Fly Ash Utilisation for Value Added Products
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Coal ash utilization in building and agricultural applications

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ABSTRACT

The increasing cause of disposal of coal ash in terms of environmental pollution stresses the urgent need to find its potential uses. In order to use coal ash fruitfully, various experiments have been carried out at RRL, Bhopal in making concrete block, brick, door shutters, etc. But these hardly consume about 5% of the total quantum of ash produced annually in India. Therefore, attempts have been made to utilise the coal ash in bulk quantity for conditioning wasteland, to increase its fertility.

Coal ash is basically an amorphous ferro-alumino silicate, which is also characteristically high in Ca^{++}, Mg^{++}, Na^{+} and K^{+}. The impact of coal ash in agriculture and in building application depends on various physico-chemical properties for which multi-disciplinary experiments have been conducted at lab scale in RRL, Bhopal and optimized the process details for pilot scale demonstration.

This paper deals with the use of coal ash in agriculture and the process of making construction materials and its properties. Crops, vegetables and cereals had grown and were found that the crop yield increased by coal ash application and there was no toxicity. Coal ashes have been used as filler and natural fibre jute as reinforcement in making polymer composite, which can be used as wood substitute materials. Coal ash addition increased the dimensional stability, hardness, durability, and wear resistance.

Key words : *Coal ash Utilisation; Fibre jute, Polymer composite, Glass re-inforced plastics*

1.0 INTRODUCTION

With the growing industrialization, energy generation is also increasing. Major part of this electrical energy is fulfilled through the coal fired thermal power plants. Coal ash is being generated in huge quantity in these thermal power plants, and causes various environmental problems.

In the recent decades, efforts have been made to utilize the huge quantity of Coal ash in road construction, land filling and producing building materials e.g. bricks, blocks, cement, clinkers, paints etc.[1-4] Recently efforts were also made to use Coal ash in bulk for waste land development.[5-6] Coal ash is a versatile materials and can be used in number of applications. Yet, no work has been reported on use of Coal ash for making wood substitute products.

Since the ban on use of timber in construction by the Central Public Works Department (CPWD), the premier construction agency of Government of India, various R&D institutions have given attention towards development of wood substitute materials per annum. The present demand of timber or alternative materials is about 4.5 million cubic meters. The substitute materials available in the market e.g. particle board, ply wood etc. are not able to fulfill the demand due to their inferior properties and cost factor and thus have limited use. Glass Reinforced Plastics (GRP) have excellent structural properties for use in building construction, but their costs are very high and also have some health hazards. As a result, the use is restricted.

The effects of Coal ash addition on the properties of composite material have been studied in detail. Spherical shape of Coal ash particles plays an important role in economic use of polymer. The scope for using jute fibre in place of traditional glass fibre is due to lower specific gravity and higher specific modulus of jute (1.29 and 40 GPa respectively) as compared with those of glass (2.5 and 30 GPa respectively). Earlier wood substitute products such as door shutters, flooring tiles, panels, partitions etc. were successfully developed using aluminium industries waste red mud and natural fibre with polymer matrix[7-11].

RRL Bhopal has developed quality bricks using coal ash. The strength of the coal ash brick is as high as 140 kg/ cm^2, water absorption capacity and shrinkage being less than 18 and 10% respectively. The precast concrete blocks are developed from aggregate, stone dust and coal ash. The compressive strngth is 80- 130 kg/cm^2 and water absorption being 5-10%. RRL has also developed paints using coal ash as a solvent borne, two-epoxy systems for protection and decoration. Coal ash paint offers improved resistance to corrosion, abrasion etc. The superiority of coal ash extender over other mineral extenders is due to its chemical inertness, less oil absorption and low specific gravity. Various R&D activities are in progress for fruitful utilisation of coal ash, but still the consumption of coal ash in India is very less in comparison to the developed countries.

Earlier work on biological effect of coal ash has been reported, where, both field and green house studies indicate that coal ash can be utilized in agriculture either as an amendant or as fertilizer, with no remarkable modification in the chemical composition of the circulating solutions. On the contrary investigations involving use of coal ash in agriculture show that coal ash produced undesirable effects on crop yield and on development of plants. The most frequently cited cause of these effects is B toxicity(3). Coal ash is shown to induce P deficiency, salt injury, pozzolanic effects and heavy metal toxicity to crops(12). Both, B and salt toxicity to plants can be reduced if the ash is preleached. Several vegetables and millets when grew in acidic ash (10%) showed enhanced uptake of As, B, Ca, Cu, Fe, Hg, Mg, Mo, Sb, Se etc. contributing to variation in crop yield so that uptake was proportional to ash application rate

In other cases, coal ash produced beneficial effects on crop yield and development. These effects are usually observed when coal ash corrects nutrients deficiency in the soil to which it has been introduced(13). Coal ash is known to improve crop growth by neutralizing soil acidity[14]. In some cases the beneficial influence of coal ash on plant growth may result from a combination of pH adjustment and nutrients addition[15].

Admixing of coal ash to soil increases the concentration of the elements essential for plant growth, referred as micronutrients required in very small amounts for the growth and their metabolic activities like formation of vitamins and enzymes. The changes in the morphology of plants and evidence of diseases are useful aids in geobotanical prospecting and morphological changes in plants under the influence of various air pollutants and results indwarfism, chlorosis of leaves, abnormally shaped fruits, changes in growth form and decrease in the yield[7].

In order to utilize coal ash as a soil modifier and micronutrients, various experiments have been carried out both in lab. and pilot scale. In order to establish the universal acceptance of the product grown in such amended soil and suitability of the food quality, the presence of the heavy metals is tested.

This paper emphasizes the use of coal ash for converting wasteland into agriculturally productive land and Development of composite materials using coal ash as filler and jute, a natural fibre as reinforcement in a polymer matrix.

2.0 MATERIALS AND METHODS

2.1.Coal Ash in Building Application

2.1.1 Coal ash

Coal ash sample was collected from electrostatic precipitators of a coal based thermal power plant owned by Madhya Pradesh Electricity Board situated at Sarni.

2.1.2 Jute Fibre

Jute fibre is a bast or stem fibre of a plant. It is a ligno-cellulosic fibre, presently used for packaging. In the present study, woven mat of jute fibre weighing 300 gm/m^2 was used as reinforcement, after treating with suitable fire retardent material.

2.1.3 Polymer

General purpose polyester resin of fire retardent grade (Acrolite 572) was taken from the market. It is a thermoset type of resin, extensively used for making glass reinforced plastics for various domestic and structural applications.

2.1.4 Additives

In order to initiate the polymerization process, Methyl Ethyl Ketone Peroxide (MEKP) and Cobalt Naphthonate were used.

2.1.5 Preparation of Composites

The composites were prepared by hand lay-up technique. Polymer and Coal ash were mixed in the ratio of 50:50 and then curing catalysts were added $\simeq$ 2% each by weight of polymer followed by thorough mixing. A thin layer of this mix was spread over moulds. A layer of jute cloth was put on it and covered again by a thin layer of mix. During this investigation, it was found that for achieving one mm finished thickness, one layer of jute is required. Therefore, for making a laminate, 5 mm thick, 5 layers of jute fabric are required. The laminates thus prepared were cured at a pressure of 0.5 MPa for one hour at room temperature (27±2°C) and post cured in an oven at 80°C for 24 hours.

2.1.6 Testing of Composites

The physical and mechanical properties of the Coal ash jute polymer composite were determined as per the procedures given in IS : 2380 - 1977. Fire retardency test was conducted according to IS :6746 -1972.

2.2. Coal Ash in Agriculture

2.2.1. Site selection

The study site selected to conduct the experiment is located at Rihand Nagar in the premises of National thermal Power Corporation (NTPC) U.P. and NALCO, Orissa. Coal ash was transported from the respective power plant ash dyke. The soil type at Rihand Nagar is slightly alkaline in nature and the coal ash is of neutral. The soil type at Angul Orissa is slightly acidic in nature and the coal ash is slightly alkaline. Prior conducting the experiments, surface and sub-surface samples were collected from different locations to evaluate the soil properties so as to assess its ability for plant life.

2.2.2. Soil Quality Analysis

Wasteland soil, coal ash, and soil treated with coal ash were tested to assess its quality in terms of its nutritional and heavy metals content. The analyses of these metals were done by adopting the standard analytical technique and the Atomic Absorption Spectrophotometer (Model No. GBC 902 beam AAS) and Orion Analyser (Model No. EA 940).

2.2.3. Field preparation and process of coal ash application and vegetation

Pilot scale experiments were carried out, which covered an area of 5 acre each by adopting the conventional techniques such as field preparation, ploughing, levelling, preparation of beds and furrows etc.

Coal ash was transported from ash dyke in dry state in the moisture range of 4.8%. and admixed with soil at the concentration of 25% (w/w) i.e. 265 tonnes/acre. This is the most appropriate concentration for modifying the soil texture together with releasing essential plant nutrients whereas optimized at lab. scale experiments[16]. The crops, vegetableand cereals were grown under identical application of chemical fertilizer, farm yard manure and other parameters. Studies on growth of plants in terms of its height, leaf area and crop yield were carried out with respect to the soil treated with coal ash and control soil where no ash was mixed.

3.0 RESULTS

Table-1 shows the Particle Size distribution of fly ash and Table-2, the chemical composition. The results of various tests conducted on Coal ash-JUTE Reinforced Polymer Composites (FJRPC) were compared with other related building materials. Density of FJRPC is comparable with PVC and GRP, but it is heavier than MDF, Rice husk board, particle board and teak. On comparing the values of moisture content, FJRPC has benn found to have minimum moisture content than that of agro based materials(5 to 15 %). Flexural strength results indicate that FJRPC is 5-6 times stronger than MDF, Rice Husk Board, particle board and teak.

The characterization of soil, coal ash, and soil treated with coal ash were evaluated in terms of its nutritional and heavy metal contents. The crop response to various elements mainly heavy metals grown in pure soil (wasteland soil) and admixed soil were very marked. Table-3 shows the physical properties of coal ash, wasteland soil and soil treated with coal ash and Table-4, the concentration of primary, secondary and micro nutrients present in wasteland soil and ash mixed soil. The concentration of all the heavy metals was found to be in the range of tolerance limit and could not exceed the toxic limit of heavy metals.

Table 1 : Particle size distribution of coal ash

Particle size (μm)	Finer by volume (%)
125.00	100
112.80	99.0
92.79	98.56
69.21	91.41
51.62	79.14
42.45	69.57
31.66	55.59
21.42	40.04
15.97	30.82
10.81	21.21
7.31	14.02
5.45	9.98
3.03	4.82
1.03	0.60

Table 2: Chemical composition of coal ash

Constituent	Content by weight (%)
SiO_2	57.64
Fe_2O_3	6.47
Al_2O_3	15.00
Na_2O	0.89
CaO	1.89
MgO	0.98
K_2O	0.67
Loss on ignition	0.52

Fig 1 shows the yield of the crops, vegetables etc. The yield was found to be more in ash mixed soil as compared to the control soil. Morphologically, also the growth of plants in the coal ash admixed soil was found better than the control soil. Fig. 2 shows a view of experimental site at Nelgiri, Rihand.

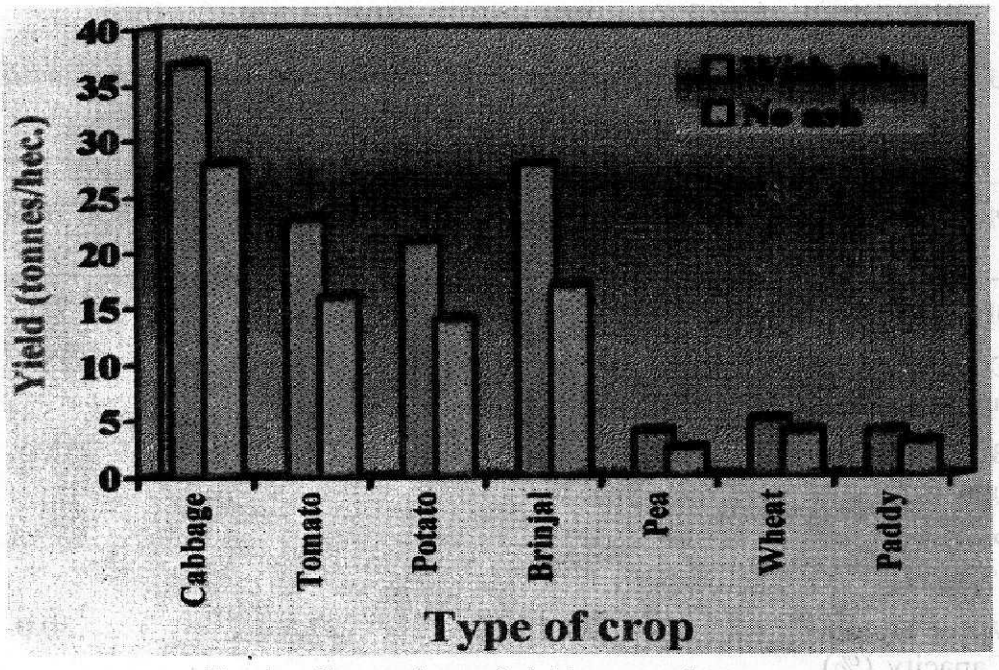

Fig. 1 : Comparison of yield (tonnes/hectare)

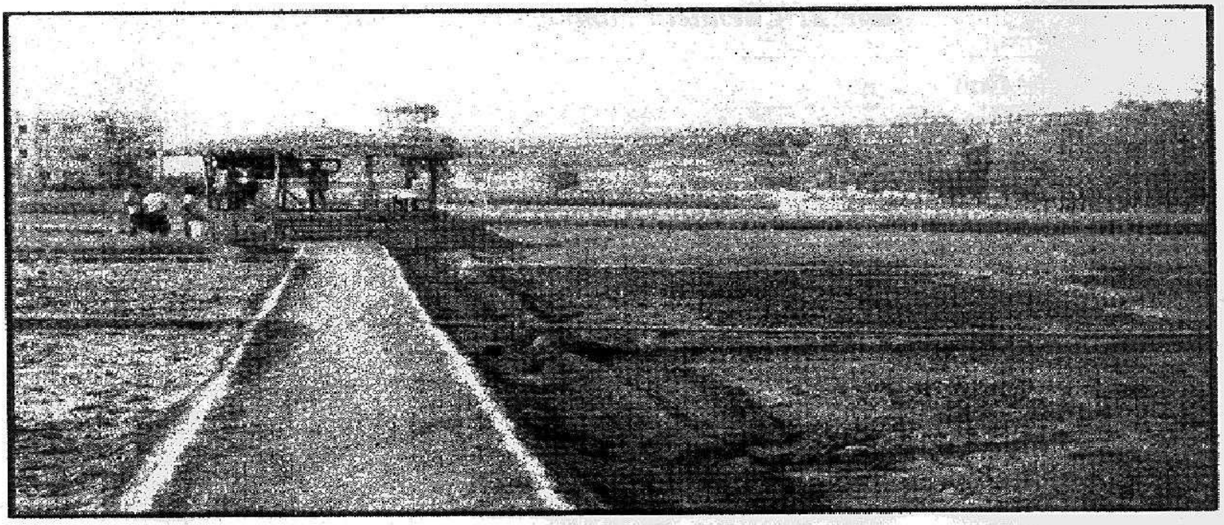

Fig. 2 : View of the experimental site at Nilgiri NTPC Rihand

Table 5 shows the elements present in the food samples grown in wasteland soil. It was observed that there was no hyper accumulation of heavy metals in the food samples grown in the test soil as compared to the control soil. The concentration was found to be in the permissible limit and comparable to the limits mentioned by PFA, 1954 Act, 1994, with 1995 supplement edition[6].

Table 3 : Physical properties of coal ash; wasteland soil; soil treated with coal ash (Rihand Nagar)

Physical Properties	Coal ash Soil	Wasteland	Soil treated with coal ash
pH	7.8	7.3	7.6
Conductivity (umhos cm^{-1})	195	275	286
Bulk density (gm cc^{-1})	1.16	1.31	1.26
Porosity (%)	47.1	56.5	53.5.8
Water Holding Capacity (%)	34.5	27.5	30.0

Table 4 : Chemical analysis of Wasteland soil coal ash soil admixed with 25% of coal ash (Rihand Nagar)

Parameters analysed	Wasteland soil	Coal ash	Soil treated with coal ash
Organic matter (%)	0.845	0.429	0.727
PRIMARY NUTRIENTS (%)			
Phosphate	0.032	0.030	0.094
Potassium	0.120	0.280	0.830
SECONDARY NUTRIENTS (%)			
Calcium	0.320	0.480	0.510
Magnesium	0.388	0.230	0.395
Sulphate	0.057	0.081	0.086
MICRO NUTRIENTS			
DTPA Extraction (ppm)			
Iron	12.0	26.5	19.4
Zinc	1.12	1.40	1.80
Copper	0.45	0.46	0.47
Manganese	2.0	3.8	3.5

Table 5: Heavy metal analysis of the vegetables in Mg gms^{-1}

S.No	Elements	Vegetables /cereal/crop					
		Cabbage	Tomato	Brinjal	Potato	Pea	Wheat
1.	Copper	1.804	10.997	9.026	3.240	6.421	3.570
2.	Zinc	4.443	25.295	27.968	14.10	24.960	8.860
3.	Cadmium	0.144	0.012	0.119	0.150	0.145	0.050
4.	Lead	2.310	12.269	2.272	1.650	2.886	0.980
5.	Iron	24.540	96.291	139.880	128.300	71.770	37.680
6.	Boron	8.331	10.814	8.693	6.980	7.460	7.420

4.0 DISCUSSION

Water absorption, which is an important property in selecting appropriate material for doors in buildings, is only 1.3 %, which is very less in comparison to other materials.

This makes the composites very durable, as the durability of any material is water uptake dependent. Due to this property, it has better out door applications. Fire retardency test also indicates that FJRPC has self extinguishing property. It is due to the combined effect of fire retardent additives and fly ash. Since the major constituents of fly ash are silica and alumina as it can be seen from Table-2, contributing towards the improved wear resistance and hardness as compared to the composite without flyl ash. The out door exposure and indoor weathering studies carried out in ATLAS weather-o-meter showing better performance as compared to other industrial waste polymer composite. Mostly the particles of fly ash are spherical in shape[17] and has wide range of sizes as can be seen in Table -1. Due to this, the composite with fly ash is a dense material and can be incorporated in the polymer upto 50% by weight of composite.

The result from the physical properties reveals that by the application of coal ash on wasteland soil the porosity has been increased in clay soil and decreased in sandy soil thus raising the water holding capacity by about 8%. The application of coal ash modifies the soil texture from sandy to silty loam which is more appropriate for agri-cultural purpose. The morphological structure of coal ash results in spherical and hollow shaped and it is also found that small size particles are inherent into the bigger size particles. These type of morphological structures may be the cause for increasing the water holding capacity. The particle size and specific surface area of coal ash have also influenced for soil modification.

A significant correlation between the concentration of the heavy metals and its exposure to plants in terms of yield are with in the permissible limit at a constant application of coal ash (25%) for a limited time period of two years.

Mn, Zn, Cu, Mo, Fe are the essential nutrients required by the plants for their growth. From Tables 2 and 3, it is evident that the yield in the wasteland soil admixed coal ash at the rate of 25% (w/w) was of good quality. The slightly alkaline nature of the soil, due to which, the heavy metal toxicity is rarely found in the food samples as well.

Results from Table-3 reveal that coal ash applications on wasteland soil maintained the soil pH in the range of alkalinity which is being helped in detoxifying the hyperaccumulation of manganese and aluminium due to less release of iron. Sometimes copper induces the iron deficiency(18) but here the results show lesser concentration of copper which helps in avoiding the iron from being induced Many forms of copper exists the uptake in the soil and their mechanism of uptake differs from plant to plant.

It is reported(19) that if the organic matter and other nutrients are in abundant supply, then Pb^{3+} toxicity does not occur. The presence of phosphate is a major factor in the precipi-tation which results in the detoxification of lead from the system. The excessive accu-mulation of lead reduces the rate of photosynthesis in the plants and mitochondrial electron transport(1, 2). The addition of coal ash on sandy soil decreases the porosity, theirby increasing the water holding capacity. Experimental results show that the or-ganic matter and organic carbon have been raised due to the higher water holding capacity and thus, supported the plant growth from the excessive accumulation of lead.

The problem of recovery of heavy metals is strongly bonded to the problem of metal leaching. Indeed, after the ions have been solublised, they must be recovered either to avoid problem of environmental pollution or to react with the increasing need for metals in industries. As reported[20] earlier, iron, copper, magnesium, cobalt and cadmium compounds can be recovered by means of Sphaerotilus natans. The detailed work with the microbial processes in the accumulation of metals is yet to explore as far as the coal ash is concerned. Although some work has been done related to Cu^{2+} and Cd^{2+} accumulation by Bacillus subtilis from coal ash (Singh and Chauhan, 1993). Since microorganisms use metals as terminal electron acceptors, or reduce these by detoxification mechanism, have important influence on the geochemistry of acquatic sediments, submerged soils and terrestrial sub-surface. The microbial metal reduction may be manipulated to aid in the remediation of environment.

5.0 CONCLUSION

Coal ash can be utilised to make polymer composites, which have excellent structural properties in comparison to other agro based related materials. This process needs fly ash up to 50% of the total raw material requirement and keeping in view the demand of wood substitute material, a considerable amount of fly ash can be utilized. If industry be set-up based on this technology, it is hoped that it will help in reducing the coal ash disposal and de-forestation problems and thus environmental hazards

From the point of view of agricultural application, the results so far obtained are found that coal ash could be used as a soil modifier and micro fertilizer for improving soil fertility. The present studies assessed the use of coal ash in agriculture and its impact on vegetation. The results from the experiments reveal that the vegetables such as tomato, potato, brinjal, cabbage, etc., crops like wheat, sunflower, etc., cereals, such as pea, etc., were grown in wasteland soil admixed with coal ash and found remarkable increase in the yield i.e., around 42% of the average. The qualitative analysis on crops yield reveals that the heavy metal uptake by plants and fruits are within the permissible limit and meeting the food quality standard.

It also reveals from the result that the improvement on the fertility of wasteland by coal ash application depends on the method of application in relation to physico-chemical, mineralogical and morphological properties, reactivity of ash, climatic conditions, moisture content under examination and finally the percentage of coal ash application. The technology developed at RRL, Bhopal for the improvement of the fertility of wasteland by coal ash application can be a unique solution for converting wasteland to productive land mass followed by protecting the environmental pollution.

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