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Geo-Technical Characterization of Pond Ash as a Highway Fill Material

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Abstract- The evolution of mankind has caused overall development of a nation with which there has been an increase in demand of daily utilities. One such increasing demand is of electric power. Though many resources are used for its production, one of the major raw materials is 'coal' used for the generation of electricity and outcomes the generation of waste in the form of coal ash is a pre-requisite to it. With more than 65 % of India's electricity capacity generated by thermal power plants, 85% of them use coal as their burning fuel and thus produces a huge quantity of coal ash and its disposal has always been a serious issue of concern for the safety of environment. The coal ash generated is dumped as Pond ash in major portions to disposal site also known as ash pond, located near the plant. Due to use of different type of coal, the properties of Pond ash vary within two thermal power plants and also near the disposal point (inflow) and outflow point within the same ash pond. To assess the feasibility of pond ash as a fill material, pond ash sample was collected from the ash pond situated near the National Thermal power plant in Badarpur, New Delhi. This paper presents a detailed study on the characterization of the Index, geotechnical and chemical properties of pond ash sample. Results reveal that pond ash has Coefficient of uniformity. 5.0 and coefficient of curvature, 1.65. Pond ash shows low specific gravity 2.30 g/cm^3 as compared to soil (2.6–2.7 g/cm^3), i.e.natural fill material, low amount of unburned carbon content 2.84 % and the maximum dry density is 1.19 g/cm^3 and 1.23 g/cm^3 whereas optimum moisture content is 28 % and 24.53 % for light and heavy compaction respectively. CBR value for un-soaked sample at light compaction is 9.02% and at heavy compaction is 19.10 % at 2.5 mm penetration. Soaked sample showed a value of 1.34 %. EDXRF test indicates the combined concentration of SiO_2, Al_2O_3 and Fe_2O_3 was 91.85 % and CaO was 0.95%, which verifies it as a Class F category fly ash. The results of chemical analysis indicates that concentration of Arsenic(As), Lead(Pb), Barium(Ba)and Chromium (Cr)are relatively higher than the standard land disposal limit, specified by United States Environment Protect agency (USEPA) TCLP limits for hazardous wastes. So it can be used adequately as embankment and subgrade construction fill material for low-lying areas. Caution must be adopted to prevent contamination of ground water due to the high concentration of some hazardous heavy metals.

***Keywords*:-** *Pond ash; Fill material; Embankment; Characterization; LOI; ED-XRF.*

I. INTRODUCTION

Coal usage for power generation results in generation of approximately 100 million tonnes of coal ash every year. In India, 65% are thermal power stations, utilizing domestic coal in 75% of them, with nearly generation of 20 million tonnes fly ash every year according to Bharathi Ganesh et.al[1]. Coal ash viz. fly ash, bottom ash and Pond ash are the by-products of thermal power plants and considered as waste materials whose dumping has been a major problem from an environmental point of view and a lot of land needs to be allocated to act as a disposable site. According to the Ministry of Environment and Forest, Government of India MOEF 1999 on September 14, 1999[2], the present thermal power plants were proposed to acquire 20% utilization of fly ash by 3 years and 100% utilization by 15 years. But till date only about 60% of thermal waste has been successfully used as useful resource. According to Shenbaga et.al[3], countries like India, China, Poland and the US, alone are responsible for production of more than 270 million tons of fly ash every year. Yet less than half of it remains un-utilized. The utilization of fly ash has increased from 3% in 1994, 13% in 2002, 56% in 2011 and nearly 62% by end of 2017[4]. The overall land required for disposal of ash would be about 82,200 ha by the end of 2020 at an estimated rate of 0.6 ha per MW.

In fact there are three types of ash produced thermally, viz. (1) fly ash, (2) bottom ash, and (3) pond ash. Huge quantity of fly and bottom ash are generated by thermally in power plants (TPPs) as a by-product. Usually 80 % of the coal ash is of the fly ash type and rest being bottom ash [5,6]. Fly ash is collected with the help of Electrostatic Precipitators (ESP) from the flue gases of power plant; whereas, bottom ash gets accumulated at the bottom of the boilers. When these two types of ashes are blended together, transported in slurry form and stored in the lagoons, the deposit material is termed as pond ash. This way of disposal is known as wet disposal system. This system causes segregation of coal ash and two distinctly significant types of materials are obtained at inflow and outflow points for the same ash pond, which have significant chemical properties than both fly ash and bottom ash. The inflow point contains the coarser and heavier particles of ash. Finer and lighter particles are transported away and settle in the vicinity of outflow point[7-9].

The specific coal bed composition determines the minor constituents of fly ash but may include one or more of the following elements or compounds in trace concentrations (up to hundreds ppm): arsenic, barium, beryllium, boron, cadmium, chromium, cobalt, copper, lead, manganese, mercury, nickel, selenium, silver, sulphur, thallium, vanadium, along with dioxins and PAH compounds in very small concentrations[10,11]. It also has percentage of un-burnt carbon[12]. Pond ash being 80 % fly ash and 20 % can be categorized in two classes defined by ASTM C618: Class F fly ash and Class C fly ash. These classes are differentiated based on the combined amount of silica, alumina, iron and the presence of free lime. Adding to this the type of coal burned (i.e., anthracite, bituminous, and lignite) also have large influence on the chemical properties of the pond ash. [13]

Fly ash itself has some amount of cementitious nature but with the presence of moisture it reacts chemically to form cementitious compounds and attributes to the strength improvement and compressibility characteristics of soils and acts an economic replacement for finely grained stones or soil which have been practiced for a long time till now.

Various efforts have been made by researchers to utilize this waste to resource as useful material such as fill material in roads and embankments, cement production, brick manufacture and construction of road embankments, Stabilization of soil, for backfilling retaining walls & embankments by Behera, B. et al. (2011), Bhattacharjee U. et al, (2000), Kolay, P.K., et al. (2011), Heidrich C.(2003)[14-15].

The primary objective of this research was to gauge the geotechnical properties like specific gravity, bulk density, moisture content, dry density, strength and chemical composition of pond ash. The present study deals with the characterization done by physical and chemical analysis and its suitability is measured to be used as a replacement of soil in highway and embankments.

II. MATERIALS AND METHODS

➢ *Materials*

In order to understand the properties of pond ash, sample was collected from the ash pond where disposal is done by wet disposal method in NTPC Badarpur, Haryana, India. For proper identification of physical and chemical properties, the ash samples collected were dried under sunlight to remove partial moisture and oven dried whenever necessary. A test for calculating the percentage of un-burnt carbon, Loss on Ignition (LOI) test was conducted.

➢ *Characterization Methods*

The characterization was carried out by performing test for physical and chemical properties of Pond ash sample in laboratory. Important physical properties of any material to be used as a fill material were determined. Parameters like Grain size; specific gravity(G); bulk density; maximum dry density(MDD); optimum moisture content(OMC); California Bearing Ratio(CBR) test for soaked(at least 96 hours0 and un-soaked sample were conducted. Unconfined compression strength of pond ash was also conducted to determine strength of sample.

Grain size test was performed as per IS:2720 (Part 4)[[16] and sample was sieved through Indian standard sieves of sizes 4.75, 2.36, 0.600, 0.300,0.150, 0.090 and 0.075 mm. This test was carried out 3 times to obtain average value of all the results obtained. Also hydrometer test was carried out on fine grained ash fraction, passing 0.075 mm sieve already collected in a pan. The specific gravity (G) of ash sample was determined by Pycnometer bottle as per IS 2720 (Part 3) 1980 sect/2[17]. Standard Proctor and Modified Proctor tests were conducted to determine Maximum dry density(MDD) and Optimum moisture content(OMC). Standard Proctor apparatus mould have 100 mm diameter and 127.3 mm height (capacity of 1000 ml) as per IS: 2720-Part 7[18] . Modified Proctor was conducted with the help of mould of 150 mm diameter and 127.3 mm height(capacity of 2250 ml) as per IS:2720-Part 8[19]. CBR was performed at OMC for both soaked and un-soaked sample with reference to IS: 2720(Part 16)-1973- Methods of test for soil-Laboratory determination of CBR [20]. A sample was kept in the mould for soaking for a period of 96 hours or more. Under this condition the sample in the mould attains optimum saturation. CBR test is then performed on the sample so as to determine the strength, if pond ash is to be used as fill material or subgrade which has to undergo adverse climatic situation such as heavy rainfall exceeding 500 mm.

Unconfined Compression (UCS) test was performed on a sample of 3.8 mm diameter and 7.6 mm height under standard loading conditions with a rate of strain of 1.2 mm/min as per IS:2720-Part 10-1991[21] . Loss on Ignition (LOI) test was performed to determine the amount of un-burnt carbon in Pond ash sample so as to facilitate the test for determining the chemical composition of the same. Energy dispersive X-ray fluorescence (ED-XRF) test was conducted in order to find out the chemical composition and presence of heavy metals the pond ash comprises. Huang (1990) experimented on the Indiana bottom ash and boiler slag to study the shear strength compacted to varying mass to volume ratio using direct shear testing. The results of friction angles shows a variation from 35 to 55°, depending on the density of the sample [22].

Manju Suthar et.al [23] determined that samples at the inflow have the major component of fine sand size i.e. (0.425–0.075 mm) and outflow samples from Khedar and Yamunanagar, had the major component of silt size (0.075–0.002 mm). Specific gravity of coal ash was 1.66-2.86 whereas 2.21–2.27 and 2.03–2.06 for inflow and outflow pond ash respectively. Bulk density point ranged between 1.114–1.275 g/cc. MDD of inflow was 1.212–1.322 g/cc and 1.093–1.312 g/cc for the outflow samples.; OMC ranges from 18.01–28.3 to 18.6–32.2 %, respectively. Pandian et.al [24] researched on the outcome of two types of fly ashes namely Fly ash-Raichur (Class F) and Fly ash-Neyveli (Class C). The CBR characteristics of the black cotton (BC) soil was determined. The fly ash content had an increase from 0 to 100%. Generally the cohesion and friction contributed to the CBR strength. The addition of fly ash to Black Cotton soil increased the CBR up to the first optimum level due to the frictional resistance and cohesion from fly ash and BC soil, respectively. A decrease up to 60% when fly was added beyond optimum level and then there was an increase up to the second optimum level. Thus the relative

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contribution of cohesion and friction from fly ash or BC soil attributes to the variation of CBR of fly ash-BC soil mixes.

P. V. V. Satyanarayana [25] investigated on a combination of recycled concrete aggregate and pond ash. Both were mixed at different proportions to determine geotechnical characteristics such as graduation, compaction and strength characteristics. The pond ash was used as a replacement below the size of 4.75mm. At 30% pond ash replacement CBR was 55% which was maximum. A 30-40 % of pond ash mixed with recycled aggregate generates CBR values greater than 60 % and 30 % which can be used as base and sub-base course materials respectively as a substitute to natural aggregate and sand in the design and construction of pavement.

The chemical composition of pond ash was pozzolonic as it contains SiO_2 (61.77 to 65.95 %); Al_2O_3 (20.56 to 21.64 %); Fe_2O_3 (8.70 to 11.48 %) and CaO (0.76 to 1.12 %) at the inflow and SiO_2 (62.45 to 63.85 %); Al_2O_3 (25.03 to 27.77 %); Fe_2O_3 (4.35 to 5.95 %) and CaO (0.66 to 0.90 %) at outflow by Manju Suthar. According to Sushovan Dutta et.al [26] fly ash consisted 63.52% SiO_2; 26.89% Al_2O_3; 5% Fe_2O_3; and 1.23% CaO. Un-burnt carbon was 1.49%. ASTM C618 categorize this fly ash as Class F. Specific gravity was 2.15. It consisted 78% of silt sized, 15% sand sized and 7% clay sized particles. The trace elements such as Zn, Cd, Pb, Mo, Ni, As, Se and B imposed a concern for land disposal regarding safety of environment. According to N.S. Pandian [27] the silica content was 37 to 75% alumina content ranges between 11 and 53% for pond ashes. The free lime lies in the range of 0.2 to 0.6% for pond ashes. It was derived that Indian coal ashes satisfy the chemical requirements to be used as a pozzolona. Neyveli fly ash was classified as Class C and other coal ashes were found to be Class F as per ASTM Classification.

Sushovan Dutta researched on the Use of Waste Plastic Bottles and Fly Ash in Civil Engineering Applications. They performed Compression test on plastic water bottles with fly ash and stone aggregates as in-fill materials. He studied the workability of reusing plastic water bottles as ideal compression member in Geotechnical applications. Compression tests at a constant displacement of 1.2mm/min were performed on the composite cells. Results of tests showed plastic bottles not only sustain 30% to 40% axial strain before failure but also fails at a high compressive pressure of 4000 kPa to 5000 kPa. Study suggested that these materials (pond ash) could be used for supporting higher loads and if required could permit higher settlements.

Bera et al. (2007) [28] studied on compaction characteristics of three different types of pond ash. Herein, the effects of compaction energy, moisture content, layer thickness, mould area, tank size, and specific gravity on dry density of pond ash were highlighted. The MDD and OMC vary within 8.40–12.25 KN/m³ and 29–46% respectively. In that investigation, the degree of saturation at OMC of pond ash varied from 63–89%. An empirical model was developed to estimate dry density of pond ash, using multiple regression analyses, in terms of compaction, water content and specific density. Linear empirical models were developed to estimate MDD and OMC in the field at any compaction energy. Practicing engineers might use these models to control compaction while in the field and for preliminary estimate MDD and OMC of pond ash.

Efforts are continuously given by making strict regulations by the Government to fully utilize the fly ash. India currently produces about 130 million tonnes of fly ash by FLY ASH RESOURCE CENTRE (FARC), STATE POLLUTION CONTROL BOARD, ODISHA [29] which calls for an increase in the utilization percentage. The dumping of fly ash would require 1000 km² which in turn shall make require new areas of disposal, involving displacement and hence rehabilitation problems. Pond ash chemically is amorphous ferro-alumina silicate, $Fe\text{-}Al_2SiO_5$ with major elements like Si, Al, Fe along with significant amounts of major / secondary nutrients (Ca, P, K, Mg, S) and micro nutrients (Cu, Fe, Mn, Mo, Zn)

As compared to other materials, fly ash being very finer and more reactive is consequently suitable as embankment and road construction material. Fly ash alone / soil stabilized fly ash / fly ash mixed with admixtures and heir potential application for road construction has been reported by a number of researchers. Arumugam K et.al(2011) [30] experimented to investigate the possibility of using pond ash in varying percentage as substitute of fine aggregate in cement concrete with the workability and compressive strength of concrete and was compared with standard concrete. With addition of pond ash a reduction in unit weight and slump value was observed for fresh concrete as specific gravity is less than soil. The strength of concrete also improved with age of concrete up to the addition of 20% fine aggregate replacement with pond ash. Further addition reduces the strength.

III. RESULTS & DISCUSSIONS

- *Grain size distribution*

The results of Grain size distribution (GSD) of pond ash sample after sieve analysis are outlined in Fig 1. Uniformity coefficient, (Cu) and Coefficient of curvature, (Cc) are calculated and is presented in graph.

$$\mathrm{Cu} = \frac{\mathrm{D}^{60}}{\mathrm{D}^{10}}$$

$$\mathrm{Cc} = \frac{(\mathrm{D}^{30})^2}{\mathrm{D}^{60}} \times \mathrm{D}^{10}$$

D_{10}, D_{30} and D_{60} are particle sizes in a way that 10, 30 and 60% of the ash are finer than these size, respectively. The results of GSD are shown in Figure 1. The results show that the pond ash sample was uniformly graded and non-plastic in nature. The major component of the pond ash sample was of fine sand size i.e. (0.425-0.075 mm). Check values of Cu and Cc from the graph. The value of coefficient of uniformity was within permissible range according to IRC:SP:58-2001[27].

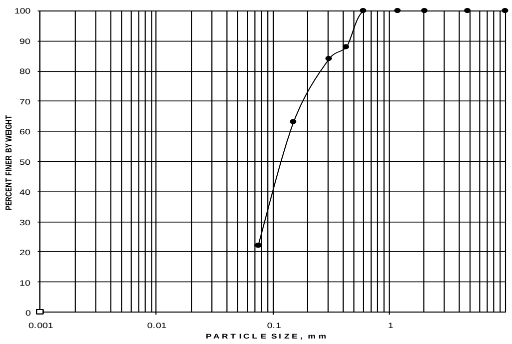

Fig 1:- Grain Size Distribution curve

➢ *Specific Gravity and Bulk Density*

The results of specific gravity (G) and bulk density (ρ) are presented in table. The specific gravity of coal ash generally lies between 1.90-2.55 g/cc as per IRC:SP:58-2001. The average Specific gravity (for 3 samples) obtained after Pycnometer test of the oven dried pond ash sample was 2.30 g/cm³. The low specific gravity could be due to the presence of a large number of hollow cenospheres from which entrapped air cannot be removed. However the specific gravity value of pond ash sample lies significantly below the specific gravity of soil i.e. natural fill material. The higher value of specific gravity of the ash sample is may be due to presence of high amount of Fe_2O_3 obtained from chemical analysis. Bulk Density (ρ) of ash sample was found out to be in between 1.117-1.517 g/cm³.

➢ *Compaction Characteristics*

The compaction test results were determined using standard procedure and presented in the following figures. The results for light compaction are shown in Figure 2. In case of light compaction(Standard Proctor method), test results it was observed that the Maximum Dry Density(MDD) of the ash sample range was 1.19 g/cc while ranging from 1.04–1.19 g/cc; Optimum Moisture Content(OMC) was 28% and ranges from 12.41–45.89 %. Whereas in case of heavy compaction i.e. Modified Proctor tests, MDD was found out to be 1.23 g/cm³ and OMC was 27.03%. MDD and OMC results for the Pond ash sample are found to be within specified limits (MDD- 0.9–1.6 g/cm³ and OMC- 18.0–38 %) as per IRC:SP:58-2001 acceptable for highway embankment construction.

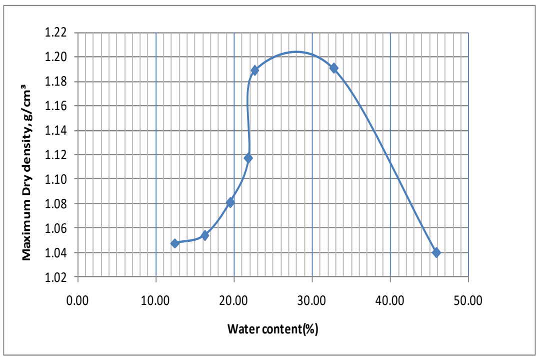

Fig 2:- Water content-dry density relation for Standard Proctor Compaction

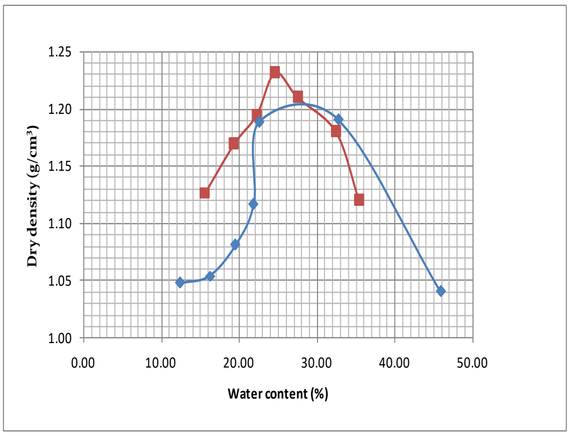

Fig 3:- Comparison of MDD and OMC for light and heavy compaction

The results of heavy compaction are shown in Figure 3. It can be observed from the results that in case of heavy compaction OMC had a decrease by 3.32 % and MDD showed higher value by 2.52 %. It can be concluded that with an increase in MDD of the sample the OMC decreases proving to be inversely proportional to each other.

➢ *California Bearing Ratio*

In order to determine the strength of Pond ash, California bearing ratio test was performed at OMC for both Standard and Modified Proctor test. CBR value was determined for un-soaked samples of pond ash. Test for Soaked sample was also conducted to understand the strength characteristics of subgrade under adverse situations such as heavy rainfall exceeding 500 mm. For the un-soaked sample at Standard Proctor OMC the CBR was found to be 9.02 % and 15.18 % for 2.5 mm and 5.0 mm penetration respectively. The soaked sample showed relatively lower value of 1.64 % and 1.87 % for 2.5 mm and 5.00 mm penetration of the plunger, respectively. The results of load against penetration are shown in the Figure 4 and 5.

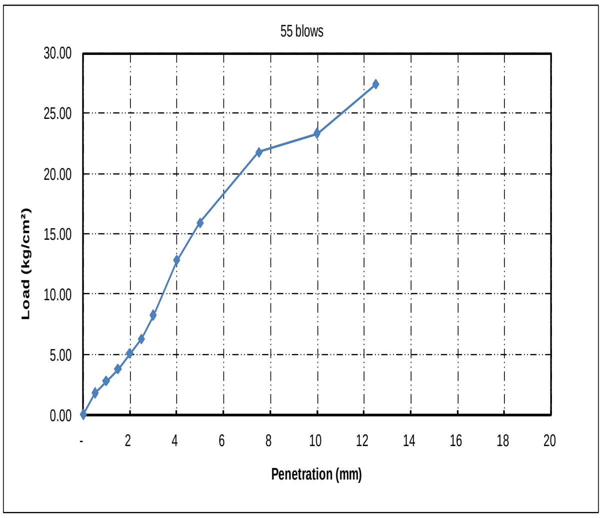

Fig 4:- Load-Penetration relation for Un-soaked Pond ash sample at 28 % OMC

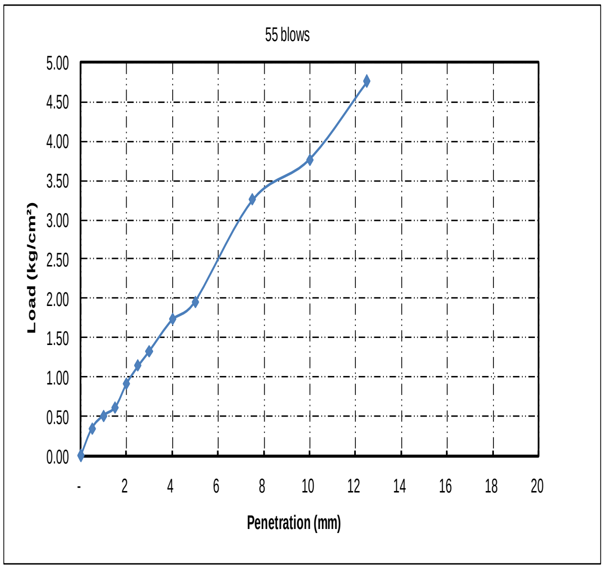

Fig 5:- Load-Penetration relation for Soaked Pond ash sample at 28% OMC

In case of CBR performed at OMC obtained by heavy compaction, for 2.5 mm and 5.00 mm penetration the sample showed a value of 19.10 % and 28.15 % respectively for the un-soaked sample. The results are analysed graphically and shown in Figure 6.

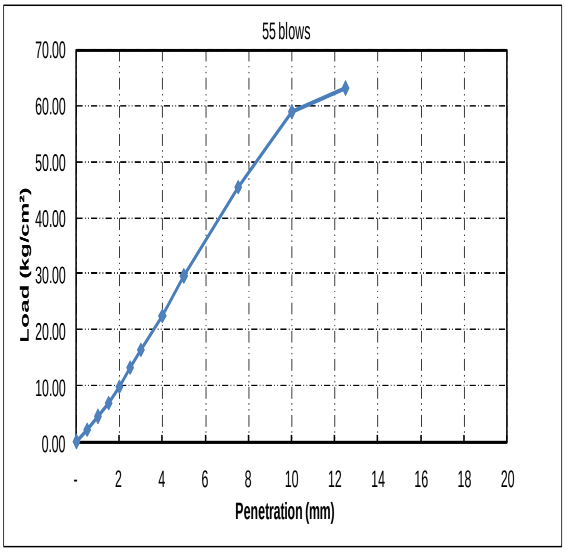

Fig 6:- Load-Penetration relation for Un-soaked Pond ash sample at MPCT

➢ *Unconfined Compression test*

Unconfined Compression test was done to determine the behaviour of Pond ash under axial load so as to find out the compressive strength and shear strength. The test was carried out on a cylindrical sample having diameter of 3.6 cm and height 7.6 cm under a rate of strain of 1.2 mm/min at standard loading conditions. The compressive strength was found to 2.037 kg/cm² and shear strength was 1.019 kg/cm² at an elapsed time of 2.5 min. Results from Figure 7 shows the ultimate compressive stress is observed at a strain of 3.68 %.

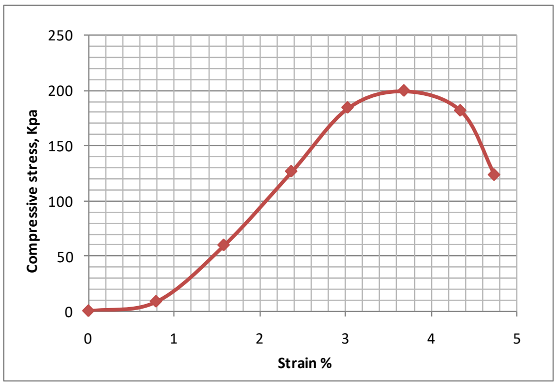

Fig 7:- Relation between Stress and Strain under axial load

➢ *Loss on Ignition*

The coal ash obtained from thermal power plants has some amount of un-burnt carbon in it which may affect the composition of oxides and heavy metals in Coal ash. So in order to determine the amount of un-burnt carbon in Pond ash, a test on loss on ignition was carried out at a temperature of 450˚C in a blast furnace for 5 hours. The weight of the sample before and after the Ignition was measured and the loss of weight due to removal of moisture was calculated with the help of the equation as given below.

$$\text{LOI} = \frac{W2-W3}{W2-W1} \times 100$$

Where, W1= Weight of empty crucible
W2= Weight of crucible + Sample
W3= Weight of dried sample + crucible
The loss on Ignition was found out to be 2.84%.

➢ *Chemical Properties*

The chemical composition was determined using ED-XRF Epsilon testing machine on the Pond ash sample. The Epsilon 5 is a fully integrated X-ray analysis system. It combines of a unique energy-dispersive X-ray fluorescence spectrometer, with instrument control and analysis software to derive the composition of major and minor elements up to PPM. The results of chemical analysis of Pond ash sample are presented in Table 1. From the results, it was observed that Pond ash sample are primarily rich in Silica (SiO_2), Alumina (Al_2O_3) and Iron oxide (Fe_2O_3). It also contains CaO, P_2O_5, K_2O, MgO, MnO, TiO_2 and ZnO in small amounts. Heavy metals like arsenic, barium, lead and chromium were found in trace amounts but they are high than the permissible limits as given by the USEPA TCLP limits for hazardous heavy metals in waste[28]. Table 2 shows the amount of heavy metals in comparison with TCLP limits for hazardous wastes. Mishra and Das reported the presence of SiO_2 (≥60 % of the total composition) in higher amount may help in increasing the strength as a fill material and offer better bearing capacity. The presence of small amount of free lime(CaO) (0.95%), which being less than 1% causes very negligible pozzolonic or cementing properties[29].

According to ASTM C 618-08a, the sample of Pond ash falls in the category of Class- F ash; this is because the combined amount of oxides of silica, alumina and iron is 91.85 % and the percentage of CaO is very less than 0.95 %.

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Results of the chemical characterization are found to be in justified with the study conducted by Jakka et al.

It is clear from Table that the LOI value (i.e. un-burnt carbon) of the sample is very low which is less than 5.0 %. i.e. maximum limit specified as per ASTM C618-08a. Due to low LOI value, the risk of self heating is eliminated or spontaneous heating if pond ash can be utilized as a fill material for highways and embankments studied by Manju Suthar et.al.

MAJOR ELEMENTS	***POND ASH %***
SiO_2	59.20
Al_2O_3	27.24
Fe_2O_3	5.41
$SiO_2+Al_2O_3+Fe_2O_3$	91.85
CaO	0.95
TiO_2	1.83
P_2O_5	0.42
K_2O	1.89
MgO	0.48
LOI	2.84

Table 1:- Chemical composition of Pond ash sample

HEAVY METALS	*TCLP LIMITS (mg/L)*	*POND ASH (mg/L)*
Arsenic	5	0.268
Barium	100	743.82
Cadmium	1	0
Chromium	5	783.35
Lead	5	54.43
Mercury	0.2	0
Silver	1	0
Selenium	5	1.88

Table 2:- Composition of Heavy metals in Pond ash sample

IV. CONCLUSIONS

The following conclusions can be drawn based on the above results and discussions:

- Grain size distribution (GSD) shows most of the particles of ash sample are of fine sand size and fine silt size. The ash sample shall be better fill material being well graded in nature.
- Pond ash sample shows low specific gravity value of 2.30 due to the presence of hollow cenospheres. The specific gravity value lies within permissible range (1.90-2.55) as specified by IS:SP:58-2001. The higher value of specific gravity can be due to the presence of high amount of Fe_2O_3 as found in the chemical analysis. The low specific gravity of pond ash as compared to natural soil is advantageous to use as fill materials in embankment and backfill for retaining walls because it shall exert lesser earth pressure.
- Compaction characteristics show that, ash sample have higher MDD but a decrease in OMC in case of heavy compaction than in light compaction method. Results of the MDD and OMC for pond ash sample are within the permissible limits as specified by IRC:SP:58-2001 for suitability of ash in embankment construction.
- From the results of Unconfined Compression tests, it is observed that the maximum compressive stress occurs at a strain of 3.684 % with an elapsed time of 2.5 minutes.
- The LOI value being < 5% indicates low amount of un-burnt carbon. Hence there is no risk of spontaneous heating if pond ash sample is used as fill material.
- Chemical analysis result, specifies that the combined amount oxides of silica, alumina and iron is more than 70 % and CaO percentage is less than 1% in the ash sample. As per ASTM C618-08a, the pond ash sample collected is classified as Class F.
- The presence of hazardous heavy metals like barium, chromium and lead in the ash sample higher than that specified by USEPA TCLP limits for hazardous wastes can have adverse impacts including contamination of surface and subsurface water, loss of soil fertility around the plant sites, etc. Hence this requires a detailed study of their chemical composition, morphological studies, pH and total soluble solids.
- The presence of heavy metals like Br, Cr and Pb in Badarpur Pond ash sample in mg/l was found higher than the specified limits. Hence there is a need for stabilization of pond ash with economical and environment friendly admixtures such as lime, marble dust, granite powder, etc. A mechanical stabilization is preferred over chemical stabilization in this case so as to avoid use of chemicals which can have adverse effects on the underlying soil in future.

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