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Effect of Fly Ash and Nano Calcium Silicates in Clayey Soil used as Clay Liner

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Abstract - *Landfill liners are provided to prevent the movement of leachate to underground water. Therefore, the materials, which are used, should have low hydraulic conductivity. This study is an attempt to use the locally available soil, nano calcium silicate, and fly ash mixture as a potential liner. In this paper, the variation in properties such as hydraulic conductivity, dry density, OMC, Atterberg's limits etc. are studied by mixing nano calcium silicate with fly ash and red soil in various percentages. Fly ash is added in different percentages from 2 to 10%. From the compaction result, it is found that 6% fly ash is the optimum dosage. To this soil mixture, tests are done with nano calcium silicate varying from 0.2 to 1%. Nano calcium silicate particles promote pozzolanic reaction by transforming the calcium and silica of the mixtures into calcium silicate hydrate gels, which enhances the strength characteristics of the soil.*

Key Words: **Landfill liner, Fly ash, Nano calcium silicate**

1. INTRODUCTION

Rapid technological advances and population lead to the generation of increasingly hazardous wastes. Thus, the long-term option available to manage the waste generated is to dispose it on the earth's surface. When waste is stored on land, it becomes a part of the hydrological cycle. During the infiltration of water through waste, numerous contaminants are removed from the waste to the adjacent areas as well as to the strata below. This action of water along with the action of wind can have significant impact on the adjacent environment. To minimize the impact of waste on the environment, final disposal is done in "Engineered Landfills". Landfill offers an environmentally sustainable methodology for disposing waste on land. Landfills are thus designed considering various parameters to meet their requirements. Landfill liners are exposed to various types of physical, chemical and biological processes which are affected by leachate produced from the decomposition of waste dumps. The aim is to avoid any hydraulic connection between the wastes and the surrounding environment, particularly groundwater. To ensure this, the important characteristics for compacted landfill liners are selection of materials, hydraulic conductivity, strength, compressibility and contaminant retention capacity. Conventional landfills were made of clay. Even though various new model liners like geosynthetics are available, they are not preferred in certain places due to economic constraints. Compacted clay liners are of low cost, large leachate attenuation capacity and resistance to damage. Natural clay is often fractured and cracked and due to non-availability of suitable soil at a site, it is necessary to mix imported clay materials with local non-productive soils and industrial process wastes to achieve a suitable material. Red soil is rich in clay minerals and it is used as compacted liner materials for their low hydraulic conductivity, which is required to be less than 1.00×10^{-7} cm/sec.

Liner requirements and specifications

1. Hydraulic conductivity of 10^{-7} cm/sec or less
2. Thickness of 100 cm or more
3. Absence of shrinkage cracks due to desiccation
4. Absence of clods in the compacted clay layer
5. Adequate strength for stability of liner under compressive loads as well as alongside and slopes
6. Minimal influence of leachate on hydraulic conductivity

In India, major energy consumption is achieved by the thermal power plants. The environmental impact of these power plants include issues such as land use, waste management, water and air pollution caused by the coal mining, processing and the use of its products. Major byproduct released from the thermal power plants are the fly ash and the bottom ash. In this paper, fly ash is effectively used as a landfill liner material. Use of Nano materials is an emerging trend, the cause being the increase in the surface area compared to the volume, which ensures greater interaction between the parent soil and other stabilizer used along the Nano material. Hence use of Nano materials in stabilization of soil helps in filling the voids of the soil mass ensuring improvement in the strength of the soil, Nano particles blend with the cementitious material in the mix and reinforce its performance by filling the voids between the particles. Since the size of Nano material is very small, which is less than a micrometer; the filling of voids takes place efficiently. The use of the cementitious materials in the process of soil stabilization like lime and fly ash are well known, the use of nano calcium silicate (NCS) is for increasing the performance of the cementitious stabilizers. Although NCS alone increase the strength of the soil as a stabilizer, the impact of NCS on fly ash as a stabilizer is studied in this work.

2. MATERIALS AND PROPERTIES

A. Soil sample

The soil sample is collected from Neyyattinkara, Trivandrum. The soil was taken from 0.5m depth below the ground surface. Laboratory tests were carried out for salient geotechnical characteristics such as gradation, Atterberg's limits, compaction and strength tests etc., and are shown in Table 1

Table 1: Properties of soil

PROPERTIES	VALUES
Liquid limit (%)	36.95
Plastic limit (%)	24.44
Plasticity index (%)	12.51
OMC (%)	17.70
MDD (g/cc)	1.70
Specific gravity	2.62
Classification of soil	CI
Percentage of silt (%)	24.00
Percentage of sand (%)	19.00
Percentage of clay (%)	57.00
Unconfined compressive strength(kg/cm^2)	0.22

B. Fly ash

Fly ash was collected from Thoothukudi Thermal Power Plant. Physical properties of fly ash are shown in the Table 2.

Table 2: Properties of fly ash

PROPERTIES	VALUES
Specific gravity	2.18
Liquid limit (%)	28.00
% sand	46.00
% silt	29.15
% clay	16.25
Uniformity coefficient(Cu)	6.13
Coefficient of curvature(Cc)	1.38
Free swell index	0.75
OMC (%)	31.30
MDD(g/cc)	1.16
Permeability(cm/s)	2.79×10^{-5}
UCC (kPa)	92.23
Class of fly ash	F

C. *Nano calcium silicate (NCS)*

Nano calcium silicate is a proprietary material, bright white crystalline powder synthesized by reaction of silica with ions of calcium. The major constituent, which forms the NCS, are the platelets like particles with thickness around 5-10 nm and dimensions across being 300 nm. The platelets join together into particles of size 1-5 μm with a "gypsum desert rose" like structure (Mohammed and Moghal 2016; Mohammed et al. 2017).

Fig.1: Nano Calcium Silicate

Table 3: Properties of NCS

PROPERTIES	VALUES
PH value	7 - 9
Ignition loss	2%
SiO_2 content	< 53%
Fe content	< 0.2%
Ca content	< 45%
Moisture	< 0.3%
Colour	White

3. METHODOLOGY

The soil samples were collected and the laboratory tests were conducted to study the geotechnical properties of collected samples. Compaction and UCC Test were conducted to find the optimum amount of fly ash in soil sample. 0.2%, 0.4%, 0.6%, 0.8% and 1% Nano calcium silicate is added with the optimum fly ash content to the soil. Series of laboratory tests such as permeability tests, Atterberg's limits tests, and unconfined compression strength tests of various mixtures were conducted. From the test results a final mix can be selected as a appropriate landfill liner.

4. RESULTS AND DISCUSSIONS

4.1 Red soil + Fly Ash

A Compaction characteristics

IS light compaction test was conducted on various percentages of fly ash (2%, 4%, 6%, 8% and 10%) with red soil in accordance with the procedure laid in IS: 2720 PART 7 to study the moisture content and dry density relationship. From the test result it is observed that increase in large amount of fly ash percentage in soil mix, OMC got increased and MDD got decreased. This may be due to the facts that, soil being a coarse material have many voids in between. These voids are filled by fly ash particles which are fine and have low specific gravity. Thus, reducing MDD. Fly ash being a finer material has more specific surface area when compared to soil, so it requires more water content for compacting the soil mix having high fly ash content. From the standard proctor test, the results obtained shows that 6% fly ash gives maximum dry density. So 6% is taken as the optimum amount of fly ash content. Maximum dry density is obtained as 2.16 g/cc and corresponding optimum moisture content is 7.24%.

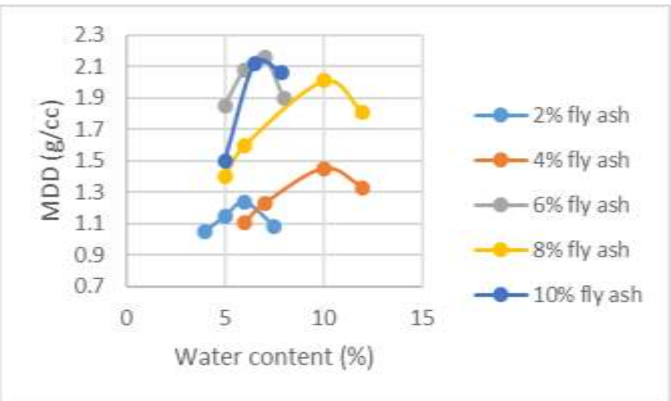

Fig. 2: Compaction curve

B Atterberg's limit test

Atterberg's limit test was performed as per IS 2720 (Part 5) 1985. Soil sample passing through 4.25 mm IS sieve was used to determine liquid limit, plastic limit, and plasticity index characteristics. Variation of Atterberg's limit with the addition of Nano calcium silicate with 6% fly ash and soil was also studied

Table 4: Properties of 6% fly ash + red soil

PROPERTY	VALUE
Liquid limit (%)	36.74
Plastic limit (%)	24.90
Plasticity index (%)	11.83
Shrinkage limit (%)	10.23
OMC (%)	7.24
MDD (g/cc)	2.16

C Effect of Nano calcium silicate on liquid limit

Red soil was treated with 6% fly ash with varying percentages of NCS such as 0.2%, 0.4%, 0.6%, 0.8% and 1%

Table 5: Liquid limit of soil mixtures

% Nano calcium silicate added	Liquid Limit (%)
0	36.74
0.2	26.80
0.4	27.20
0.6	29.00
0.8	29.50
1	30.40

The result shows that liquid limit decreases than the original soil. But while increasing the dosage of NCS, liquid limit increases. With the increase of specific surface of NCS, the water required to cover the particles increases and hence increasing plastic and liquid limits.

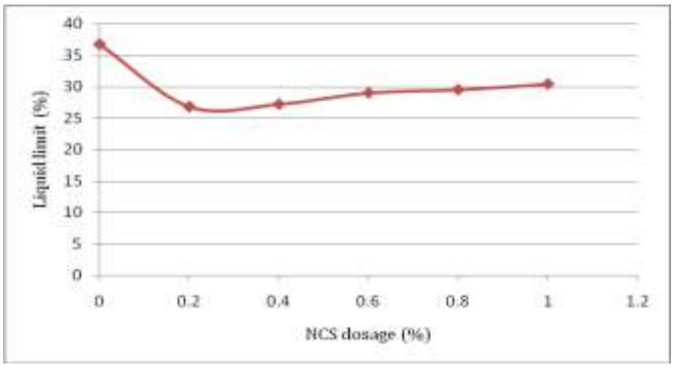

Fig. 3: Variation of liquid limit with the addition of NCS

D Effect of Nano calcium silicate on plastic limit

When NCS was added into soil, the plastic limit decreased than the original soil. While increasing the NCS dosage plastic limit increases from 17.35 to 23.51%. This is due to the increased surface area of NCS. The variation of plastic limit is shown in the Table 6 below.

Table 6: Plastic limit of soil mixture

% Nano calcium silicate added	Plastic Limit (%)
0	24.90
0.2	17.35
0.4	18.94
0.6	20.88
0.8	21.58
1	23.51

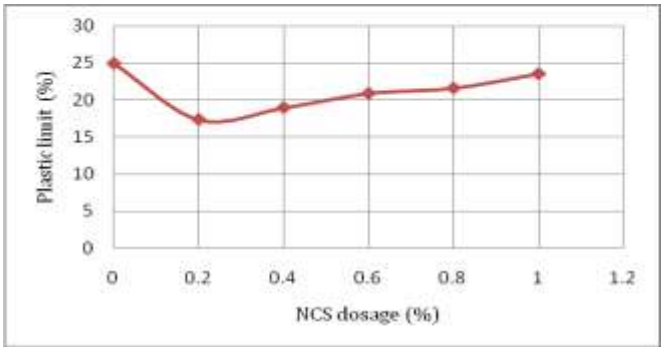

Fig. 4: Variation of plastic limit with the addition of NCS

E Effect of Nano calcium silicate on plasticity index

Study of the plasticity characteristics of soil throw light on the strength behavior of soil. Plasticity index is expressed as the difference between the LL and PL. PI gives the indication that to what extent the soil remains plastic. Increase in plastic limit and liquid limit which results in the reduction in PI and also assures the improvement in terms of strength.

Table 7: Plasticity index of soil mixture

% Nano calcium silicate added	Plasticity Index (%)
0	11.83
0.2	9.45
0.4	8.26
0.6	8.12
0.8	7.92
1	6.89

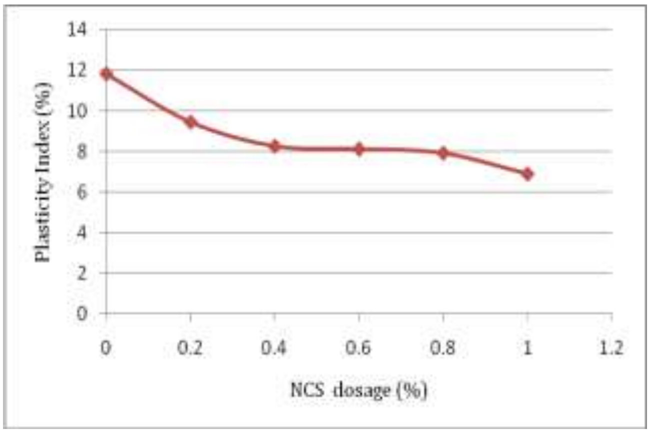

Fig.5: Variation of NCS in plasticity index

F Effect of NCS on optimum moisture content (OMC) of soil mixtures.

Standard proctor test result shows that, a slight increase in percentage of water was required to reach the OMC with increase in dosage of NCS. Fig.6 shows the variation of OMC with change in NCS dosage. It can be observed that with increase in NCS content, the OMC decreased.

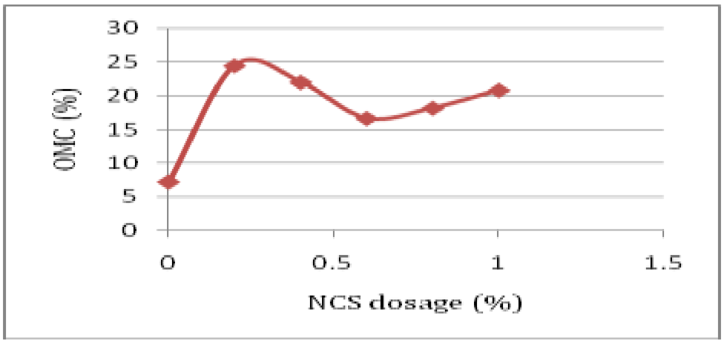

Fig.6: Variation of OMC in soil mixture

G Effect of NCS on Maximum Dry Density (MDD) of soil mixtures

The effect of addition of NCS dosage with soil mixture is shown in the Table 8. From the results, it is clear that the MDD is decreased than the original soil. However, with increase in dosage of NCS the MDD is increasing.

Table 8: Variation of MDD in soil mixture

% Nano calcium silicate added	MDD (g/cc)
0	2.16
0.2	1.87
0.4	1.88
0.6	1.90
0.8	1.91
1	1.93

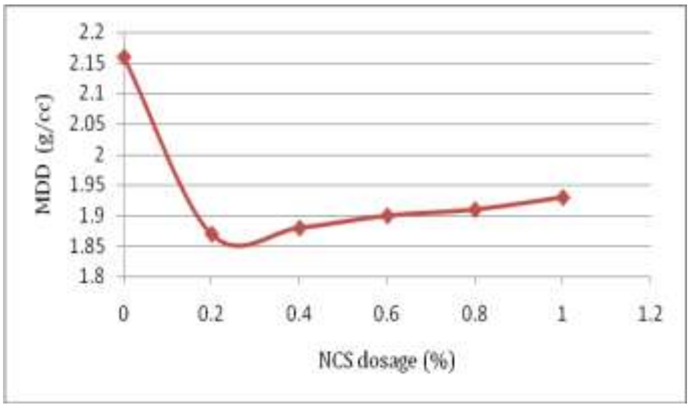

Fig.7: Variation of MDD with NCS

H Effect of UCS on soil mixtures

Effect of NCS on the soil with different dosages along with fly ash shows that the compressive strength increases with increase in the dosage of the NCS, however the dosage of a Nano material is preferred to be kept within 1%, since it absorbs more water. Fig.8. represents the UCS results for samples cured for three days. It can be observed that the increase in dosage of NCS increases the UCS value, which is an indication that the NCS causes a change in the behaviour of the soil mass by producing greater bonding between the soil particles. NCS also reduces the spacing between the soil particles; even the generation of viscous gel is proposed to be formed due to Nano material (Changizi and Haddad 2016).

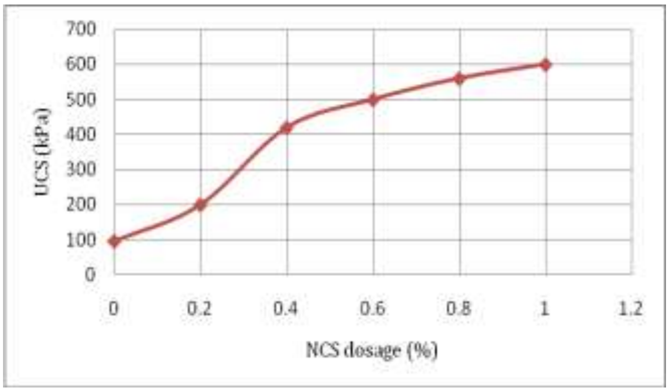

Fig.8: Variation of UCS with NCS

I Effect of NCS on permeability of soil mixtures

This is the most important requirement of a liner. For an effective liner the hydraulic conductivity should be minimum. Coefficient of permeability decreases with increase in dosage of fly ash. Least value for coefficient of permeability is for 1% dosage of NCS - 4.8×10^{-6} cm/sec. This is due to the high specific area of fly ash which tends to absorb more water which fills the pores in soil structure and lowers the soil porosity and hydraulic conductivity

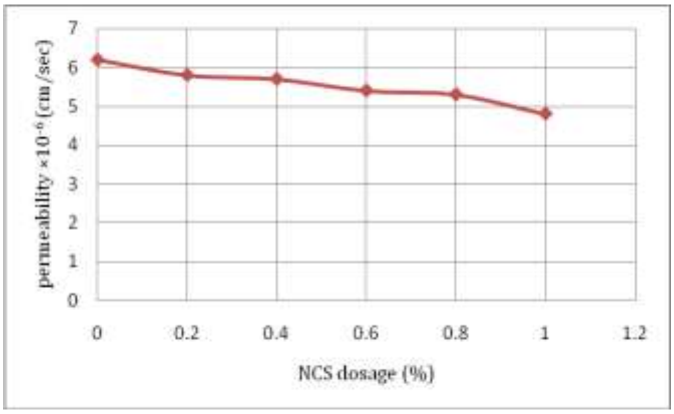

Fig.9: Variation of permeability with NCS

5. Liner Criteria

Table 9: Liner criteria

Property	Value
Plasticity Index (PI)	10 - 30%
Liquid Limit	25 – 30%
Permeability	≤ 1 x 10^{-7}cm/sec
UCS (kN/m^2)	200

6. CONCLUSIONS

- The present study deals the geotechnical properties of the soil amended with fly ash in different dosages of the NCS
- Based on the liner specification all mixes are suitable for liner
- As the percentage of NCS increases from 0.2% to 1%, consistency properties such as liquid limit, plastic limit increasing, plasticity index is decreasing- showing improvement in soil strength
- Compressive strength increases with increase in dosage of the NCS, however the dosage of NCS is kept within 1%., since it absorbs more water.
- Presence of NCS allows for better blending with the soil particles in triggering pozzolanic reaction eventually producing CSH gel like structures that in turn makes the soil mass denser and more resistant to the loads acting on it.
- Hydraulic conductivity of the soil when mixed with 6% fly ash and varying percentage of NCS was decreasing from 6.2×10^{-6} to 4.8×10^{-6} cm/sec

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