An Assessment of Physical Properties of Coal Combustion Residues w.r.to Their Utilization Aspects

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***Abstract*-Coal Combustion produces huge amount of residues called as Coal Combustion Residues collectively. Nowadays, these are used for bulk utilisation applications like mine back filling, as agricultural amendments, in construction of roads, bricks etc. To achieve the maximum utilisation of coal combustion residues in diverse applications it is necessary to know about its various properties. An insight into physical properties of coal combustion residues is a must in order to apply it in construction and geotechnical applications. This paper aims at presenting the physical characteristics of these coal combustion residues from four different thermal power plants of India for their possible utilisation.**

Keywords-Coal combustion residues; Fly ash; Bottom ash; Pond ash; Physical characteristics

I. INTRODUCTION

Environmental pollution by the coal based thermal power plants is cited to be one of the major sources of pollution all over the world. It affects the general aesthetics of environment in terms of land use, air, soil and water and health hazards in particular and thus leads to environmental degradation. Coal combustion residues (CCRs) are a collective term referring to the residues produced during the combustion of coal regardless of ultimate utilisation or disposal. It includes fly ash, bottom ash, boiler slag, and fluidised bed combustion ash and other solid fine particles (Asokan, 2003 [1]; Keefer, 1993 [2]).

In India, presently coal based thermal power plants are releasing 105MT of CCRs which possess major environmental problems (Kumar and Mathur, 2004 [3]; Sharma et al., 2003) [4]).

In this paper, we report study of physical characteristics from four thermal power plants of India. Dry fly ash has been collected through Electro Static Precipitator (ESP) in dry condition as well as pond ash in semi-wet condition from ash ponds. In India most of the thermal power plants do not have the facility for automatic dry ash collection system. Commonly both fly ash and bottom ash together are discharged as slurry to the ash pond/lagoon.

In 1995 CCRs generation in India was only 40MT. Although the rate of CCRs generation is not uniform, an average of 7.4% of annual increase in CCRs is witnessed from 1995 to 2004. It is obvious that the CCRs generation increased when the power generating capacity increased from the last five decades from 1350MW in 1947 to ~100,000MW in 2004 to cater the need of the Nation. Out of the present installed capacity, about 75,000MW of electricity is from the coal-based thermal power stations, ~20% is from hydro-electric plant and the rest is from nuclear and non-conventional energy sources (Kumar and Mathur, 2004 [3]; Mishra, 2004 [5]; Roongta, 2000 [6]). India has about 211 billion tons of coal reserves, which is known to be the largest resource of energy and presently ~240MT of coal is being used annually to meet the Nation's electricity demand. In terms of energy, the rate of annual increase in power generation in India is ~5% and at this rate the annual power generation is expected to be 180,000MW by the year 2020, which may release about 190MT of CCRs per annum. However, to achieve sustainable development the Nation may have to generate at least 260,000MW of power (i.e. 10% increase in rate of annual electricity generation) by the year 2020 and as a consequence 273MT of CCRs is expected to be released. Keeping in view the formidable future problems due to these huge quantities of CCRs to achieve Sound Environmental Management, it is very crucial time for CCRs utilization and increase in acceptability of CCRs based products among the end users.

Potential Avenues of Fly Ash utilization

- Fly Ash Bricks
- Dry Fly Ash used as raw material Cement
- Fly ash used in underground mine stowing
- Use in Agriculture
- Roads and Embankment construction
- Fly ash used as fill material
- Used as admixture in concrete
- Improvement of soil properties

II. MATERIALS AND METHODS

A. Sampling

Fly ash samples were collected from Bokaro, Farakka, Tata Power and NTPC Korba thermal power plants. 1kilogram of sample was collected every day till 7 days. All the 7 samples collected from each thermal power plant were mixed together to result in a homogenised representative sample of 7 kilograms. The samples of all the power plants were collected by the same procedure.

1) Materials

Fly ash was supplied from four thermal Power Plants in India. Sodium hydroxide was procured from CDH, New Delhi, India. Sulphuric acid was supplied by Ranbaxy, New Delhi. All the chemicals were used as received, without further purification.

B. Methods

The physical characteristics of the samples of fly ash from four thermal power plants were studied in detail. The interpretation of the physical characteristics helps us to derive the suitability of CCRs for varied applications.

1) Moisture Content

100 gm of the CCR samples were dried in separate crucibles at a temperature of 105-110^{0}C for an hour in an oven. Then the crucibles were cooled in desiccators and weighed. Loss of weight of the samples was calculated to determine the moisture content. Table 3.1 gives the Moisture Content of the CCR Samples.

$$\text{Moisture content} = \frac{Ww - W_d}{W_d} \times 100 \quad (1)$$

Where,

Ww = Wet weight (g)

W_d = Dry weight (g)

2) Water Holding Capacity (WHC)

CCR samples were dried for an hour in an oven maintained at 105^{0}C-110^{0}C. A circular box was taken and a filter paper (Whatman no.1) was placed at its perforated bottom. The weight of the box with the filter paper was taken. Oven dried samples were placed in the circular box. The box was placed in a petridish of 10 cm diameter containing water, for 12 hrs, so that water entered the box for complete saturation of the sample. The box was taken out from the water, dried and finally its weight was measured.

Water holding capacity was computed using the following equation:

$$WHC(\%) = \frac{W_3 - W_2}{W_2 - W_1} \times 100 \quad (2)$$

Where,

W_3 = Weight of box with water saturated soil (g)

W_2 = Weight of box with dried soil (g)

W_1 = Weight of empty box (g)

3) Permeability

The permeability of the CCRs samples was determined using a falling head permeability apparatus. This consists of a metallic mould, 100 mm internal diameter, 127.3mm effective height and 100 ml capacity according to IS: 2720 (part XVII). The sample was placed inside the mould and a standpipe was attached to the top of the sample. The whole assembly was placed in a chamber filled with water to the brim at the start of the test. The standpipe was filled with water to the required height. The test was started by allowing the water in standpipe to flow through the sample to the chamber where it overflows and spills out. As the water flows through the sample, the water level in standpipe falls. The time required for the water level to fall from a known initial height (H_1) to a known final height was (H_2) noted. The head was measured with reference to the level of water in the chamber. The coefficient of permeability was calculated using the formula given below.

$$K = \frac{2.3 \times a \times L}{A \times t} \times \log \frac{H_1}{H_2} \quad (3)$$

Where,

k = Coefficient of permeability (cm/sec)

t = Time interval (sec)

a = Cross sectional area (cm^2)

L = Length of specimen column

H_1 = Initial head (cm)

H_2 = Final head (cm)

A= Area

4) Specific Gravity

Specific gravity of the CCRS samples was determined using the density bottle method. The density bottle was fitted with a stopper having a hole. As per IS: 2720 (Part III) 1980, density bottles of 50 ml capacity were used. The density bottles were cleaned, oven dried at 105-110^{0}C and then cooled. Initially, the mass of the empty density bottles with stopper M was measured. About 5 to 10 gm of oven dried CCR samples were taken in the bottles and weighed (M_2). Kerosene oil was then added to cover the samples. The samples were allowed to soak oil for about 2 hrs. More oil was added to the bottles to make it full. The bottles with sample soaked in oil and stoppers were weighed (M_3). The bottles were then emptied, filled again with distilled water to the same mark as in the case of oil. Again, the mass of the bottles with distilled water was noted (M_4). Finally, the mass of the bottles with oil was noted. (M_1). Specific gravity of the sample was calculated as given below:

$$\frac{G = (M_2 - M_1)G_k}{(M_2 - M) - (M_3 - M_1)} = \frac{M_d G_k}{M_d - (M_3 - M_1)} \quad (4)$$

Where,

M_d = Dry mass of soil (g) (5)

G_k = Specific gravity of kerosene oil at the test temperature (g/cm^3)

5) Bulk Density

To determine the bulk density, oven dry weight of a known volume of CCR sample was taken and mass per unit volume was calculated. The sample was rammed sufficiently to give normal compaction that can be observed in the field. The following relationship was used for computing the bulk density of the coal combustion residue samples.

$$V = \frac{Wd}{v} \quad (6)$$

Where,

V = Bulk density

W_d = Weight of oven dried sample

v= Volume occupied by the sample

6) Atterberg's Limits

The water content at which the soil or soil like material changes from one state to other is known as consistency limits or Atterberg's limits. The consistency of a fine-grained soil refers to the physical state in which it exists. A fine-grained soil can exist in four states, namely, liquid, plastic, semisolid and solid states. Atterberg's limit consists of determination of

liquid limit, plastic limit and shrinkage limit of soil or soil like material.

The water content at which the soil changes from the liquid state to the plastic state is called as liquid limit. It is the minimum water content at which soil is still in liquid state but has a small shearing strength against flowing, which can be measured by standard available means. In the test, a portion of wet material was placed in a standard cup, and a groove of standard depth and dimension was made in the material. The test apparatus then dropped the cup 25 times from a height of 10 mm at a rate of 2 drops per second. If the groove flow shut over a distance of 13 mm, the material was said to have reached its liquid limit. If the liquid limit was not reached in the test, then a moisten sample portion was tested in the apparatus until the liquid limit was reached .The plastic limit was taken as the minimum water content required to make a soil like material behave as a plastic mass rather than loose individual grain. An attempt was made to roll a moistened mass of material into a thread about 3.2 mm in diameter. Below the plastic limit the material would crumble. The shrinkage limit is the value of moisture content at which further loss of moisture will not result in any change in moisture content.

7) Proctor Test (IS: 2720 Part VII)

Proctor Test was used to determine the OMC (Optimum Moisture Content) and Maximum Dry Density (MDD) to assess the amount of compaction and the water content required in the field. From the experiment, a relationship between the water content and the dry density can be obtained and this can further be made use of in finding out MDD and OMC. For the purpose of experiment about 3 Kg of air-dried CCR sample passing through 4.75 mm sieve was taken. Water was added to the sample to bring it to about 8% level. The CCR sample was mixed thoroughly, covered with a wet cloth and left for maturing for 15 to 30 minutes.

In the experiment, as per IS: 2720 (PartVII), 1965, a mould of 1,000 ml capacity with an internal diameter of 100 mm and an internal effective height 127.5 mm was used. The mould was cleaned, dried and greased lightly. The mass of the empty mould with base plate, without collar was taken. The collar was then fitted to the mould. It was placed on a solid base and filled with matured ash sample to about one third height. The soil was compacted by 25 blows of rammer, with a free fall of 310 mm. The blows were evenly distributed over the surface. The sample surface was scratched with spatula before the second layer was placed. The mould was filled to about two-third height with the ash sample and compacted again by 25 blows. Likewise, the third layer was placed and compacted.

The mass of the mould base plate and the compacted ash sample was taken and then the mass of the compacted sample was determined. This way the masses of all the ash samples were determined. The dry density was calculated from the bulk density and the water content.

The following relationship was used for computing dry density

Dry density,

$$\rho_d = \frac{\rho}{1+w} \tag{8}$$

Where, ρ_d = Dry density

ρ = Bulk density (gm/ml)

w = Water content (%)

Compaction curves were plotted between water content and dry density. The water content corresponding to the MDD was found from the graph and is commonly known as OMC or Optimum Water Content (OWC). Table 8 gives the OMC and MDD of the CCR Samples.

8) Texture Analysis (USDA Method/International Pipette Method)

The relative proportion of sand, silt and clay in a soil or soil like sample is determined by texture analysis. As all the particles do not exist as separate ones, the accuracy of estimation depends entirely on complete dissociation of the sample prior to fractionation. For this purpose all particles are first separated from each other by oxidizing the organic matter by using a dispersing agent and the amount of each size group is determined by withdrawing a aliquot of the suspension after a pre-calculated time based on Stoke's equation.

4 to 5 ml of 30% H_2O_2 was added to 10 gm of air dried sample (<2mm size) in a 500 ml beaker and covered with a watch glass. After reaction slowed down, 4-5 ml more of H_2O_2 was added and sample was digested on hot plate. If the organic matter had not yet been destroyed, further 20 ml of 30% H_2O_2 was added and suspension was gently boiled until the reaction subsided. After all the organic matter was destroyed, the suspension was further heated for about 30 minutes to remove the remaining H_2O_2. Then 25 ml of 0.1(N) HCl followed by five portions of distilled water. Now this sample was hydrogen saturated and it was reweighed (A). The hydrogen-saturated sample was then transferred to a 2000 ml glass bottle and 10 ml of sodium hexametaphosphate was added and stirred for about 2 hrs. Thereafter, the suspension was transferred to 2000 ml measuring cylinder and the volume was made up to the mark. The measuring cylinder was then placed in a constant temperature chamber. The special mechanical analysis pipette (10 ml) was used to withdraw 10 ml aliquot of the suspension from 5 cm depth after the desired lapse of time. At 25^0C, 2 min 48 sec (B) was elapsed time for silt and clay and 3h 28 min (C) for clay only. The pipette was lowered to 5 cm depth five second before the correct time. Aliquot was taken in 100 ml beaker and evaporated to dryness at 105^0C and reweighed. The sample was slowly decanted and bottom sediment (sand) collected, dried and weighed.

The following relationships were used in computation:

10 ml aliquot was in 1/100 of 1000 ml suspension-

$$\%\ \text{silt} + \text{clay} = \frac{\text{wt. of } 20\mu \text{ sample (B)}}{\text{wt. of H sat. sample (A)}} \times 100 \tag{9}$$

$$\%\ \text{Clay} = \frac{\text{Wt. of } 2\mu \text{ sample (C)}}{\text{Wt. of H sat. Soil (A)}} \times 100$$

$$\%\ \text{Silt} = (1) - (2)$$

$$\%\ \text{Clay} = \frac{\text{Weight of Sample (D)} \times 100}{\text{Weight of H saturated soil (A)}}$$

9) Particle size analysis

Particle size distribution of the coal combustion residue samples was analysed through the following experiments.

a) Sieve Analysis

It is a method of separation of soils into different fractions based on the particle sizes. It expresses quantitatively the mass proportionate of various sizes of particles present in the sample. It is shown graphically in the particle size distribution curve. A known quantity of ash sample was sieved through a set of sieves. As per the IS: 1498-1970, the sieves are designated by the size of the opening in mm or microns (1micron=10^{-6} m=10^{-3} mm). The diameter of a sieve pan is generally about 20 cm. A known quantity of each CCR sample was taken and dried in oven at about 110^0C. Sieves of 72, 100, 150, 240, 300, 325 and 400 mesh sizes were placed one over the other with decreasing aperture size from top to bottom. A known quantity of each sample was placed in the top sieve and covered. Bottom pan was placed at the bottom of the finest sieve. The set of sieves was then subjected to mechanical shaking through the shaker, where it was sieved for 10 minutes. The mass of the sample retained on each sieve and on the pan was weighed and percentage of different sizes was calculated. Sieves used in this analysis ranged in size from mesh 72 to mesh 400 (212 micron to 38 micron).

10) Proximate analysis

The proximate analysis of coal combustion residue sample was carried out to find out moisture, ash, volatile matter and fixed carbon content.

a) Volatile matter

1.0 gm of air-dried CCR sample was taken into a standard VM crucible, covered and heated in a muffle furnace at about 5-7 minutes at about 500^0C. Crucible was then removed from the muffle furnace and cooled.

$$\% \text{ V.M.} = (\text{Loss in wt. x100}) - \% \text{ moisture} \quad (10)$$

Where,

V.M.: Volatile Matter (in %)

b) Ash

1.0 gm of air-dried CCR sample was taken in a silica crucible and heated for 2 hours in an oxidizing atmosphere in a furnace at about 750^0C. The crucible was cooled in a desiccator and weighed.

$$\% \text{ ash in sample} = \frac{\text{Wt. of residues}}{\text{Wt. of sample}} \times 100 \quad (11)$$

c) Fixed Carbon

The Fixed Carbon (5) was calculated by putting the above values in the formula as given below:

$$\text{Fixed C (\%)} = 100 - \text{V.M.} + \text{Ash} + \text{Total Moisture (\%)} \quad (12)$$

Where, Fixed C = Fixed Carbon (%) (13)

V.M. = Volatile Matter (%)

Ash = Ash (%)

11) Loss on Ignition

1.0 gram of CCR sample was heated at 105^0C for one hour. The LOI was calculated as below.

$$\text{I.M.}(\%) = \frac{\text{Diff. in wt. of residues}}{\text{Wt. of sample taken}} \times 100 \quad (14)$$

Where,

I.M. = Inherent Moisture (%)

Again 1.0 gm of CCR sample was taken in a silica dish and heated in a muffle furnace for 1 hr at 850^0C.

$$\text{L.O.I.} = \frac{\text{Diff. in residue wts.}}{\text{Wt. of sample taken}} \times 100 \quad (15)$$

Where,

L.O.I. = Loss in Ignition (%)

III. RESULTS AND DISCUSSION

TABLE 1 PHYSICAL PROPERTIES OF CCR SAMPLES

Parameter	TPP-1	TPP-2	TPP-3	TPP-4
Moisture content (%)	0.400	0.390	0.245	0.515
W.H.C (%)	79.50	89.80	76.26	79.62
Permeability x10^{-5}(cm/s)	2.989	2.525	2.063	3.815
Specific Gravity (g/cc)	1.865	1.755	1.848	1.947
Bulk Density (g/cc)	0.535	0.659	0.584	0.611
OMC (%)	32.93	66.13	45.24	34.63
Maximum Dry density (g/cc)	1.092	1.023	1.070	1.104
Loss on Ignition (%)	13.02	11.4	16.57	13.97
Proximate analysis				
Volatile matter (%)	3.26	2.97	2.68	4.24
Ash (%)	72.42	78.94	75.12	71.61
Fixed carbon (%)	10.09	9.46	8.87	10.43

The moisture content of the CCR samples varied from 0.245 (Bokaro) to 0.515 (NTPC Korba). The fly ash samples were found to have low moisture content compared to bottom ash. Moisture content depends on the type of storage or disposal being followed for any particular material and the method of sample collection employed. It is an important parameter as it helps in finding out the amount of moisture to achieve good compaction, the plastic or liquid limit behaviour during handling. The TPPs under study followed a wet disposal system and hence the chances of CCRs getting airborne during handling are ruled out. Wet conditions prevent the problem of air pollution which arises in dry state. Proper moisture has to be maintained in ash ponds during summers else the water of ash ponds evaporates and aggravates the trouble. On the other hand High moisture

content is undesirable for use in manufacture of Portland cement.

The water holding capacity of the CCR samples was found to be above 50%. WHC was higher for fly ash samples compared to bottom ash and pond ash samples. High values for WHC indicates the presence of fine particles with greater surface area leading to elevated levels of water adsorption. WHC of any material is controlled by chemical and physical nature of the material. Maximum WHC reflects the condition when all pore spaces of the material get water logged and no space is left. Higher values of WHC may also be attributed to the morphological features of the samples. The spherical shaped particles provide more space for retention of water. CCR samples showed higher WHC values (76.26 to 89.80 for Bokaro and Tata Power respectively) which is appreciably higher than normal soils (30 –40%).

Permeability depends upon the particle size, degree of compaction and pozzolanic activity. Lower permeability values are due to fine nature of particles. Low permeability is a problem when used as a stowing material. Bottom ash samples had higher values of permeability due to coarser nature of particles and absence of fines compared to fly ash samples.

Presence of unburnt carbon and cenospheres may be the reason for low specific gravity of the samples. The variation of specific gravity may be attributed to a combination of factors like gradation, particle shape and chemical composition. Low values of specific gravity could be explained by presence of hollow cenospheres from which entrapped air cannot be removed.

Bulk density of almost all samples was less than 1.000g/cc except for some samples. The bulk density values of all the samples were less than that of normal soils. This can again be attributed partly to presence of hollow cenospheres.

Plastic limit could not be determined due to non-cohesive and non-plastic nature of CCRs. The materials could not be rolled which is necessary to carry out the plastic limit test. These properties form a part of a set of parameters collectively known as “Index properties” and give the basic idea to determine the suitability of geotechnical applications.

The shrinkage limit of the samples could not be conducted as fly ash is brittle by nature. The extraction of shrunk sample from the shrinkage dish in a single intact solid form was not possible.

The OMC and MDD are useful to measure the density achievable for good compaction as a function of moisture. The observations of this analysis were made use in preparation of the column for the leaching experiments. The columns were packed to OMC condition.

Un-burnt carbon in CCR is highly undesirable, as it reduces the strength of mortar and concrete due to their deleterious effect. High carbon content retards the pozzolanic activity. High values of loss on ignition in case of Pond ash samples can be correlated with high values of fixed carbon percentage.

Sieve analysis reveals that the particle size range varies widely. For Pulverised Fuel Combustors, it is desirable that the particle size of the feed coal should be less than 75 Am for efficient burning. However, in the present case the percentage of larger coal particles is quite high. This results in inefficient combustion. After the larger coal particles had undergone de-volatilisation and char burning, substantial portion of mineral matters left are quite large. It appears that these have not undergone further fragmentation / transformation and melting. Hence, sieve analysis of the feed coal has given a new insight on the ash formation. The % weight fractions obtained from sieving could not be correlated with the particle size distribution profiles obtained from the particle size analyser. The reason being manual sieving along with shaking leads to passing off the particles through the finer mesh dimensions longitudinally which otherwise could not have passed laterally.

TABLE 2 PARTICLE SIZE ANALYSIS OF CCR SAMPLES

SIEVE	TPP-1	TPP-2	TPP-3	TPP-4
SIZE (MM)	CUM. % RET	CUM. % RET	CUM. % RET	CUM. % RET
4.75	0	0	0	0
4.00	0	0	0	0
3.35	0	0	0	0
2.80	0	0	0	0
2.00	0	0	0	0
1.40	0.03	0	0	0
1.00	0.14	0	0	0.12
0.60	0.79	0	0.05	0.22
0.30	2.05	0.08	0.21	6.2
0.212	4.48	0.23	0.59	18.18
0.106	8.7	2.57	5.31	49.72
0.063	16.28	5.81	13.73	59.16
PASSING	83.72	94.19	86.27	40.84

TABLE 3TEXTURE ANALYSIS OF THE CCR SAMPLES

SAMPLE	TPP-1	TPP-2	TPP-3	TPP-4
GRAVEL (%)	4.5	0.5	3.56	NIL
SAND (%)	10	11.5	26.6	59.16
SILT (%)	85.5	88	67.5	32.7
CLAY (%)	NIL	NIL	2.36	3.76

The texture analysis of the CCR samples was done to assess the texture quality. Percentage of sand in all the samples was above 10%. Silt and clay together accounted up to more than 35%. A comparison with the standard soil chart shows that the CCR samples resembled with sandy material in the fine sand range. Such CCRs can be used in texture modification of poor soils with desired characteristics. It can also be used in reclamation of wasteland or as a replacement of sand for stowing purpose or as a structural fill.

IV. SIGNIFICANCE OF CCRS PHYSICAL CHARACTERISTICS

The CCRs particles are generally grey in colour and some of the pond ashes are blackish grey, which are devoid of unburnt carbon. Physical properties like bulk density, texture, porosity and water holding capacity, etc., play an important role as far as the utilisation is concerned whether in engineering applications or in agriculture purpose (Adriano et al., 1980 [7]; Asokan, 2003[1]; Ferraiolo et al., 1990 [8]; Schure et al., 1985 [9]; Sridharan et al., 1996 [10]).

CCRs constitute an assemblage of particles of wide variety of shapes and sizes, ranging from coarse sand to clays. As per the United States Department of Agriculture standards, 55% of Indian dry fly ash collected from ESP falls within the silt and clay sized particles and the rest is sand sized particles (Asokan et al., 1999 [11]). Fig. 3 shows the particle size distribution and textural classification of CCRs collected from Satpura Thermal Power Station, Central Indian, ESP hopper No.4 and from the Ash Pond at a distance of 150m from the ash slurry discharge zone.

The study carried out by Wigley and Williamson (1998) [12], indicates that medium size of fly ash particle diameter is 20 m and the maximum fly ash particles are usually in the range of 150–200_m. The particles size distribution and texture of the CCRs varied distinctly based upon the source, topography of disposal site and location from where the ash is collected and which was confirmed by several authors (Asokan, 2000 [13]; Rajasekhar, 1995 [14]; Sivapullaiah et al., 1998 [15]; Skarzynska et al., 1989 [16]). The size distribution and surface area of a particular ash are important because they tend to influence the texture, sorption capacity, physico-chemical and engineering properties for different applications.

V. CCRS UTILIZATION SCENARIO IN INDIAN CONTEXT

Looking into the physio-chemical, engineering, mineralogical and morphological properties of ash, the Bureau of Indian Standard has released IS 10153:1982 indicating various applications of CCRs. Presently in India, CCRs is being used as a raw material in cement, cellular concrete, fly ash lime bricks, fly ash lime gypsum block, building tiles; as admixture in cement concrete, timber substitute products; as aggregate in concrete, road and building block; as pozzolana in lime pozzolana mortars/plasters, portland pozzolana cement; as stabilizer in soil stabilisation, road construction; as filler in consolidation of ground, land and mine-filling. The other applications of CCRs are metals extraction, cenosphere, soil amendment/ soil modifier, fertiliser and wastewater treatment (Asokan et al., 1999 [11]; Chandrasekar, 1997 [17]; Iyer and Scott, 2001 [18]; Kolay and Singh, 2001) [19]. In India several laboratories of Council of Scientific and Industrial Research, Agricultural Universities, Indian Institutes of Technology, Tata Energy Research Institute, National Thermal Power Corporation, various Governmental and Non Governmental organizations are actively involved in conducting various in-depth experiments and demonstration trials in recycling and use of CCRs effectively. As a result, in India the CCRs utilisation rate has considerably increased and 27% of it was used in various applications by the year April, 2004 (Kumar and Mathur, 2004 [3]). Fig. 5 shows Indian scenario, from 1992 to 2004, representing quantity and rate of CCRs utilisation. it can be seen that during 1993, the utilisation of CCRs in India was only 2.3% of the annual generation which was of 35MT. The Ministry of Environment and Forest (MOEF, 2003 [20]), Government of India regulatory framework, due to various environmental concern, has stressed the importance in increasing use of CCRs. However, lack of awareness among the users on the beneficial aspect of CCRs based products, the utilisation rate greatly influenced. But in India availability of quality CCRs confirming to IS 3812:1981 from modern Thermal Power Station (TPS) and various proven research work through demonstration trials on use of CCRs both in civil engineering applications such as developing building materials (cement, bricks, concrete, aggregate, wood substitute, etc.); road embankment; wasteland development and agriculture have generated confidence and thus the rate of utilization has substantially increased. Further keeping in view of the present growth, demand and necessity, it is expected that by the year 2020, CCRs utilisation rate may reach up to 60% in India. However, micro information on density variation, crystalline nature, mechanical properties, microchemistry of CCRs as a function of CCRs size for a well-defined source are not yet available. And still more micro studies are required to be carried out to explore further potentials on use of CCRs with clear understanding on the effect of CCRs on different applications as a function of all above properties. The details on utilisation of CCRs in different applications is summarised in the following section.

VI. FUTURE POTENTIAL

Coal is the major natural resource available in abundance in India and hence the coal based electricity generation obviously will increase in the near future to meet the demand and per capita consumption due to industrialisation and advancement in newer technologies. In India about 75% of the power generated is coal based and similar trend is expected for another couple of years.

Lignite use has further expanded from 24.3MT in 2001–2002 to 44.96MT in 2006–2007 (Poothia and Basu, 2004 [21]). As a consequence, there is a production of huge quantity of CCRs followed by emission of green house gases and intrude significantly for global warming. Hence, to comply with environmental requirement and to tackle this alarming situation of fly ash management to reduce the adverse effect on environment, ecology and future hypothesis it has become mandatory to find remedial measures.

In view of the complexity of CCRs disposal, Fly Ash Utilisation Programme, Department of Science and Technology, Government of India has taken several effort in “Confidence building” in CCRs based products and technology (TIFAC Home Page, October, 2002). Ministry of Environment and Forest, Building Materials Technology and Promotion Council and Housing and Urban Development Corporation, Government of India have taken various initiatives and contributed not only for the financial and technical support to carryout research and development work but also for promoting of CCRs based building materials for large-scale production and utilisation. As a result the Bureau of Indian standards, 3812:1981 and 456:2000, has been revised to use CCRs as pozzolana and admixture. By substituting ash the quality parameters has been further tightened.

P. Asokan et al. / Resources, Conservation and Recycling 43 (2005) 239–262 257 Soil is one of the valuable resources. It takes several hundred years to produce a layer of 2.5 cm thick natural soil by weathering. In India 53% of the total land (175 million ha.) are non-cultivable due to water logging, sandy, rocky nature, undulation, salinity, alkalinity and acidic nature. The technology demonstrated by several research

organizations at different parts of the country indicates that CCRs has wider potentials to increase the agricultural productivity and convert the wasteland in to agricultural land (Saxena et al., 1998 [22]; Shukla and Mishra, 1986 [23]). The usage of soil for road embankments, mine filling and uses as aggregate in various civil construction applications like bricks, concrete filler materials in foundations, etc., destructs the soil system and contributes to the ecological imbalance. In agriculture, depending up on the characteristics of soil 50–650 t of fly ash per hectare of land can be utilized to improve the agricultural productivity. Building materials like bricks, blocks, paints, timber substitute products, etc., is also another important area in which 35–50% of CCRs can be utilized without compromising the quality. Cost benefit analysis of CCRs versus conventional building materials are needed to be thoroughly evaluated for the concrete recommendation for maximising the use of CCRs. For the effective and efficient utilization of CCRs, there is an urgent need for extensive R&D work towards exploring newer applications.

CCRs utilisation as replacement of soil can be a worth full proposition.

VII. CONCLUSION

Our experiments show that CCR samples have high WHC and low permeability, hence can be used to enhance water retention ability of poor soils and improve their fertility by increasing the mobility of plant nutrients. Low specific gravity improves the flow characteristics of the CCRs which make it suitable stowing material in place of sand for underground mines. The reduction in unit weight is of advantage in case of its use as backfill material for retaining walls since the pressure exerted on the retaining structure as well as the foundation structure will be less. Fly ash could be used in road construction as it could be compacted over a wide range of moisture content and also minimal swell pressure even at moisture content >50%.The other application areas include embankments especially on weak foundation soils, reclamation of low-lying areas. Due to low bulk density of CCRs, it may be used as additives in clayey soils to reduce their plasticity and produce clay/fly ash bricks with better quality. They can also be used in increasing the workability of clay soil for agricultural applications as well as for improving the moulding characteristics of the soils for making earthenware. Texture modification of poor soils with desired characteristics can also be done.

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