Characterization of Pond Ash as Fine Aggregate in Concrete

Bharathi Ganesh, H. Sharada Bai, R. Nagendra and B.K. Narendra

Abstract--- *There is a great demand for the concrete, the second largest consumed material and concrete making materials, for constructions due to the stimulated growth of the infrastructure worldwide. This has lead to the scarcity of natural resources, resulting in creating vast interest in the research area to look for alternative materials which could satisfy both strength and performance criteria of concrete Constructions.*

Pond Ash, a waste product of Thermal Power Plants, is one such material, that can be adopted as a suitable material as Fine aggregate in concrete, replacing Natural Sand partially or fully. Encouraging the usage of such a waste material as constituent in concrete so as to address the issues related to its disposal, environmental and ecological problems, is a social responsibility of researchers , thus contributing to 3Rs - Reduce Reuse and Recycle, there by promoting sustainable construction.

It is commonly thought that as inert filler, fine aggregate has very little effect on the finished concrete properties. However fine aggregate (natural sand or alternative material) and its characteristics play a substantial role in controlling the workability, strength, and durability of the concrete constructions. Thus its detailed characterization is essential to boost the confidence of user.

This paper deals with the characterization by means of analysis of engineering properties of Pond Ash as fine aggregate in concrete. Properties such as specific Gravity, fineness, gradation, texture, physical and chemical characteristics of Pond Ash samples collected from Raichur Thermal Power Station as per standard sampling procedure were evaluated and compared with that of Natural Sand. Pond Ash is finer in size and hence the water demand is more in comparison with natural river sand. Utilisation of Pond Ash is proved as a sustainable material as Fine Aggregate in concrete constructions to bring in environmental & economic benefits.

Keywords--- *Industrial Waste Product, Alternative Material in Concrete, Fine Aggregate, Characterization, Suitability*

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I. INTRODUCTION

WHEN pulverized coal is burnt in a dry, bottom boiler, about 70 percent of the ash is entrained in the flue gas and is captured and recovered as fly ash. The remaining 30 percent of the ash is dry bottom ash, a dark grey, granular, porous material that is collected in a water-filled hopper at the bottom of the furnace (1).

The lagooned bottom ash (Fig.1) is usually combined with fly ash. This blended fly ash and bottom ash together is referred to as Pond Ash (Fig.2). Approximately 30 percent of the coal ash is handled wet and disposed of as Pond Ash [2]. One of the important cautions of World Bank to India is that by 2015 disposal of coal ash would require 1000 square km. or one meter square of land per person (3).

Huge amount of Coal ash generated from Thermal Power Stations, if utilised in concrete manufacturing, address the issues related to its disposal, as well as environmental and ecological problems, offsetting traditional materials thus conserving non renewable natural resources, allowing for the recovery of both energy and material from selected waste, is a step called co-processing(3).

Figure 1: Lagooned Bottom Ash

Figure 2: Pond Ash Sample

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Figure 3: Sample Collection - RTPS

II. NECESSITY OF CHARACTERIZATION

Pond Ash is potentially useable as Fine Aggregate, but the properties of Pond Ash depend on various factors such as source of coal, and its type, design of coal fired boilers, power plant operating parameters, point of disposal of wet coal ash, the efficiency and type of coal grinding processes adopted at the power plant(4). Moreover because of differences in the unit weight of fly ash and bottom ash, the coarser bottom ash particles settle first and the finer fly ash remains in suspension longer. The ash deposited with in about 100 m of ash slurry discharge point in the pond is coarser ash as compared to the ash deposited away from 100m, in between these two areas is of medium particle size (4).

Hence it is the necessary for the researchers to know the variation in the properties of Pond Ash for a given plant by collecting Pond Ash at different locations around the discharge outlet, studying its properties as fine aggregate and comparing it with the properties of Natural Sand. Characterization of Pond Ash thus plays a very important role in assessing its suitability as a material in the field of concrete construction.

A. Sampling and Characterisation of Pond Ash

Samples of Pond Ash were collected as per IS 6491 - 1972 at 10 different pits (P1 to P10) from Ash Pond II (Fig.4,5) at Raichur Thermal Power Stations – RTPS, selecting pits (Fig.4) around 100m apart in which 6 pits (Pit No.4,5,6,7,8,10) were selected around 200m away from the bund., two pits very close to the bund (Pit No.3,9) and two pits about 75 m away from discharge outlet (Pit No.1,2) of Ash Pond (Fig.6). These samples were oven dried at 100 ^{0} C and detailed characterization was carried out as Fine Aggregate in Concrete as per relevant IS Codes of Practice.

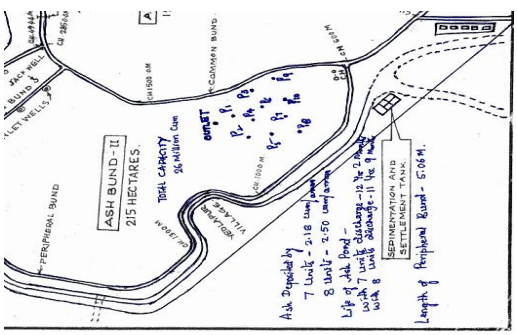

Figure 4: Plan of Ash Pond II with Pit Locations

Figure.5: Ash Pond II– RTPS, Bird's Eye View F igure.6 Ash Pond II– Discharge Outlet

The following are the details of characterization conducted by the authors on the samples of Pond Ash and Natural Sand.

III. CHARACTERIZATION OF POND ASH

Cream to dark grey (5). Characterisation of Pond Ash consists of determining its physical properties such as specific gravity, fineness, Fineness Modulus, grain size distribution, chemical properties and morphological characteristics, and then the relevant properties as Fine Aggregates are compared with that of Natural Sand.

A. Physical Characteristics

- *Specific Gravity*

Specific Gravity of the aggregate is used in concrete mixture proportioning and changes in Specific Gravity will alter the volumetric composition of the mixture and likely to result in discrepancies in the yield of concrete batches (9).

The specific gravity of samples from different pits were determined as per IS: 2386 – 1963, Part III (Fig. 7 & Table1) which varied from 1.734 (pit 9) to 2.09 (pit 6) on an average of 1.875, (Table 1) with Standard Deviation (SD) of 0.107 (Table.2) which is very low. Specific gravity lower than natural sand, indicates that it is lighter than the sand.

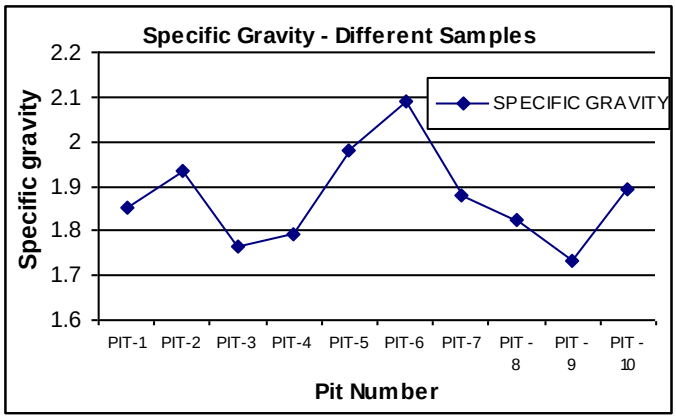

Figure 7: Specific Gravity - Samples from Different Pits

As per the literatures, Specific gravity varies significantly for particles of different shape, colour and chemical composition. Irregularly shaped, black, coal particles which contain few mineral grains have a specific gravity between 1.3 to 1.6. Pond Ash with relatively low specific gravity (below 2.2) is often indicative of the presence of porous popcorn particles. Bottom ash with relatively high specific gravity

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(above 3.0) may indicate high iron content (7).

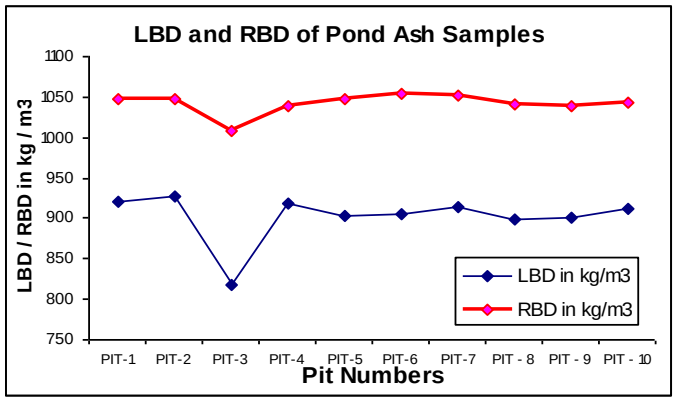

Figure 8: LBD / RBD – Samples from Different Pits

The maximum dry density value of bottom ash is usually 10 to 25 percent lower than that of naturally occurring granular materials. The concrete of slightly lesser density is produced when Pond Ash is used as fine aggregate in it(6). As reported earlier the bulk density of Pond Ash is (800 – 1350) kg / m^3 is less than that of natural sand (1300 – 1800) kg / m^3.However LBD of samples from different pits (fig.8) varied from 818 kg/m^3 (pit 3) to 928 kg/m^3 (pit 2), RBD 1038 kg/m^3 to (pit 4) to 1052 kg/m^3 (pit 7), neglecting very low value of LBD for pit 3(fig.8), LBD and RBD of Pond Ash samples is concluded as 931.444 kg / m^3 & 1046.44 kg / m^3 with an SD of 30.93 kg / m^3.

Table 1: Properties of Pond Ash from Different Pits (1 to 10) and Properties Sand

Properties of Pond Ash	PIT-1	PIT-2	PIT-3	PIT-4	PIT-5	PIT-6
Moisture Content (%) of fresh Sample	25	24.5	22	20	17	17.66
Specific Gravity	1.854	1.936	1.765	1.791	1.978	2.09
LBD in kg/m^3	921	928	818	918	904	906
RBD in kg/m^3	1048	1048	1038	1043	1048	1055
Fraction – between 4.75 mm- .150mm (%)	67.2	61.4	67.56	63.9	63.9	53.7
Fraction retained on 4.75 mm sieve(%)	10.4	11.5	12.8	9.7	14.4	9.9
Fraction passing 0.150mm sieve(%)	22.4	27.1	19.64	26.4	22	36.4
Fineness Modulus - before sieving	2.126	2.225	2.126	2.155	2.098	2.097
Fineness Modulus -after sieving*	2.55	2.55	2.511	2.548	2.548	2.562
Water Absorption	7.8	18.1	17.4	21.3	9.9	18.1

Properties of Pond Ash …. continuation	PIT-7	PIT – 8	PIT – 9	PIT – 10	Sand
Zone as per BIS	Zone IV	Zone IV	Zone IV	Zone IV	Zone IV
Moisture Content (%) of fresh Sample	17	23.8	22.4	24	2.1
Specific Gravity	1.878	1.825	1.734	1.895	2.62
LBD in kg/m^3	915	898	902	911	1584
RBD in kg/m^3	1052	1041	1039	1044	1678
Fraction – between 4.75 mm- .150mm (%)	67.4	67.3	64.5	62.8	---
Fraction retained on 4.75 mm sieve(%)	10.2	13.2	12.7	13.8	---
Fraction passing 0.150mm sieve(%)	22.4	19.5	22.8	23.4	-----
Fineness Modulus - before sieving	2.126	1.955	2.016	2.12	2.15
Fineness Modulus -after sieving*	2.536	2.483	2.394	2.412	
Water Absorption	15.0	17.5	16.2	18.1	----
Zone as per BIS	Zone IV	Zone IV	Zone IV	Zone IV	Zone II

- *Water Absorption*

Absorption is used to calculate the batch water content of the concrete and using incorrect values can lead to inaccurate mixing water amounts, incorrect w/c ratio and therefore variations in strength and other concrete properties impacted by water content(9). Fresh Pond Ash after five days of sample collection was tested for its moisture content which varied from 17% to 25%, Water absorption of Pond Ash samples ranges from 7.8% - 21.3% (Fig.9 & Table 1)

- *Particle Size Distribution and Aggregate Grading*

Physical characteristics of Pond Ash are controlled by the coarser particles above 75 microns which distinguishes Pond Ash from true fly ash (7). Smaller particles influence the specific gravity, fineness and lime reactivity of Pond Ash.

Sieve analysis of Samples collected was carried out as per standard procedure, once on dried sample and again on separated fraction between 4.75mm - .150mm. Percentage fraction of this range varied from 61.4% to 67.4%, (Table 1) except for pit 6, (53.7%) The separated material samples sieved (Fig.12) for fraction retained on 4.75mm were found to be (9.7% - 14.4 %) and particle passing through 0.150mm sieve were found to be (19.5% - 27.1%, except for pit6 with 36.4%).

Sieve analysis (Table 3) conducted on unsieved Pond Ash samples shows that it conforms very close to Zone IV and separated samples (particle fraction between 4.75mm - 0.150mm) after sieving, conforms to Zone IV (Table 1, fig.10) as per IS 383- 1970.

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Table 2: Mean, Variance and Standard Deviation of Properties of Pond Ash from Different Pits

Pit No. details	Moisture Content (%) of fresh Sample	Specific Gravity	LBD in kg/m^3	RBD in kg/m	Fraction between 4.75 mm .150mm (%)	Fraction retained on 4.75 mm sieve(%)	Fraction passing 0.150mm sieve(%)	Fineness Modulus - before sieving	Fineness Modulus –after Sieving	Water Absorption
Mean	21.336	1.8746	902.1	1045.6	63.966	11.86	24.204	2.1044	2.5094	15.94
Variance	10.119	0.0114	959.433	30.933	17.768	3.0137	24.321	0.00544	0.00369	16.776
Standard Deviation	3.181	0.1069	30.974	5.561	4.215	1.736	4.931	0.0737	0.061	4.096

Table 3: Results of Sieve Analysis – Samples from Different Pits – before Fraction Separation

Sieve Size	Pit -1	Pit -2	Pit -3	Pit -4	Pit -5	Pit -6	Pit -7	Pit -8	Pit -9	Pit -10	Sand	Zonation as per IS 383-1970
4.75	100	100	100	100	100	100	100	100	100	100	100	95-100
2.36	95.5	95.5	94	95.8	97	96	95.7	95.7	95.7	95.7	94.5	95-100
1.18	96.1	96	95.5	96	96.5	95.5	95.8	91.8	93.8	94	86.6	90-100
0.6	94.5	94	94	95.4	95	97	93.9	84	90.5	91.9	73.4	80-100
0.3	78	77	55	75.8	69.5	83.5	72.5	71	74.9	70.5	36	15-50
0.15	49	47.5	67	46	52	41	47	52	58	61	14	0-15
Zone	---	---	---	----	---	---	---	---	----	----	Zone II	Zone IV

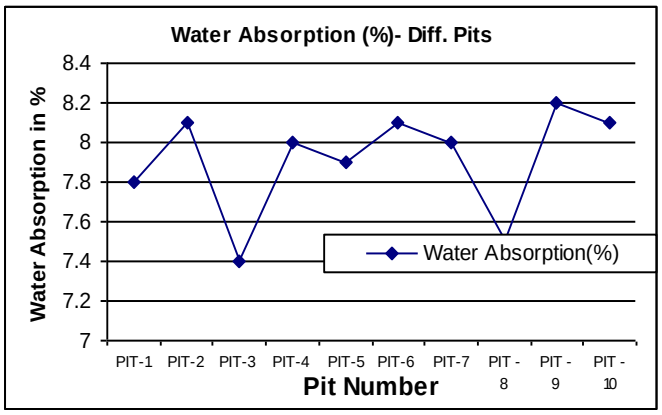

Figure 9: Water Absorption – Samples from Different Pits

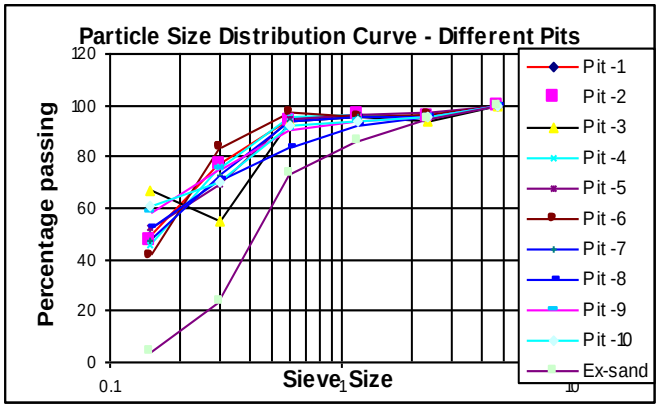

Figure 10: Particle Size Distribution – Samples from Different Pits

- *Fineness Modulus*

The Fineness Modulus (FM) is an empirical number related to the aggregate grading with lower FMs corresponding to fine aggregates that are finer. However, aggregates with the same FM can have different grading. ASTM C33 requires(9) concrete fine aggregate to have an FM between 2.3 and 3.1. The amount of fine aggregate passing the 300-µm (No. 50) and 150-µm (No. 100) sieve have a great influence on workability, finishability, stickiness, potential for segregation and bleeding of concrete. In fine aggregate the amount of material passing the 300-µm (No. 50) sieve should be 15 to 30% for good pumpability. Fine aggregate grading influences concrete performance more than coarse aggregate (9).

Fineness Modulus of the samples from different pits were determined before sieving the sample for fraction separation, and after sieving it. The Variation in FM values for different pits was found to be 2.016 – 2.225 (Fig. 11) before sieving the samples and variation is very minimal in samples fraction between 4.75mm - 0.150mm was 2.394 – 2.562.

There is an improvement in the grading of Pond Ash fraction between 4.75mm to 0.150mm, when compared to the grading of Pond Ash before sieving (Table 3).

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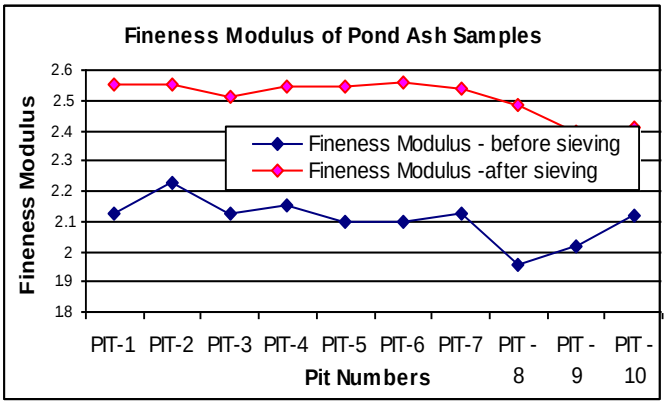

Figure 11: Fineness Modulus – Samples from Different Pits

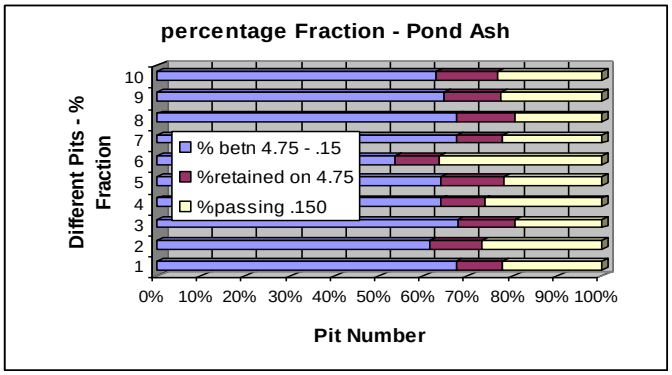

Figure 12: Percentage Fraction – Samples from Different

Table 4: Physical Properties of Typical Sample of Pond Ash

Test Conducted	Results of RTPS Typical Sample	Requirements as per IS 3812 -2003 Part 1	Part 2
Specific Gravity	1.936	----	-----
Fineness – Specific surface in m^2/kg Blain's Air permeability Method in mm	178.0	320	≥ 200
Soundness by Autoclave Test Expansion of specimens percent (Max.)	0.024	≤ 0.8	≤ 0.8
Residue 45 micron sieve percent (max.)	95.0	≤ 34	≤ 34

Table 5: Zonation as per IS 383 1970 for F.A

Sl. No.	Sieve Size	Percentage passing for RTPS sample	Grading Zone - II
1	4.75mm	100	100
2	2.36mm	94.5	90-100
3	1.18mm	86.6	75-100
4	600µm	73.4	55-90
5	300µm	36	35-59
6	150µm	11	8--30

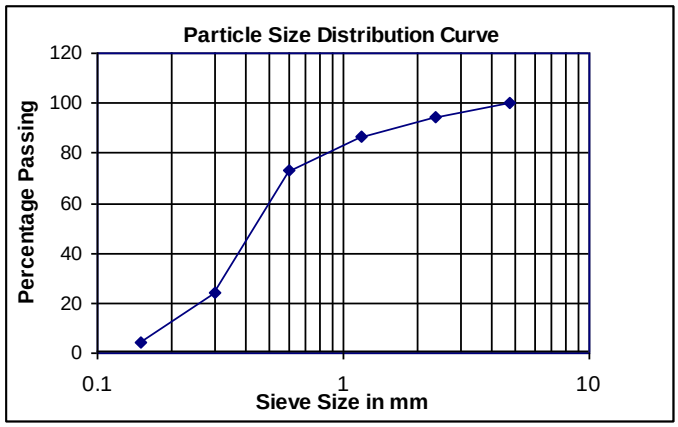

Figure 13: Particle Size Distribution – Sand

- *Fineness*

Fineness can be expressed in terms of specific surface area determined by Blaine's air permeability method. The Blains fineness of typical sample was 178 m^2/kg, (table 4) indicationg that particles are of very coarser in nature.

- *Natural River Sand*

Natural River Sand considered for comparison of properties of Pond Ash as fine aggregate, was conforming to Zone II(Table 5, fig.10), having a specific Gravity of 2.62, Finess Modulus of 2.15 Loose Bulk Density (LBD) of 1584 kg/m^3, Rodded Bulk Density (RBD) of 1678 kg/m^3.

B. Chemical Properties

The main constituents of Pond Ash are silica ($Si0_2$), ferric oxide (Fe_20_3) and alumina ($A1_20_3$). Smaller quantities of calcium oxide (CaO), potassium oxide (K_20), sodium oxide (Na_20), magnesium oxide (MgO), and sulphur trioxide ($S0_3$) are also present in coal ash (7).

The chemical composition of Pond Ash (Table 6) shows that the major constituents in it are silica, alumina and iron oxide (SiO_2+Al_2O_3+Fe_2O_3) and is 93.7%, further, silicon dioxide (60.08%), MgO 0.71%, SO_3 0.40%. Although these constituents are reported as oxides, they occur in Pond Ash as a mixture of silicates, oxides, and sulphates with small quantities of phosphates and other compounds [10].

- *Loss of Ignition (LOI)*

The unburnt carbon in Pond Ash ash is determined by loss on ignition, is one of the important parameters for the assessment of the quality of Pond Ash. LOI mainly represents deleterious effects on concrete the unburnt carbon is has(6). The presence of carbon influences the water requirement in concrete(8). LOI of coal ash from most of Indian TPP - Thermal Power Plants (except for few old Power Plants) is found below 2.5 %, which is within the limit of 5% as per BIS standards for cementitious applications. LOI of typical sample of Pond Ash from RTPS was found to be 2.60(Table 6).

Though the chemical composition of Pond Ash does not sffect its behaviour as Fine Aggregate, its chemical composotion shows that it has a potential to behave as a pozzolana in concrete.

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Table 6: Chemical Composition of Pond Ash

Test Conducted	Results of a RTPS Raichur Sample	Requirements of IS 3812 - 2003
Silicon dioxide ($Si0_2$) plus aluminium oxide (Al_2O_3) plus iron oxide ($Fe20_3$), percent by mass, (Minimum)	93.70	> 70
Silicon dioxide ($Si0_2$), percent by mass, (Minimum)	60.08	≥ 35
Magnesium oxide (MgO), percent by mass, (Maximum)	0.71	≤ 5
Total sulphur as sulphur trioxide (SO_3), percent by mass, (Maximum)	0.40	≤ 3
Loss of Ignition, percent by mass, (Maximum)	2.60	≤ 5

- *Mineralogical / Morphological Composition*

The mineralogy / morphology of a Pond ash is important in understanding its utilization. Authors have submitted the samples for XRD analysis / Sem analysis for mineralogy /morphological studies respectively. The results are awaited. However it was understood from the literatures (7, 8) that mineralogy of Pond Ash contains Quartzs Mullite as major phases and morphology of Pond Ash represents a mixture of spherical, irregularly shaped and lumped particles with glassy spheres having smooth surface and irregularly shaped particles , relatively coarser having vesicular texture.

- *Workability of Concrete with Pond Ash*

Studies carried out by authors using Pond Ash in concrete (though beyond the scope of this paper) reveal that concrete mix with various proportions of Pond Ash as fine aggregate show very harsh mix at higher percentage (typically >40) of replacement levels which is difficult to work with, demanding more for water for the mix during mixing to satisfy workability criteria and segregation of water content after few minutes of mixing (12), which can be taken care using suitable admixtures.

IV. DISCUSSIONS

Sample of Pond Ash collected from different locations around the outlet point showed that

- nearly (63.6% - 80.5%) of Pond Ash was coarser than 150 microns.
- variation in grain size distribution was very small and can be ignored.
- specific gravity values recorded did not show noticeable variation.
- Blain's fineness of typical sample was found to be 178 m^2 / kg indicating the presence of large amount of coarser particles in the samples.
- variation in terms of Physical properties evaluated is not much significant at pits considered for sample collection, around the outlet point at different locations for the source(RTPS) considered for the study.
- ponded ash is mainly composed of silica, alumina, and iron oxide, from the chemical analysis

Studies carried out by authors using Pond Ash in concrete (though beyond the scope of this paper) and even the literatures reveal that concrete mix with various proportions as fine aggregate showed that it is possible to use only Pond Ash as fine aggregate without compromising on strength and durability parameters. This study opens up a major avenue for utilisation of Pond Ash (11).

V. CONCLUSIONS

The variation in the properties of samples of Pond Ash collected from different locations around the outlet point at RTPS Ash Pond II, with respect to its physical properties were not much. This may be due to the fact that the variation in RTPS plant operations are controlled and are maintained least due to automation of its operation and also coal is taken from the same source.

Improved Fineness Modulus of fraction between 4.75mm – 0.150mm recommends to use the Pond Ash sample after sieving it, so as to consider this fraction in concrete work, which accounts for about 61.4 % to 67.4%.

The results of characterization of Pond Ash sample from TPS from Raichur as Fine Aggregate, though totally not very satisfactory when compared to natural sand, but confirm its suitability in concrete as fine aggregate in terms of its strength and durability studies (though beyond the scope of this paper) conducted on concrete with Pond Ash as fine aggregate in various replacement levels(12).

Hence effective utilization of Pond Ash as constituent in various concrete constructions encourage the large scale utilization of industrial waste, facilitating human habitation, replacing fast depleting natural resource, so as to contribute to sustainable construction and also helps in conserving the precious top soil required for growing food contributing to environmental and ecological benefits(12).

ACKNOWLEDGEMENT

Authors are highly grateful to Civil-Aid Technoclinic Private Limited (CTPL), Bangalore for supporting in respect of characterization of samples and also for conducting various tests in its NABL accredited laboratory, encouraging research activities.

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