurements of fly powder in the network impact the watched conductivity esteem. The outcomes got from these composites are more prominent logical and mechanical intrigue. Efforts have been made to understand the electrical conductivity and dielectric behavior of fly ash and it was observed that these materials possess very high relative dielectric constant of the order of 104. Such a high dielectric constant is one of the important parameters in capacitor fabrication and microwave absorption application [34].

3. 2.2 Epoxy Resin-Fly Ash Polymer Composites

The demand for the lightweight materials such as for surfaces of ships had led to the development of fly ash based thermosetting resins. In fibre epoxy composites the addition of fly ash led to a reduction of the density and increases the modulus of composites [35] [36] [37] [38]. With the addition of fly ash in epoxy resin - fly ash composite the compressive strength has been found to increase with an increase in fly ash particles. The increase is attributed to the hollowness of fly ash particles & strong interfacial energy between resin & fly ash. In SEM analysis it has been found that fly ash particles have been uniformly segregated [39].

4. Polyester - Fly Ash Based Composites

Fly ash polymer composites reinforced with natural fibres are also being used wood substitutes products. They have been developed using polyester as the matrix and jute fabric and fly ash as the reinforcement. The Jute fabric is laminated by passing through a polymer - fly ash mix and then cured. The number of laminates is increased to get the desired thickness. The product can be used in many applications like door shutters, partition panels, flooring tiles, wall panelling, furniture, panels for instant house and ceiling [40]. The developed material is stronger more durable, resistant to corrosion and cost effective as compared to wood.

L. Fly Ash Based Paints

The development of protective and decorative industrial coatings as solvent borne, cold curing, two pack epoxy systems, using fly ash as an extender, is reported. The effects of fly ash on coating properties and film characteristics are also discussed. A two body (high stress) abrasion test was conducted to assess the abrasion resistance of the coatings. The properties of fly ash that contribute to its usefulness as an extender are its abrasion resistance, chemical inertness, low oil absorption, and low specific gravity. The coatings that were developed have shown improved corrosion and abrasion resistance and also better resistance to chemicals and organic solvents. Fly ash can be a cost effective substitute for conventional extenders in high performance industrial coatings [41] [42].

M. Use of Fly Ash in Electromagnetic Interference Shielding

The use of fly ash as an admixture results in enhancement of the electromagnetic interference (EMI) shielding effectiveness from 4 to 8 dB at 1 GHz, whereas the use of silica fume as an admixture results in a negligible effect on the shielding effectiveness. The DC electrical resistivity is decreased slightly by silica fume but is essentially not affected by fly ash. Both fly ash and silica fume cause slight increase in the reflectivity. The effectiveness of fly ash for shielding is attributed to the Fe_2O_3 component in the fly ash.

The above results on shielding and resistivity suggest that the shielding provided by the use of fly ash is not only due to reflection, but is also due to absorption, which is attributed to some of the oxide components (particularly Fe_2O_3) in the fly ash. That Fe_2O_3 indeed enhances shielding is indicated by the increase of the shielding effectiveness from 6.1 to 12.5 dB (1.0 GHz) when the fly ash is replaced by Fe_2O_3 particles in the same proportion. The use of fly ash as an admixture results in an increase of the effectiveness of the cement paste for EMI shielding, due to the enhancement of the absorption and reflection of the radiation, as tested at 1.0 and 1.5 GHz. The Fe_2O_3 in the fly ash (15.4 wt.%, compared to <0.5 wt.% in silica fume) contributes to the shielding. By contrast, silica fume has little effect on the shielding effectiveness, although it decreases the resistivity slightly [43].

N. Bio-Mobilization of Fly Ash Nutrients through Vermitechnology

The accumulation of the heavy metal on the repeated addition of fly ash can be avoided by processing fly ash through vermitechnology and thus, prevents the hyper accumulation of these metals [44]. Organic waste sisal green pulp, parthenium and grass cuttings admixed with fly ash proved to be a potentially valuable material for *Eisenia foetida* (a species of earthworm) biomass and biofertilizer (vermicompost) production. Nitrogen, phosphorus and potassium content are found comparatively higher than the commercially available organic manures. The availability of nutrient enhances on the addition of fly ash to the soil. It is reported that Vermicomposted fly ash is an improvised product of degraded fly ash and humified organic wastes, facilitated with the help of the intestinal microflora of epigeic earthworms. This material exhibits considerably higher availability of different plant nutrients which leads to the production of the good crop and reduced use of mineral fertilizers. Application of this vermicomposted fly ash in agricultural fields has shown considerable potential in reducing the quantum of application of mineral fertilizers. Since vermicomposted fly ash is a good source of phosphorus and potassium, as fertilizers are largely imported from abroad, large scale adoption of this practice is likely to have a positive impact on the economy of the country also [45].

O. Fly Ash Pesticides

Though limited quantity could be utilized for this purpose, the dust formulations prepared using fly ash is cost effective. One of the modes for use of fly ash is identified as a pesticide [46] or carrier of insecticide [47]. Since the readymade formulation based on P. nigrum is not available, a simple low cost formulation was made using fly ash as filler and tested against rice bug [48]. Considering the need for the safe and cheap insecticide to manage the stored products insects, a study was undertaken to study the effect of Pn10D (P. nigrum 10% dose) with 90% fly ash as filler against the serious storage pest of pulses, pulse beetle Callosobruchus maculates [49].

III. CONCLUSION

It is estimated that coal ash production in the country has been reached 175 MT by 2012 and will 600 MT by 2030 as coal will remain a major source for power generation for many more coming years because of huge reserves. Presently, there is limited potential in the areas of manufacturing of Portland pozzolana cement, ready mix concrete, asbestos cement products, construction materials, road and embankments etc. though the use of fly ash is commercially profitable, high transportation cost for ash limits the utilization in land development and also in road embankment projects. For increasing ash utilization, development and innovation in new areas of ash utilization are essential. Further, the recycling of fly ash has become an increasing concern in recent years due to increasing land fill cost and current interest in sustainable development. It has led to realizations that alternative uses for fly ash are identified such as zeolites, cenospheres, geopolymers, polymer matrix composites, metal matrix composites, paint and coatings, distempers, ceramic products, light weight aggregates etc. Recently, few more application potential of fly ash as a raw material is studied in mineral wool, foam insulation products, fire abatement, light weight refractories etc. Fly ash is also investigated to study its impact on biomobilization of fly ash nutrients through vermitechnology and pesticidal activities.

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