Evaluating the Utility of Pond Ash as an Alternative Foundation Material Partially Replacing Sand for Foundation Layers

Aditya Shankar Ghosh and Tapash Kumar Roy

Abstract The target of cent-percent utilization of the coal combustion ash likely to be generated in India in the upcoming years is definitely going to be a daunting task with its disquieting production and defined usage. Moreover, the harmful environmental and human health impact of the coal combustion ash stored in ash lagoons (Pond Ash) is demanding some immediate step for its effective bulk usage in a more eco-friendly way. The Supreme Court of India's order of imposing regulation on unconstrained fine aggregate excavation have turned the attention of the researchers toward Pond Ash (PA) and its potential usage as partial replacement of the Conventional Granular Material (CGM) for foundation layers. In this investigation the samples of PA were collected from Kolaghat Thermal Power Station (KTPS) ash pond in India and tested for its engineering properties (Specific gravity, Compaction behavior, Hydraulic conductivity, and Shear strength) along with gradation. Five mixtures of PA and zone-III sand with different mixture ratios (3, 6, 9, 12 and 15% PA content by weight of zone-III sand) were prepared for testing. Mineralogical analysis (XRD and FTIR) of the Virgin PA sample was conducted for verifying the pozzolanic nature of the collected PA sample. The test results showed favorable comparison of ash with the conventional granular material and PA is a promising Non-Conventional Granular Material (NCGM) which can be used effectively as well as economically by the industries as a foundation layer material, which will also address its disposal problems.

Keywords Pond ash · Chemical composition · Engineering properties · XRD · FTIR

1 Introduction

The year 1920 marked the beginning of burning of coal for the power generation which spread worldwide, yielding huge amounts of ash and associated by-products

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at an alarming rate. Incineration of coal itself generates 780 MTs of ash all around the globe, possessing a serious disposal issue. The ash generated is stored in ash ponds to prevent dust escaping, which bears tremendous initial investment. Researchers have already investigated that 1 megawatt (MW) of a thermal power plant's installed capacity consumes 0.4 ha storage space [1, 2]. The review of the reserved lives of the countries producing major amount of coal, based on their current production level revealed that, most of the developing countries have to confront this mounting problem in the upcoming decades [2].

The thermal power plants in India are mostly dependent on the combustion of bituminous coal having ash contents of 40–50% [3]. The ever more increasing capacity of coal-fired thermal power plants spurs the quantity of ash generation abruptly. Its rate of generation which is 130 MTs hugely surpasses the rate of its use of 60 MTs [1].

In the upcoming years, the cent-percent target of utilization of the ash likely to be generated is an intimidating task. The projected volume of ash production over the coming years is immense, and the planning as well as execution of using it has to be far more stimulating than what is perceived today. Conventional utilization strategies need to be backed up with newer avenues of bulk usage of the generated ash. This paper makes an attempt to determine the physio-chemical and engineering characteristics of ash collected from the ash pond of KTPS, West Bengal, India and showcase its prospects as alternate foundation materials where it can find bulk usage.

1.1 Indian Scenario

With the Honorable Supreme Court of India imposing total ban on sand mining in November 2017, resulted in scarcity of one of the most crucial foundation layer construction ingredients. This has also lead to manifold increase in the prices of the available sand, and altogether badly hit the running projects [India Today August 13, 2018]. These circumstances invoke the utilization of the Pond Ash (PA) from the ash ponds as an alternate foundation layer material, replacing the sand partially or fully, where it can find bulk utility and additionally can also reduce the construction cost hence become economically more beneficial.

2 Methodology

The sample collection, determination of preliminary properties of the sample, and testing methods undertaken for this study are mentioned below.

Sampling of Pond Ash. PA samples for this study have been extracted from KTPS shown below in Fig. 1 directly from near the place where the ash mixed with water are getting discharged using a sampling scoop. The sampling was done following

Fig. 1 Map showing the location of the Kolaghat Thermal Power Station Ash Pond

IS: 6491–1972. This was done to separate out arbitrarily the finer and comparatively coarser ash particles.

Chemical composition analysis of virgin Pond Ash. The chemical composition analysis of the collected ash sample was carried out by volumetric titration in the chemistry laboratory of IIEST, Shibpur and the results are provided in Table 1 given below.

Grain size analysis. The ash ponds usually contain silt-size fraction more than sand-size fraction. Investigators have however observed that the bottom ashes predominantly contain sand-size fractions along with fractional silt-size fractions [2]. Explanations have also been made in their work about the predominance of particle size in the settlement of coal slurry, which directly affects the rheological behavior [2, 4]. In this study the grain size analysis was performed on pond ash, sand and pond ash/ sand mixtures. PA content of the mixtures was 100% (Virgin), 97, 94, 91, 88 and 85% by weight of the sand. The grain size of the samples was obtained using IS: 383–1970. The grain size analysis of the fractions passing 75μ IS sieve is carried out according to Hydrometer Method, conforming to IS: 2720 part-IV (1985).

Table 1 Chemical properties of Kolaghat pond ash

Constituents in percentage	Kolaghat pond ash (%)
Silica (SiO_2)	70.00
Alumina (Al_2O_3)	1.20
Magnesium Oxide (MgO)	0.30
Iron (II) Oxide (Fe_2O_3)	10.00
Calcium Oxide (CaO)	1.00
Loss on Ignition	1.00

Specific gravity, Compaction behavior and Permeability. Investigational studies have stated that specific gravity of coal ash varies considerably depending on grain size distribution, particle shape and chemical composition [5, 6]. The specific gravity of the pond ash, sand and the sand/ ash mixtures was determined using IS: 2386 part-III (1963). The removal of the lower specific gravity PA particles was prevented by removal of air gaps, which was done by very slow heating.

Standard compaction tests were performed following IS: 2720 part-VII (1980). Premeasured quantities of PA and sand were prepared conforming to the requirements of IS: 460 part-I (1978) and were slowly hand-mixed at first, then suitable amount of water was sprayed gradually along with the slow mixing on a steel plate. The blended samples were then compacted in a standard compaction mold.

The permeability of the ash, sand and the ash/ sand mixtures was measured by the falling head tests as described by IS: 11,209–1985. The test was conformed to IS: 2720 part-17 (1986). The ash mixtures were compacted to 95% of the maximum density in the mold permeameter that was obtained from the standard proctor compaction test.

Shear strength test. In their study, the researchers stated this parameter to be one of the most important as shear strength characteristics is the main factor on which, the problems occurring in the field with slope stability of embankments, design of pavements, retaining structures and bearing capacity depends [7]. The shear strength behavior study of the ash samples for this study has been performed using Direct Shear Strength Test conforming to IS: 2720 part-13 (1986). Investigators in their work obtained the friction angle value to be in the range 26°–42 for pozzolanic coal-based ashes [8, 9].

X-ray diffraction (XRD) and Fourier Transform Infrared spectroscopy (FTIR) analysis. XRD measurement was performed on PA sample using the ULTIMA IV X-RAY DIFFRACTOMETER (RigakuKyowaglas-XA, Japan), automated with Cu-Kα radiations. XRD samples were prepared by back loading technique. This minimizes preferred orientation [10]. The readings were taken in vertical Bragg–Brentano (2ϴ) geometry between 10° and 80° at 0.02° step size at 1 step/second, which resulted in a time of total measurement of 36 min/scan [11]. The X-Ray Tube Generator was operated at 40 kV and 40 mA [12].

The quantitative FTIR analysis of PA samples prepared alike as the XRD analysis, pressed into KBr pellets was done in a Nicolet 7199 FT-IR. For quantitative analysis of such spectra, a curve analysis program was employed to synthesize the IR spectra over a wide spectral range (450–4000 cm^{-1}).

3 Test Results and Discussion

The experimental data analysis for this study has been discussed accordingly.

Grain size analysis. Figure 2 below shows the grain size distributions for each PA, sand zone-III, as well as the PA/ sand mixtures, ranging from mostly silt to fine sand sizes. The grain size distribution curves of the ash mixtures shown in Fig. 2 are quite similar. Their sizes ranged from sand to small-size gravel. Table 2 represents the variation of Uniformity Coefficient (Cu), Coefficient of Curvature (Cc) and Effective size of the particles (D10).

Specific gravity, Compaction behavior and Permeability. The values of the specific gravity of the PA, Sand and PA/ sand mixtures are briefed in the Table 3. These values ranged from 2.501 to 2.856, that have been explained as a result of presence of PA particles with porous textures [13]. The higher specific gravity values are due to the presence of high iron oxide content. On examining the chemical composition, it revealed that the hollow ash particles have lower iron content and are also affected by the porosity of its particles [14, 13].

Table 3 shows that, as the PA content increases, the Maximum Dry unit weight (Yd,max) (MDD) increases, while the Optimum Moisture Content (OMC) decreases.

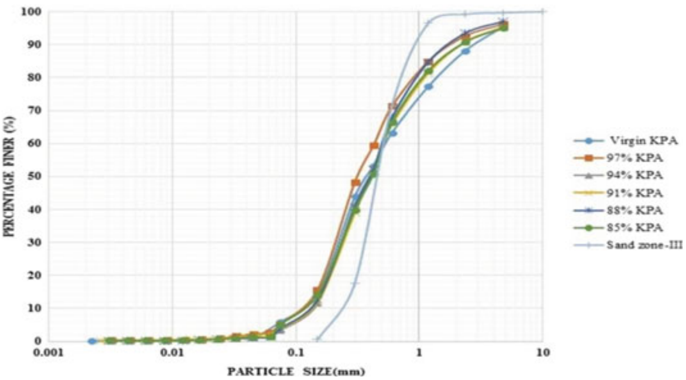

Fig. 2 Particle size distribution of pond ash, sand and pond ash/ sand mixtures

Table 2 Gradation analysis of the experimental samples

Description	D10 (mm)	C_u	C_c
Virgin Kolaghat PA	0.135	3.926	0.7075
97% KPA + 3% Sand	0.110	3.730	0.9320
94% KPA + 6% Sand	0.140	3.570	0.6914
91% KPA + 9% Sand	0.130	3.846	0.7446
88% KPA + 12% Sand	0.120	4.167	0.8067
85% KPA + 15% Sand	0.110	4.550	0.8800
Sand zone-III	0.150	2.318	0.9700

Table 3 Specific gravity, OMC, MDD, permeability data of pond ash, sand and pond ash/sand mixtures

Description	Specific Gravity	OMC	MDD (gm/cc)	Permeability (cm/sec)
Virgin Kolaghat PA	2.856	23.00%	1.53	0.00225934
97% KPA + 3% Sand	2.501	22.80%	1.56	0.00289355
94% KPA + 6% Sand	2.535	22.20%	1.58	0.00355713
91% KPA + 9% Sand	2.585	22.00%	1.62	0.00365988
88% KPA + 12% Sand	2.703	21.80%	1.68	0.00221749
85% KPA + 15% Sand	2.706	21.60%	1.72	0.00309080
Sand zone-III	2.675	12.50%	1.58	0.00743891

Studies revealed that for silty sands Yd,max increases with increasing fines. They occupy the gaps in between the sand particles, and addition of PA results in a more well-graded size distribution. It allowing the ash to associate more closely, hence increasing the Yd,max [15, 16] and [17].

Table 3 shows the value of permeability for compacted PA, sand and PA/ sand mixtures. The measured values varied from 0.002259335 cm/s to 0.007438907 cm/s, the former one is of the virgin PA and the latter is of zone-III sand respectively. With the increase of PA content in sand the permeability decreases. Researchers also supported this fact by stating that the larger specific surface of the PA particles causes increasing resistance to the water flow through the voids [13]. They also found out that the fines in the PA have a huge effect on the permeability [18, 13].

Shear strength analysis. The stress–strain behaviors of PA, sand and PA/sand mixtures, compacted in the shear box, conforming to IS: 11,229 (1985) and sheared in Direct Shear Strength testing machine, performing the CU Test, are represented by Fig. 3a–c. Table 4 shows the Cohesion (C) and Friction Angle (φ) data obtained. It is clearly observed from the shearing stress v/s strain graph under all the Normal stress conditions, that there is very small variation of effective friction angle [7]. Studies have revealed that, high shear strength parameters of these ashes prove to be favorable for their use in the field [5, 7] and [19].

XRD and FTIR analysis. The XRD studies are carried out primarily to identify the mineral phases of the PA sample. Figure 4a shows the presence of Mullite

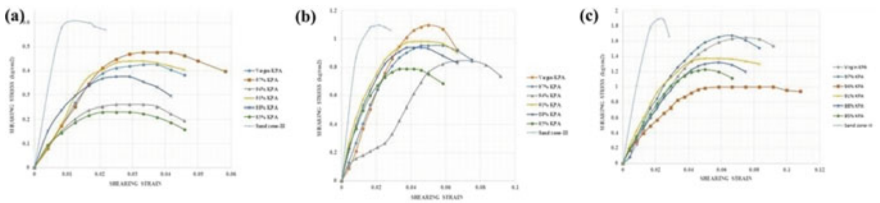

Fig. 3 Shearing stress versus strain graph under normal stress **a** 0.5 kg/cm^2, **b** 1.5 kg/cm^2 and **c** 2.5 kg/cm^2

Table 4 Direct shear test data of pond ash, sand and pond ash/ sand mixtures

Description	Cohesion (C) kg/cm^2	Friction Angle (ϕ)
Virgin Kolaghat PA	0.1883	31.17
97% KPA + 3% Sand	0.1667	31.38
94% KPA + 6% Sand	0.1558	31.61
91% KPA + 9% Sand	0.1400	31.87
88% KPA + 12% Sand	0.0825	32.09
85% KPA + 15% Sand	0.0333	32.34
Sand zone-III	0.0000	40.00

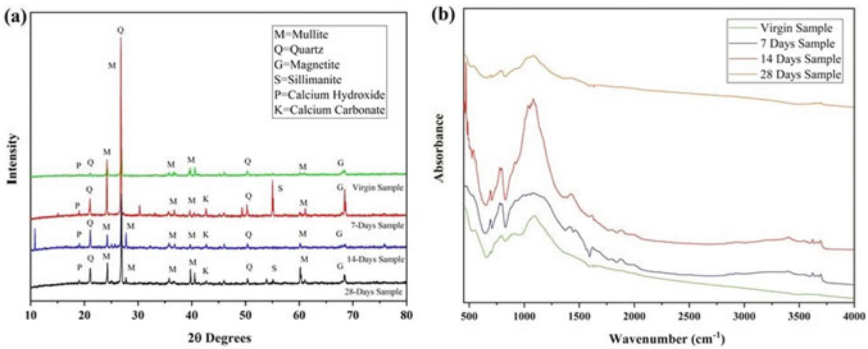

Fig. 4 **a** XRD and **b** FTIR spectra of PA sample virgin, 7 days, 14 days and 28 days hydration

predominantly, followed up by partial presence of silica in crystalline form of Sillimanite and Quartz, combining with alumina as Mullite. Iron appears as the oxide of Magnetite. The figure also reveals the formation of peaks of Calcium Hydroxide and Calcium Carbonate which were found to match well with the Joint Committee on Powder Diffraction Standards (JCPDS File No. 44–1482) and (JCPDS File No. 85–1108) respectively [20].

FTIR Spectroscopy technique is used to obtain an infrared spectrum of absorption of the PA sample. The absorbance at 3440 cm-1 and 1630 cm^{-1} as shown in the Fig. 4b is due to the presence of (O–H) asymmetric stretching due to water and Silanol groups. Broad peak centered around 1083 cm^{-1} is due to Si–O-Si bonds of amorphous silica which transform into Si–O-Al bonds of Poly-Sialate around 912 cm^{-1}[11]. A shoulder at 1161 cm^{-1} is marks the presence of Quartz.

4 Conclusions

The present study throws light on the chemical, physical and mineralogical properties of the PA collected from the KTPS. Tests are performed to analyze its pozzolanic properties and whether it could find effective application as alternate foundation material by partial replacement of fine aggregates. Besides these, the following conclusions are summarized based on this study:

- The chemical composition of the PA sample reveals higher percentage of Silica followed by Iron(II) Oxide and lower percentages of Alumina, Magnesium Oxide, Calcium Oxide and traces of some other compounds and elements.
- The grain size distribution of the experimental sample particles ranges between 0.001 and 0.075 mm. the increasing percentage of sand and decreasing percentage of PA in the blended mixture increases the Cu and Cc values of the mix.
- The specific gravity values of the experimental samples show steady increase with the increasing percentage of sand and decreasing percentage of PA in the blended mixture.
- The compaction test reveals that, as the PA content increases, the maximum dry unit weight increases, while the optimum moisture content decreases.
- The permeability results showed the larger specific surface of the PA particles causes more resistance to the flow of water through the voids, revealing the higher the percentage of PA in the mixture the lower is the permeability.
- The Direct Shear Test data shows that with an increase in the PA content the cohesive property of the blended sample increases however the friction angle decreases.
- In the mineralogical property analysis of the PA sample the XRD test followed up by the FTIR test performed to identify the mineral phases of the PA sample clearly reveals the pozzolanic nature of the PA sample.

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