Performance of Lagoon Ash As Bottom Liner in MSW Landfill

Bidula Bose, Sudeep Kumar Chand, Maheswar Maharana

Abstract:** Proper management of Municipal Solid Waste dumping in landfill site require adequate bottom liner to mitigate the seepage of leachate from contaminating the ground. To make landfill system sustainable, adequate liners are provided at the bottom of engineered landfill system. Liners act as impermeable cover mitigating effect of leachate on ground and groundwater. Pond ash collected from lagoon of thermal power plant is a preferable building material for municipal solid waste impounding system if properly stabilized and compacted. To meet the mandatory requirement of landfill liner having permeability 10^{-7} cm/sec or less, detailed experimental study was carried out on pond ash collected from Nalco Captive Power Plant, Angul, India. The parameters Unconfined Compressive Strength (UCS) and coefficient of permeability (K) were determined by conducting the laboratory experiments following Indian standard code procedure for all the mixes as stated in Table 1. Experimental results of UCS test were found to increase the strength upto 5.4 MPa for S3 mix sample after curing period of 180 days. It was further observed that for the sample S7 mix the strength reached upto 6.9MPa which was due to the binding effect of 1% gypsum in the mix. The hydraulic conductivity value of stabilized Pond Ash came down to 10^{-7} cm/sec after 180 days of curing period even after acid and base permeation. It was observed from R square value established for all sample mixes of pond ash that a strong linear correlation existed between curing time and UCS value. The strength and permeability results clearly indicate that pond ash, stabilized with optimum mix of lime-gypsum satisfies both Environmental Protection Agency (U.S) and Central Pollution Control Board (India) guidelines for landfill liner. Hence lime and gypsum stabilised pond ash is proved to be an effective eco-friendly material adhering to the requirements of landfill bottom liner for MSW engineered landfill system.

***Keywords:** Unconfined Compressive strength, Hydraulic conductivity, Pond ash, Acetic acid, Methanol*

I. INTRODUCTION

Municipal solid waste confinement by engineered landfill consists of barrier layer at the bottom that must prevent toxic elements prone to contamination of soil and groundwater. A necessary condition for adequate operation of a landfill strongly emphasizes on need of low hydraulic conductivity of bottom liner material to retard percolation of leachate.

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By providing appropriate liner material landfill will perform better by preventing entry of toxic constituents into subsoil beneath. If the natural soil present beneath the landfill base consists of porous material or clayey soil that shrinks when dried, an alternative liner material is used in place of bottom liner. A typical landfill liner material must possess resistance against permeability of leachate and adequate strength. Generally, clay has been traditionally used along with stabilizing agents as landfill liner material. But one of the disadvantages of clay is that it develops shrinkage cracks.

Clay liners are proved not to be very effective liners because the chemicals present in the leachate affect the geotechnical properties of the clay liners negatively. Alternatively, Pond Ash, the waste material generated from most of the power plants in India if efficiently stabilized are best suited to be used as liner material at MSW landfill. The coal ash stored in lagoons, which is nothing but fly ash hydraulically disposed off in to the ash pond either alone or along with the bottom ash is normally known as pond ash or lagoon ash. Having very less pozzolanic property, they are most suited for backfilling and mine filling. By utilizing fly ash and pond ash in bulk quantity, the major problem being faced by the coal based thermal power generation sector related to the storage and disposal are also efficiently met. Industrial waste utilised as landfill base imparts strength when chemically stabilised even in tropical countries (Subbarao and Ghosh 1997).Stabilized Pond ash serves effectively as an impermeable liner construction material (Prakash and Sridharan 2009., Sahin and Anapali 2005.,Rout and Singh 2020.,Gupta and Paulraj 2016.,Suthar and Aggarwal 2016., Suthar and Aggarwal 2018).Lime stabilization is proved to be an effective measure to minimize the metal element concentration coming out of fly ash and pond ash(Sivapullaiah and Moghal 2011.,Prakash and Sridharan 2009.,Sahin and Anapali 2005.,Rout and Singh 2020.,Gupta and Paulraj 2016., Suthar and Aggarwal 2018). A combination of adequate lime percentage to reach equilibrium condition is needed along with very small percentages of gypsum for pond ash stabilization wherein gypsum plays a crucial part for evolution of closely packed base and reduces flow of calcium from stabilized matrix(Pandian 2004.,Ghosh and Subbarao 2001.,Ghosh and Subbarao 2006.,Ghosh 2010).Gypsum mixed in small amount with lime stabilisation enhances the strength of coal ash in mechanical mixing of lime and gypsum with curing time (Sivapullaiah and Moghal 2011.,Sivapullaiah and Baig 2011.,Shankar and Niranjan 2015.,Ghosh and Subbarao 2001.,Chand and Subbarao 2007).

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Most of the limitations of coal ashes efficiently are improved by controlling the unburned carbon content and by mechanical stabilisation of pond ash with gypsum or cement as chemical admixture (Chatterjee 2011., Das and Yudhbir2005., Mishra and Ravindra 2015., Rout and Singh 2018). Though many work has been done on permeability of stabilised pond ash, very few have emphasized the effect of permeant other than water on the material. Furthermore, the effect of acid and base solutions penetrating into the liner possess much importance from practical point of view. Considering the real problem of MSW landfill site, the present study is performed to examine the suitability of pond ash as a landfill liner material in practical landfill conditions where the leachate will comprise of acid and base liquid leachates.

II. EXPERIMENTAL INVESTIGATION

2.1 Material collection

In this study, Pond ash was collected from NALCO Captive Power Plant, Angul, Odisha, India. Lime was collected from local market and 75% purity was determined by titration method. Powdered gypsum was ordered and collected from online site ‘biomall.in’. The manufacturer (Research lab-fine chem industries) guaranteed 96% purity of the product. The mixes are designated in Table.1 with a customary coding system consisting of prefix S for easy identification. Acetic acid having density 1.05 gm/cc and Methanol having density 0.792 gm/cc were used to prepare 3% acetic acid and 5% methanol solutions.

2.2 Methodology

In order to characterise pond ash, the grain size distribution was carried out using hydrometer. The specific gravity of pond ash was determined by pycnometer bottle. The chemical composition of lagoon ash, lime and gypsum were identified by conducting Energy-Dispersive X-Ray Spectroscopy (EDS) test. Scanning electron microscope system (SEM) was used to examine the morphology of the particles. All the samples were compacted by following light compaction test method as per IS 2720: Part VII. Dry density was determined for each of the sample compacting it in a proctor mould of 1000ml capacity. To perform Unconfined compression strength test, the sample mixes were compacted in layers into a split mould of size 38 mm diameter and 76mm height to achieve dry weight corresponding to maximum dry density. Specimen for UCS test was extracted from split mould and each specimen was checked for error in dry density and moulding water content with permissible error of ±0.15 % and ± 0.25% respectively. To measure unconfined compressive strength, test was conducted in UCS apparatus

Fig 1. Wax coated stabilized Pond ash samples prepared for curing in humidity chamber

on specimen immediately compacted and a set of cured specimens. The wax coated samples were tested at intervals of curing period of 7,30,60,90 and180 days respectively those were kept in humidity chamber maintaining temperature of 30°C and 95% humidity.

Table 1. Proportioning of Pond Ash, Lime and Gypsum mixes for sample preparation.

Proportioning of mixes			
Pond ash (Percentage by weight)	**Lime (Percentage by weight)**	**Gypsum (Percentage by weight)**	**Sample ID**
100	0	0	S1
90	10	0	S2
86	14	0	S3
89.5	10	0.5	S4
85.5	14	0.5	*S5*
89	10	1	S6
85	14	1	S7

Permeability of different samples of Pond ash, lime, and gypsum mixes were studied by conducting falling head permeability test by following IS:2720: Part 17 on cylindrical sample size of 100 mm diameter and 127.4 mm long. To measure permeability, after a set of samples were cured in permeability mould using a simple type of curing apparatus consisting of tin container where one permeability mould can easily be accommodated well packed with perforated board and air tight lid to maintain humidity inside the tin.

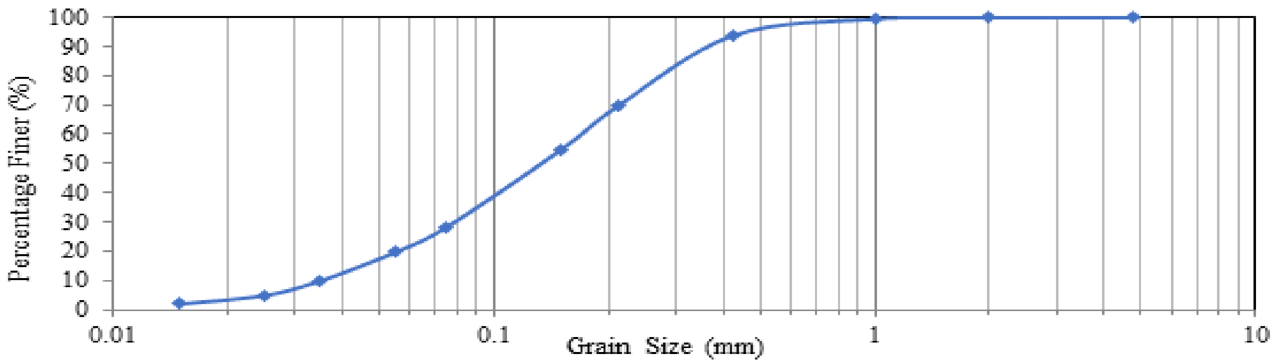

Fig 2. Grain Size distribution of pond ash

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The curing arrangement made for permeability test samples consisted of a prism shaped tin container 240x240x350 mm (height) with an air tight lid filled with water standing up to 90mm . This type of apparatus as shown in Fig 3 was used for permeability test sample curing creating humid environment and kept at room temperature around 30°C. Observations for determination of permeability were made after 7,30,60,90 and 180 days of curing in falling head permeability apparatus.

III. RESULTS AND DISCUSSION

3.1. Physical and chemical properties of pond ash

The physical and chemical properties of pond ash are shown in Tables 2 and 3 respectively. Grain Size Distribution curve gives the coefficient of uniformity (c_u) and coefficient of curvature (c_c) value of pond ash as 5.14 and 1.01 respectively. The soil is being classified as SP as per Unified soil classification system and the particle size distribution curve indicates uniform gradation of sample. Chemical composition of pond ash shows predominant Aluminum and Silicious compounds present in the material.

Table 2. Physical properties of pond ash

Physical parameters	Values
Colour	Light grey
Shape	Rounded/sub-rounded
Silt &clay (%)	25
Fine sand (%)	71
Medium sand (%)	4
Coarse sand (%)	0
Uniformity coefficient, Cu	5.14
Coefficient of curvature, C_c	1.01
Specific Gravity, G	2.37
Plasticity Index	Non- plastic
Classification	SP

Table 3. Chemical properties of pond ash

Constituents	Percentage(%)
SiO_2	56.8
Al_2O_3	25.0
Fe_2O_3	8.82
MgO	0.79
P_2O_5	0.18
SO_3	0.29
K_2O	0.80
CaO	1.15
Na_2	0.16
TiO_2	1.65
Carbon	4.10

3.1.1 Scanning electron microscope (SEM) test

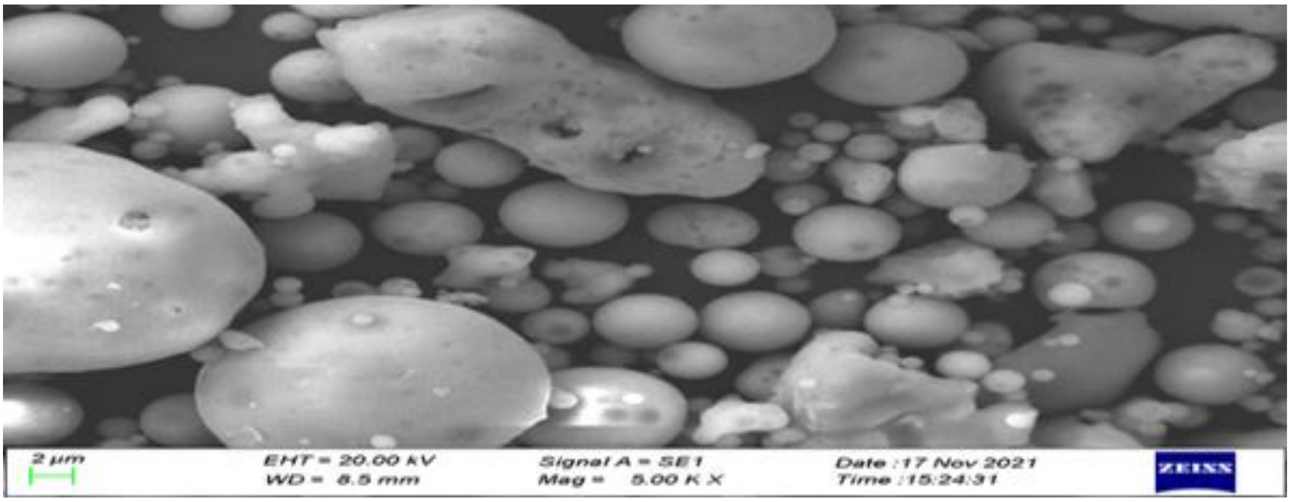

Fig 3. Scanning Electron Micrograph of Pond ash at 5 K X magnification

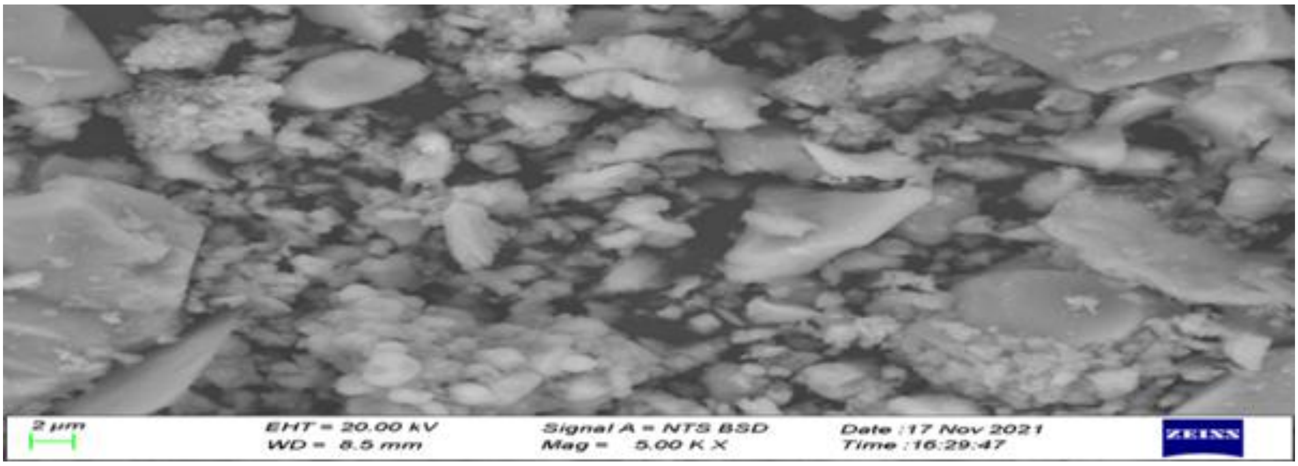

Fig 4. Scanning Electron Micrograph of Lime powder at 5 K X magnification

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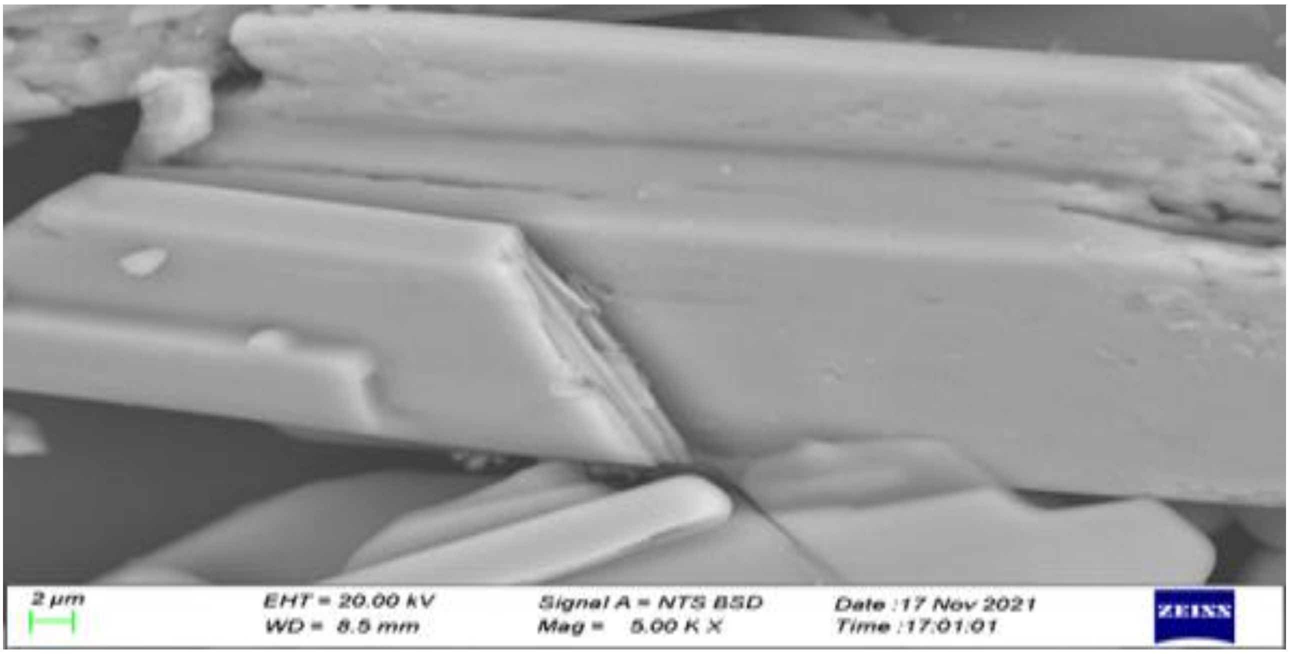

Fig 5. Scanning Electron Micrograph of Gypsum powder at 5 K X magnification

Scanning electron microscope (SEM) techniques available at CSIR(IMMT), Bhubaneswar was used to study the morphological characteristics of pond ash collected from lagoon of captive power plant, NALCO, Angul, India. The autonomy studies show that ash structure is a combination of glassy spheres, including solid and hollow ones. Very little amount of pond ash sample (5 to 10 gm) was taken in a vessel with 5 ml of deaired water. Then the prepared solution was set in frame on a glass slide and was kept in desiccators for 24 h. After that the mineralogy analysis tests were performed using the facility available at CSIR(IMMT), Bhubaneswar, India.

3.1.2 Energy-Dispersive X-Ray Spectroscopy (EDS) test

The Energy-Dispersive X-Ray Spectroscopy (EDS)studies indicate that the coal ashes predominantly contain quartz and feldspar minerals. Quartz, mullite, magnetite and calcium compounds constituting about 10-15% by weight of pond ash. EDS plots are shown in Figs 6, 7, and 8 respectively. The EDS pattern of pond ash shown in Fig. 6 shows that there is predominant SiO_2 and Al_2O_3 composition present in pond ash.

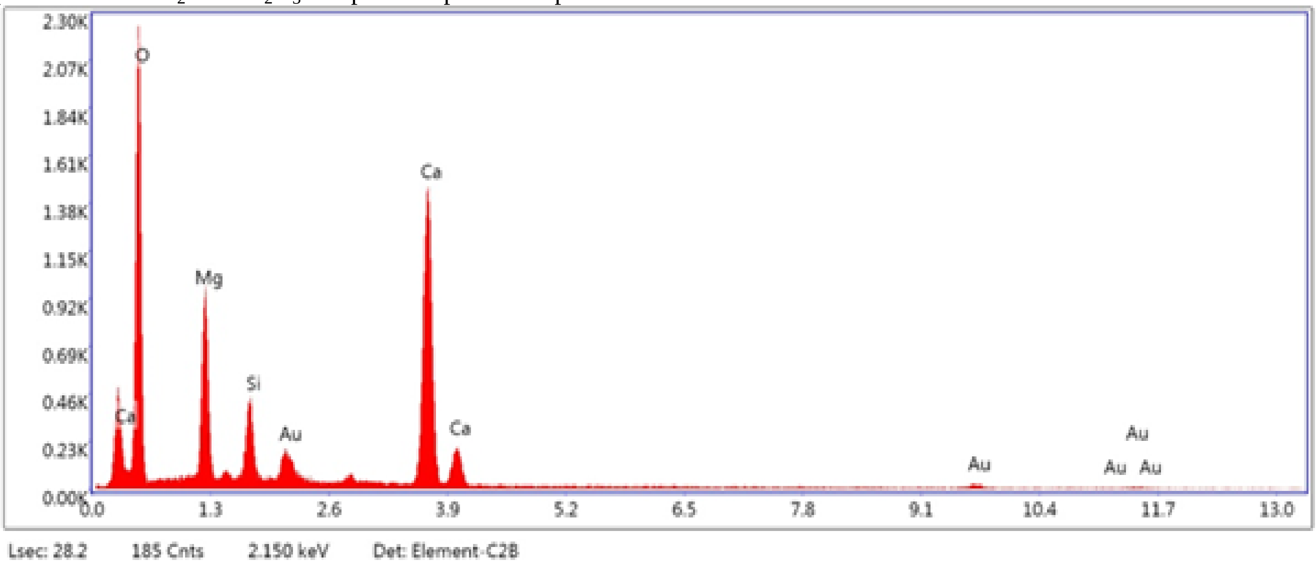

Fig 6. Energy-Dispersive X-Ray Spectroscopy pattern of pond ash

According to the chemical requirements stated in ASTM C618-19(2019), the pond ash used in this study can be classified as class F pozzolan containing total sum of (SiO_2+ Al_2O_3+Fe_2O_3) composition expressed as total percentage of weight of total composition within 70% and CaO percentage as weight of total composition lies below 18%. The EDS pattern of lime in Fig 7. shows that there is predominant CaO composition (24.06%) present in lime which will help in further pozzolanic reaction in stabilized pond ash.

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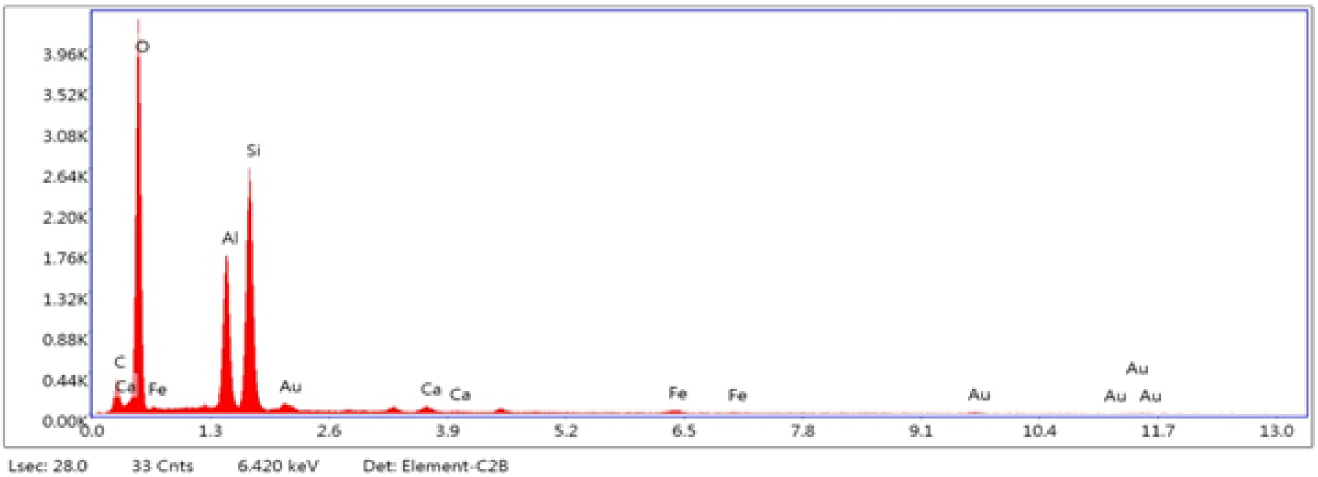

Fig 7. Energy-Dispersive X-Ray Spectroscopy pattern of lime

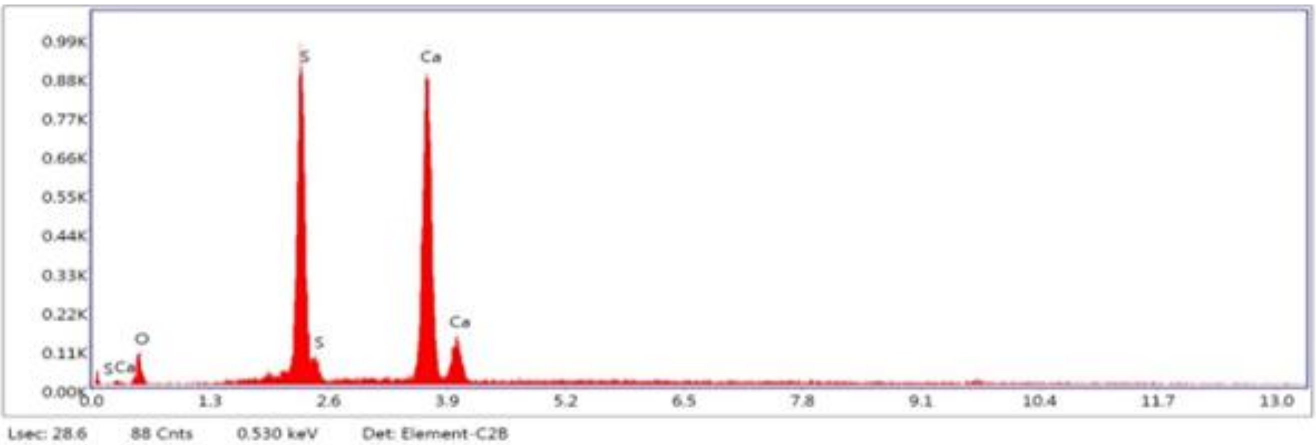

Fig 8. Energy-Dispersive X-Ray Spectroscopy pattern of gypsum

The EDS pattern of gypsum as shown in Fig 8. shows that there is predominant CaO composition (53.79%) present in lime which will help in further fixation of pozzolanic reaction in cured stabilized pond ash.

3.2 Moisture content -dry density relationship

Light weight compaction tests with different proportions of pond ash mixes were conducted to find out the maximum dry density. In order to conduct compaction test of various combinations, lime content of 10% and 14% by dry mass of pond ash and gypsum content of 0.5% and 1% by dry mass of pond ash was added to dry pond ash. Light compaction test was carried out for various proportions of pond ash and stabilizing agent mixes.

Table 4. Moisture density relationship of stabilized Pond ash

Sample ID	Dry Density(kN/m^3)	Moisture Content (%)
S1	11.51	30.23
S2	11.48	31.21
S3	11.43	32.57
S4	11.63	30.52
S5	11.61	31.15
S6	11.75	29.08
S7	11.72	29.56

The moisture content and dry density relationships obtained from standard proctor tests for pond ash mixes containing 0,10 and 14% lime and 0.5 and 1% gypsum mixes are shown in the Table 4. The maximum dry density and optimum moisture content of pond ash were found to be 11.51 kN/m^3 and 30.23% respectively. With addition of 1% of gypsum and 10% lime to total mass of pond ash gives MDD value of 11.75 kN/m^3. The MDD value of Pond ash and lime mixes varied from 11.51 kN/m^3 to11.43 kN/m^3 but with addition of gypsum further to pond ash -lime mixes OMC decreased to 29.56% and MDD increased upto 11.70 kN/m^3. It means that the particle gets closely packed with addition of even small amount of gypsum. Gypsum gives additional strength to lime stabilized fly ash (Sivapullaiah and Moghal, 2007).

3.3 Unconfined Compressive Strength Test

UCS is one of the most reliable tests to study the strength aspect of stabilized soil. Pond ash with 10% and 14% lime along with variation of 0.5% and 1% gypsum was used to stabilize pond ash.

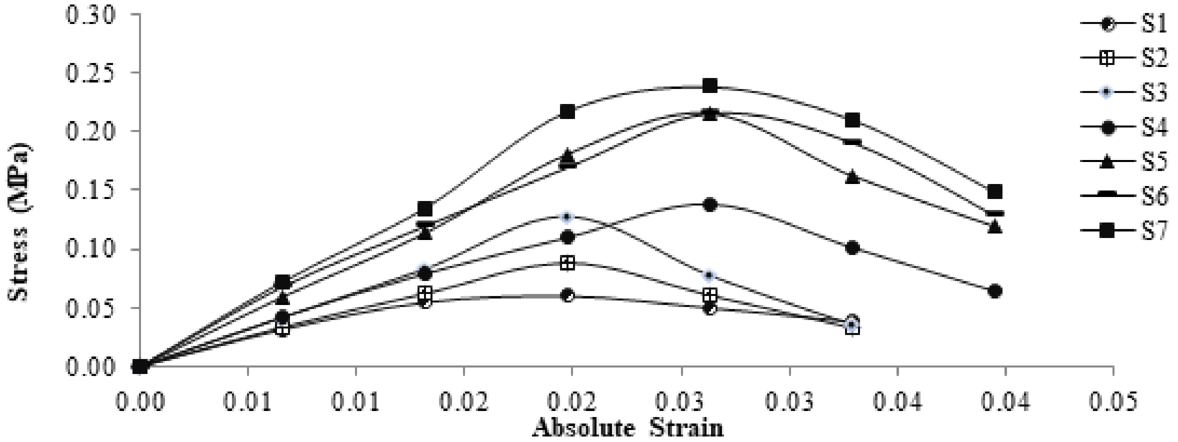

Fig 9. Stress -Strain variation of lime and gypsum stabilised pond ash

Furthermore, Figs 9 ,10, 11,12,13, and14 depict the variation of stress and strain over interval of curing time(days). It is observed that a general strength gain is occurring for only lime and lime -gypsum stabilised samples also. UCS value of unsterilized pond ash did not show much variation even after 180 days of curing time and remained nearly 0.062 MPa without showing much alteration even after curing period. This may be attributed to absence of reactive silica in pond ash. Lime as a chemical additive at first is responsible in this increase in UCS by changing the mix workability.

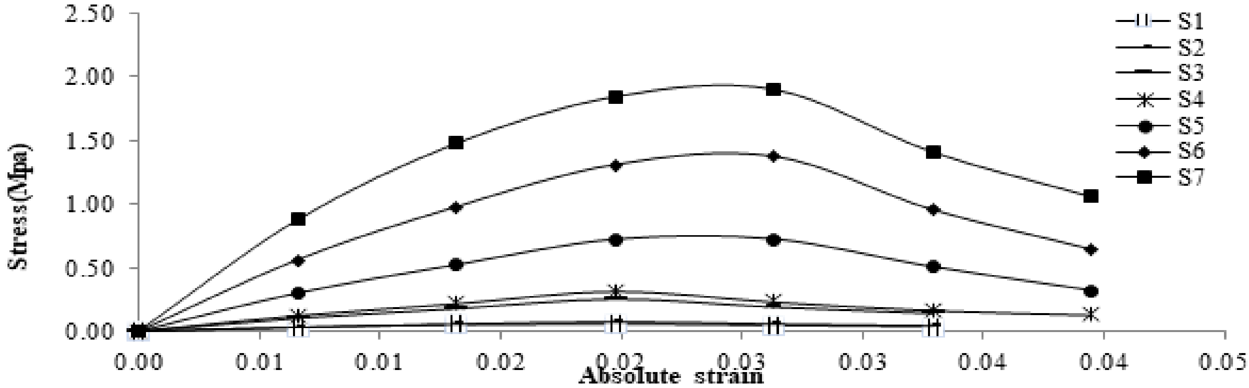

Fig 10. Stress – Strain variation of lime and gypsum stabilised pond ash after 7 days of curing period

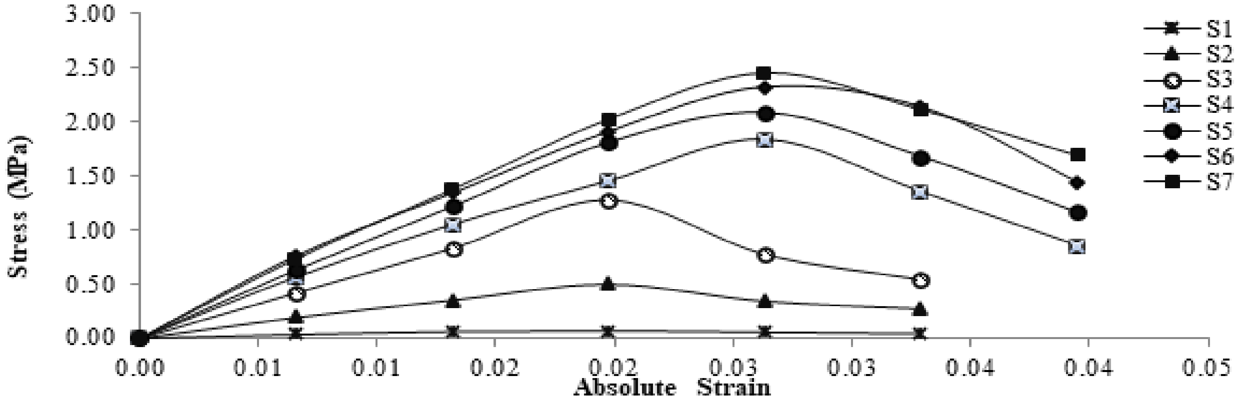

Fig 11. Stress -Strain variation of lime and gypsum stabilised pond ash after 30 days of curing period

Further pozzolanic reaction results on addition of gypsum which helps in the formation of various cementitious agents which increase mixture strength as earlier interpreted by Sarkar et al. (2012)., Mishra and Das (2010). Similar result has also been interpreted by Sivapullaiah and Baig (2011); Sivapullaiah and Moghal (2011);Prasanth et al.(2001).,Moghal and Moghal (2012).,Heittiaratchi et al.(1999).

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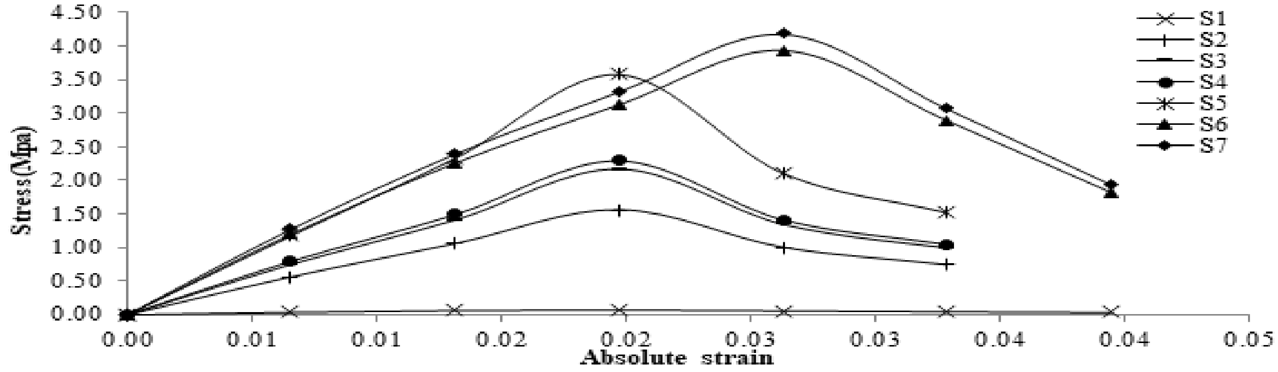

Fig 12. Stress -Strain variation of lime and gypsum stabilised pond ash after 60 days of curing period

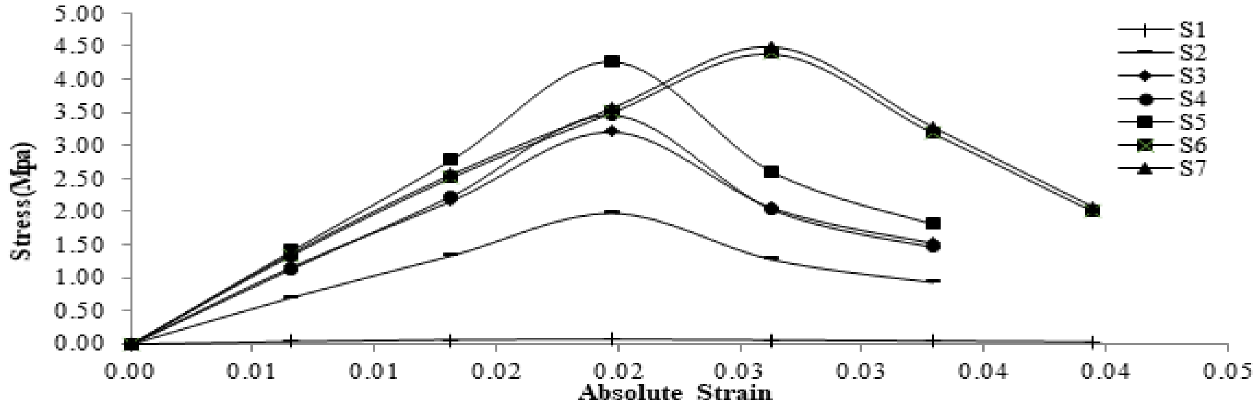

Fig 13. Stress -Strain variation of lime and gypsum stabilised pond ash after 90 days of curing period

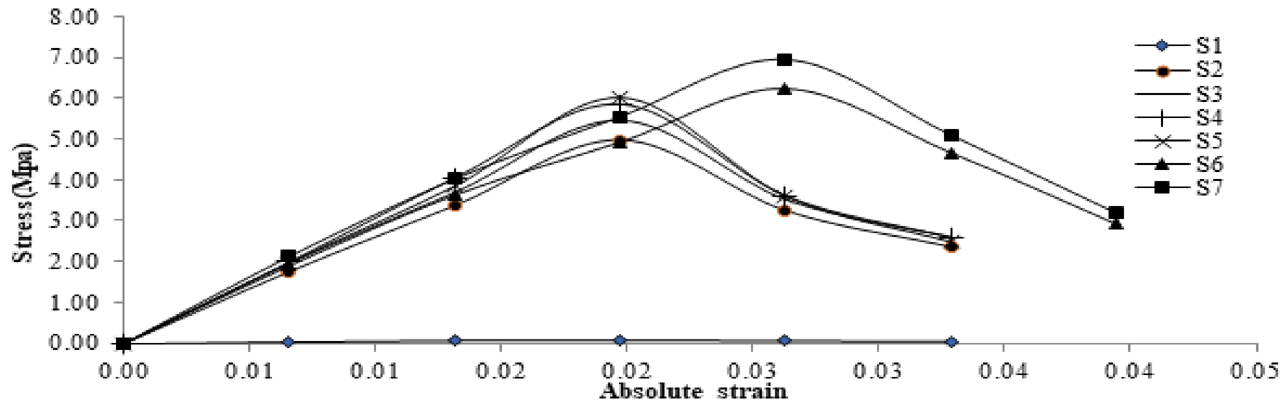

Fig 14. Stress-Strain variation of lime and gypsum stabilised pond ash after 180 days of curing period

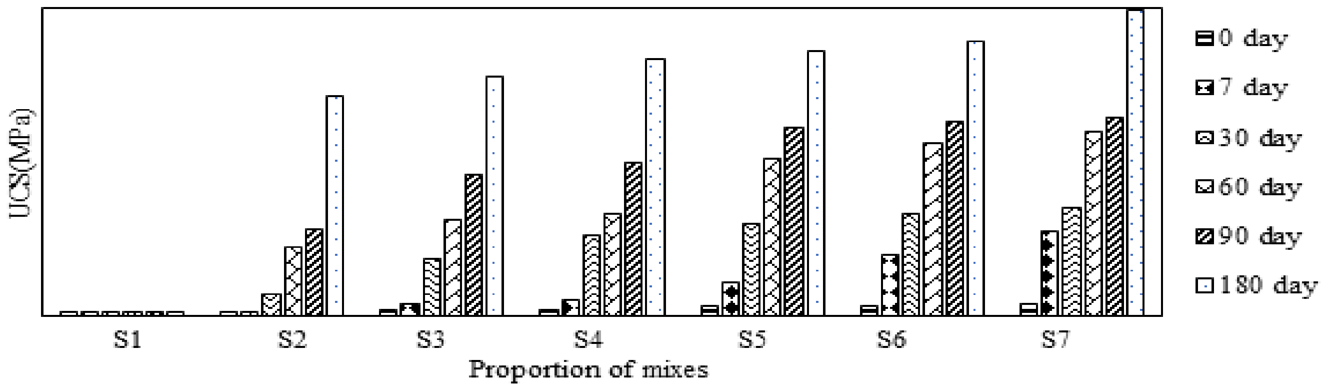

Fig 15. Variation of UCS of stabilised pond ash with curing time

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The effect of curing period at 30°C on unconfined strength of stabilized pond ash mixes shown in Fig 15. shows a significant increase in unconfined compressive strength with increasing lime-gypsum mixes. The optimum lime and gypsum percentages for improving the shear strength of treated soil under present condition are 14% and 1% respectively.

3.3.1 Study of correlation between Curing Time and UCS

Using correlation model data analysis tool of Microsoft excel, the relationship between curing time and UCS were related to establish relationship of each sample's UCS variation with curing time.

Table 5. Regression Statistics correlation of UCS variance with Curing time of different sample

Sample ID	Correlation	R square
S1	1	1
S2	0.9950	0.9901
S3	0.9959	0.9919
S4	0.9914	0.9829
S5	0.9707	0.9423
S6	0.9599	0.9214
S7	0.9602	0.9220

Linear regression analysis was performed taking assumptions that error was normally distributed and variance of error is constant. The coefficient of correlation is calculated as per the formula given in Equation 1.

$$R = \left[\frac{n(\sum xy)-(\sum x)(\sum y)}{\sqrt{[n\sum x^2-(\sum x)^2][n\sum y^2-(\sum y)^2]}}\right] \quad (1)$$

Here Y represents the UCS value evaluated and X represents the curing time in days. The statistical correlation shown in Table 5 depicts that the Unconfined compressive strength was strongly adhering to linear relationship established with curing time for all sample mixes.

3.4 Permeability Test Result

Permeability is the major parameter to decide the performance of pond ash in a waste disposal site. Falling head permeability test was conducted following IS:2720 (Part 8)-1986 [31] for all the cured and uncured samples of different mixes.

Table 6. Coefficient of permeability of pond ash: lime: gypsum mixes permeated with water

Sample ID	Water-Curing Period(days) Hydraulic Conductivity ($K*10^{-4}$ cm/sec)					
	0	7	30	60	90	180
S1	1.9131	1.8752	1.8236	1.8200	1.7866	1.7850
S2	1.8273	1.0962	0.5513	0.0749	0.0029	0.0023
S3	1.6255	1.0058	0.5185	0.0554	0.0023	0.0018
S4	0.9874	0.4935	0.1852	0.0128	0.0015	0.0012
S5	0.9416	0.4225	0.0622	0.0122	0.0014	0.0011
S6	0.9252	0.4107	0.0557	0.0080	0.0013	0.0011
S7	0.9150	0.4071	0.0283	0.0156	0.0011	0.0010

Table 7. Coefficient of permeability of pond ash: lime: gypsum mixes permeated with acetic acid

Sample ID	Hydraulic Conductivity ($K*10^{-4}$ cm/sec) Curing Period(days)					
	0	7	30	60	90	180
S1	1.8592	1.8122	1.7136	1.7114	1.7014	1.7014
S2	1.7776	1.0666	0.4960	0.1984	0.1488	0.1135
S3	1.6006	0.9907	0.3840	0.0828	0.0680	0.0074
S4	0.9642	0.4821	0.1000	0.0344	0.0194	0.0016
S5	0.9315	0.4182	0.0850	0.0212	0.0145	0.0011
S6	0.8944	0.3971	0.0810	0.1134	0.0127	0.0008
S7	0.8042	0.3579	0.0910	0.0653	0.0122	0.0007

As for water permeant, tank was filled with water, same way for acetic acid solution and methanol solution, the tank was filed with acetic acid and methanol solution respectively. A set of samples were cured in permeability mold using a simple type of curing apparatus consisting of tin container where one permeability mold can easily be accommodated well packed with perforated board and air tight lid to maintain humidity inside the tin. After 7, 30, 60, 90, and 180 days of curing time, the permeability of cured sample inside the mold were tested for permeability in falling head permeability apparatus by permeating the cured sample with tap water, acetic acid and methanol solution. Permeability test was conducted on Falling head permeability apparatus after compacting the samples at their corresponding optimum moisture content and maximum dry density.

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As Pond ash did not show self-cementation properties, with curing period no change in hydraulic conductivity value of Pond Ash was noticed. The initial hydraulic conductivity value of compacted pond ash was of the order of 10^{-4} cm/s. After 180 days of curing period, hydraulic conductivity value of pond ash was not observed to be decreased considerably. Permeability test conducted on 10% and 14% lime stabilised samples immediately after preparation and no curing condition showed permeability value of 1.827×10^{-4} cm/sec and 1.625×10^{-4} cm/sec respectively. However rapid decrease in permeability of one order of magnitude was seen for14% lime and 1% gypsum stabilised pond ash. After gradual increase in lime and gypsum percentages after curing period of 180 days, hydraulic conductivity of lime and gypsum stabilized pond ash reduced to power of 10^{-7} cm/sec. All of the regulatory authority including Environmental Protection Agency (United States) and Central Pollution Control Board (India) emphasize the mandatory requirement of landfill bottom liner material possessing a minimum value of permeability of 10^{-7} cm/sec. The decreased permeability due to closer packing of particles indicate that it takes almost 180 days of curing period to reach equilibrium and ultimately satisfies the requirement of hydraulic conductivity parameter of Municipal Solid Waste landfill liner material.

Table 8. Coefficient of permeability of pond ash: lime: gypsum mixes permeated with Methanol solution

Sample ID	Hydraulic Conductivity ($K*10^{-4}$ cm/sec) Curing Period(days)					
	0	7	30	60	90	180
S1	1.9015	1.8213	1.7622	1.7011	1.7233	1.7255
S2	1.8160	1.0896	0.6000	0.3263	0.0854	0.0085
S3	1.6168	0.9862	0.5221	0.2921	0.08422	0.0074
S4	0.9791	0.6356	0.2154	0.0861	0.0025	0.0003
S5	0.9372	0.4820	0.1405	0.0757	0.0021	0.0002
S6	0.9111	0.4655	0.1093	0.0151	0.0016	0.0001
S7	0.9076	0.4361	0.0907	0.0870	0.0014	0.0001

Hence it is expected that with increase in curing period, the permeability of stabilized pond ash will reduce further giving rise to an adequate liner material for landfill. The variation of Permeability depicted in Tables 6, 7, and 8 illustrates that there is further scope of reduction in permeability value with curing time for liner material permeated in water, acetic acid and methanol solutions even.

IV. CONCLUSIONS

This work highlights the utilization of Pond Ash in the landfill as a liner construction material relevant to environmental concerns.

- A continuous increasing trend is observed in Unconfined compressive strength values of pond ash mixes starting from uncured sample to cured samples at 180 days of UCS test for all stabilized mixes. 898% rise in the value of UCS was observed at 14% lime mixes and this trend further continued for increased curing period.
- In case of S7 sample, addition of gypsum is proofed to be more effective at higher lime contents.
- From the linear regression analysis observation established between UCS and curing time, it was found that for all the sample mixes, quite remarkable R^2 value was observed that is nearly equal to unity.
- Permeability test conducted on 10% and 14% lime stabilised samples with no curing condition showed permeability value of 1.827×10^{-4}cm/sec and 1.625×10^{-4} cm/sec respectively. However rapid decrease in permeability of one order of magnitude was seen for14% lime and 1% gypsum stabilised pond ash. After gradual increase in lime and gypsum percentages after curing period of 180 days, hydraulic conductivity of lime and gypsum stabilized pond ash reduced to power of 10^{-7}cm/sec. Permeability of uncured specimen even though stabilized with 14 % lime and 1% gypsum was not able to execute permeability of 10^{-9} cm/sec. After 180 days of curing period of S7 mix was able to execute permeability of the order of 10^{-9} cm/sec. It was observed that permeation with acid solution lowered the permeabilities as compared to methanol solution. It is strongly attributed to increasing rate of curing period upon acid reaction with pond mixes.

Conflict of Interest: The authors declare that there is no conflict of interest.

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