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Experimental Study on Utilization of Bottom Ash to Stabilize Expansive Soil Subgrades

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Abstract: Expansive soils exhibit undesirable problems in foundations, pavements, etc. due to drastic volume and strength changes with change in moisture content. This cause's significant structural damage to foundations, including pavements. One way for overcoming these problems in soils is to stabilize with admixtures. Owing to this fact, continuous researches have been carried and still being carried out by individual, firms and institutions on ways to improve the engineering properties of soils. The need to bring down the cost of soil stabilizers and the environmental damage has led to intense global research towards economic utilization of wastes for engineering purposes. Bottom ash is obtained by combustion of coal and consists of combustibles in coal burning furnace during its operation. This study is carried out to determine the effect of bottom ash utilization for road application on clay. The laboratory investigations are done to examine the index and engineering properties of soil sample. The soil falls under CI category of Indian standard soil classification system. The experiments are done to study the changes in properties of soil such as plasticity characteristics, free swell index, pH, calcium carbonate content, total dissolved solids and cation exchange capacity using bottom ash in varying percentages of 10%, 20%, 30%, 40% and 50%. This study shows promising results with effective utilization of bottom ash in the improvement of soil strength.
Keywords: Expansive soil, bottom ash, CBR, Chemical properties.

1. Introduction

Expansive soils are a worldwide problem that poses several challenges for civil engineers. They are considered a prospective natural hazard, which can cause excessive damage to structures if not effectively treated. Such soils swell when given an access to water and shrink when they dry out. Infrastructure projects such as highways, railways, water reservoirs, reclamation, etc. requires earth material in very big quantity. In urban areas, borrow earth is not easily available which has to be hauled from a long distance. Quite often, large areas are covered with highly plastic and clayey soil, which is not suitable for such purpose. Extensive laboratory / field trials have been carried out by various researchers and have shown promising results for application of such expansive soil after stabilization with additives such as sand, silt, lime, fly ash, etc. As bottom ash is available at very lower cost, for projects in the vicinity of a Thermal Power Plants, it can be used for stabilization of expansive soils for various uses (1, 2 and 6).

Coal-based thermal power plants all over the world face serious problems of handling and disposal of the ash produced. The high ash content of the coal in India makes this problem difficult. At present, about 80 thermal power stations produce nearly 100 million tons of coal ash per annum. Safe disposal of the ash without harmfully affecting the environment and the large storage area required are major concerns. Hence attempts are being made to utilize the ash rather than dump it. The coal ash can be utilized in bulk in geotechnical engineering applications such as construction of embankments, as a backfill material, as a sub-base material, etc (3).

In this study, characteristics of soil stabilized with bottom ash are studied. Geotechnical properties of clay such as Atterberg's limits, compaction characteristics, and unconfined compressive strength are determined. The clay is classified as clay of intermediate compressibility (CI) as per BIS. Bottom ash is added to clay in varying proportions of 10%, 20%, 30%, 40% and 50% and chemical properties such as total soluble solids, calcium carbonate content, pH value, cation exchange capacity and soluble sulphates are studied. The results are discussed.

2. Methodology and Materials

2.1 Methodology

Methodology mainly consists of three parts. Part 1 includes identification of problems in construction of roads in black cotton soil, review of literatures and collection of soil and bottom ash. Part 2 and part 3 are laboratory works which are mainly focused on determination of index, engineering, chemical properties of soil and chemical properties of soil and bottom ash mixture. Methodology is graphically represented by figure1.

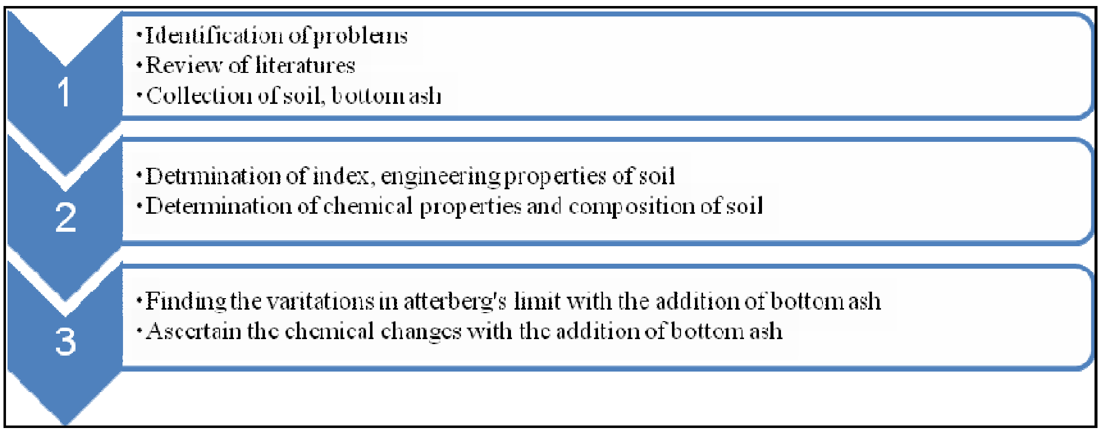

Figure1. Methodology

2.2 Collection of Materials

2.2.1 Collection of Soil

Soil for this research work is collected from Cheranmaanagar, Coimbatore, tamilnadu state, India. The locations are 11.0542^0, 77.0183^0. The soil sample was present at depth of 4 feet from ground level.

2.2.2 Collection of Bottom Ash

Bottom ash is obtained from Mettur Thermal Power Plant, Mettur, tamilnadu state, India.

3. Laboratory Investigation on Chemical Properties

Chemical analyses are very much important to ascertain the mechanism behind the stabilization and also to know the influence of various parameters such as Total Soluble Solids, pH, Cation Exchange Capacity, Calcium Carbonate content and Soluble Sulphates. These analyses are carried out for soil with 0%, 10%, 20%, 30%, 40% and 50% addition of bottom ash.

3.1 Total Soluble Solids

Total soluble solids indicate the amount of presence of soluble salts and other soluble materials present in soil. This test is done in accordance with IS 2720 part 21(gravimetric analysis) and the results are tabulated in table1.

Table.1 Total Soluble Solids

S.No.	% of Bottom Ash Added	Soluble Solids (PPM)
1	0	104
2	10	113
3	20	128
4	30	136
5	40	144
6	50	149

3.2 Calcium Carbonate ($CaCO_3$) Content

The $CaCO_3$ content can be found from volumetric analysis of soil bottom ash mixture blended with 0.1 N HCl against 1N NaOH as per IS 2720 part 23 (1976).Table.2 shows the amount of calcium carbonate present.

Table.2 Amount of Calcium Carbonate Present

S.No.	% of Bottom Ash Added	Calcium Carbonate (% By Weight)
1	0	21
2	10	21.8
3	20	22.4
4	30	22.9
5	40	23.7
6	50	24.4

3.3 Determination of pH:

The pH of the samples were determined using the method of Eades and Grim specified by IS 2720 part 26, which involves mixing the solids with pure water (1:5 solid:water), periodically shaking samples, and then testing with a pH meter after 1 hour.

Table.3 pH of Soil With Bottom Ash

S.No.	% of Bottom Ash Added	pH
1	0	8.94
2	10	8.77
3	20	8.57
4	30	8.48
5	40	8.43
6	50	8.38

3.4 Cation Exchange Capacity (CEC)

CEC represents the exchangeable cations present in soil. Tests are conducted based on IS 2720 part 24: 1974.

Table.4 Cation Exchange Capacity Of Soil

S.No.	% of Bottom Ash Added	CEC (meq/100g)
1	0	92.575
2	10	83.021
3	20	79.647
4	30	77.759
5	40	76.373
6	50	75.724

3.5 Soluble Sulphate Determination

These methods are specified by IS 2720 part 27 to determine total soluble sulphates namely precipitation method, volumetric method and calorimetric method. The last two methods are subsidiary methods; precipitation method is used in this analysis.

It is observed that sulphate present in the soil is 0.012% by mass. This shows that only a trace of sulphate is present and there is no sulphate present in bottom ash. Hence this test is not conducted for soil – bottom ash mixture as the influence of sulphate on the stabilization process of this particular soil is nil.

4. Laboratory Investigation on Index and Engineering Properties

This elaborates the various index and engineering properties of soil namely liquid limit, plastic limit, maximum dry density, unconfined compressive strength, CBR test.

4.1 Properties of Clay

Initial Moisture Content	- 8.76%
Specific Gravity	- 2.71
Grain Size Distribution	
% of Gravel	- 2.1%
% of Sand	- 30.5%
% of Silt	- 22.1%
% of Clay	- 45.3%
Liquid Limit	- 47%
Plastic Limit	- 17%

4.2 Atterberg Limits

Liquid limit and plastic limit tests were conducted as per IS: 2720 (Part 5) – 1985and the soil is classified based on plasticity chart as per Bureau of Indian Standards. The analysis is carried out for soil with 0%, 10%, 20%, 30%, 40% and 50% addition of bottom ash. The variation of liquid limit and plastic limit, are shown in figure 2 and figure3.

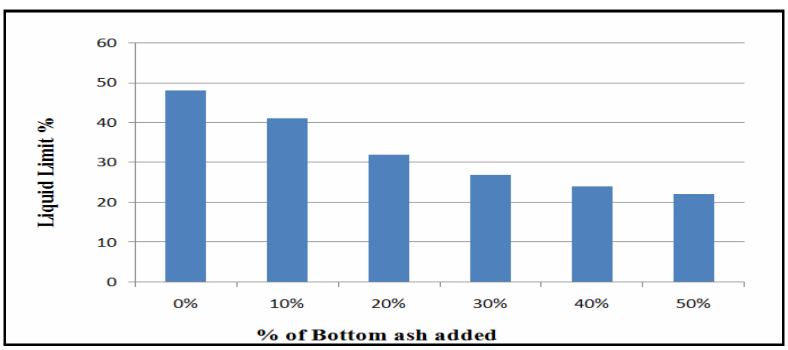

Fig.2 Variation of Liquid Limit

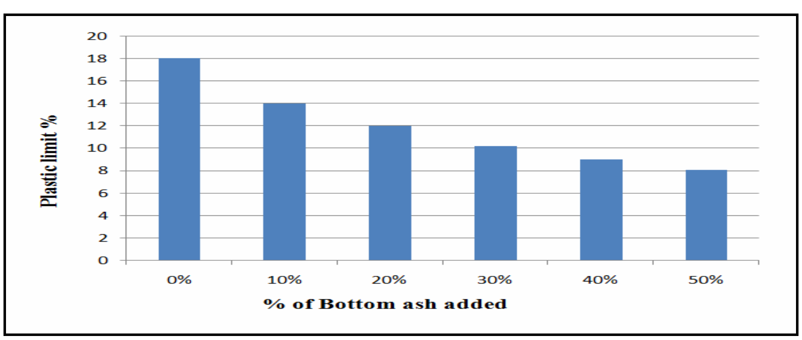

Figure.3 Variation of Plastic Limit

4.3 Standard Proctor's Compaction Test

The Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) is determined by conducting Standard Proctor's Test as per IS: 2720 (Part7) – 1980. The analysis is carried out for soil with 0%, 10%, 20%, 30%, 40% and 50% addition of bottom ash. Variation of Optimum Moisture Content and variation of Maximum Dry Density are represented below.

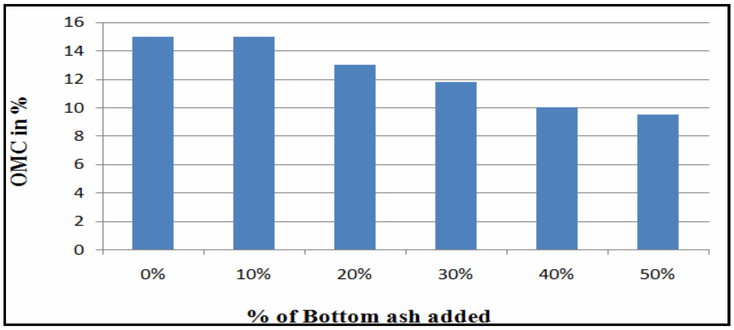

Figure.4 Variation of OMC

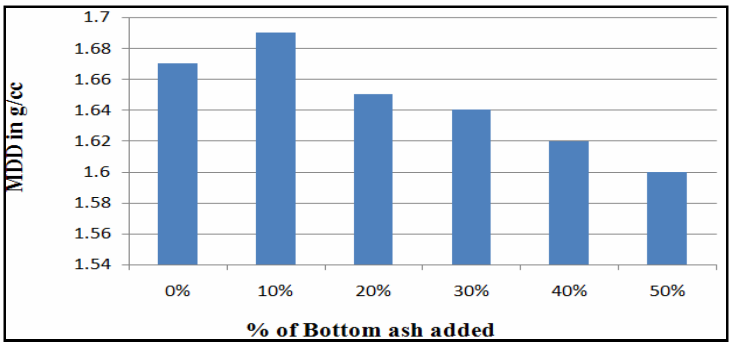

Figure.5 Variation of MDD

4.4 Determination of CBR

For any pavement design, CBR is the prime factor which determines the thickness of each pavement layer. CBR (unsoaked & soaked) test is done as per IS 2720 part 16. The analysis is carried out for soil with 0%, 10%, 20%, 30%, 40% and 50% addition of bottom ash.

Table.5 Variations in Soaked CBR

S.No.	% of Bottom Ash Added	Soaked CBR %
1	0	2.95
2	10	3.57
3	20	4.52
4	30	3.84
5	40	3.12
6	50	2.93

Table.6 Variations in Unsoaked CBR

S.No.	% Of Bottom Ash Added	Soaked CBR %
1	0	6.74
2	10	7.43
3	20	8.57
4	30	7.75
5	40	7.28
6	50	6.62

4.5 Unconfined Compressive Strength Test:

Unconfined compressive strength and cohesive strength is obtained by conducting Unconfined Compressive Strength test. This test is conducted as per IS: 2720 (Part 10) – 1991. The analysis is carried out for soil with 0%, 10%, 20%, 30%, 40% and 50% addition of bottom ash.

Table .7 Variations in Unconfined Compressive Strength

S.No.	% of Bottom Ash Added	Unconfined Compressive Strength (KN/m^2)	Cohesive Strength (KN/m^2)
1	0	85.4	42.7
2	10	118.71	59.35
3	20	160.88	80.44
4	30	216.08	108.04
5	40	286.54	143.27
6	50	260.16	130.08

5. Discussion on Results

5.1 Variation in Total Soluble Solids with Addition of Bottom Ash

Total soluble solids increase with addition of bottom ash. The increased soluble solid content with addition of bottom ash indicates that amount of bottom ash available for cementing actions. This gives a positive result.

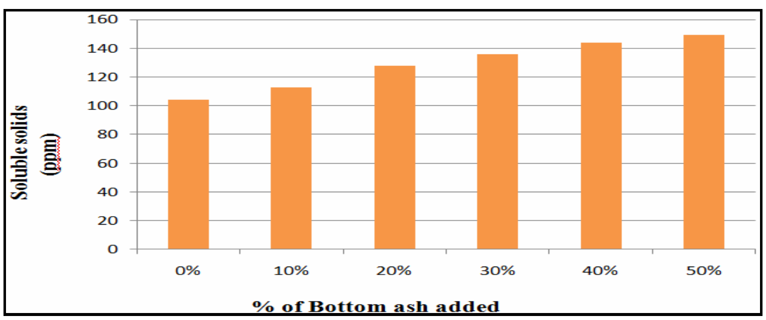

Figure.6 Total Soluble Solids

5.2 Variations In Calcium Carbonate Content

Calcium carbonate acts as a binding material and it increases with increase in bottom ash content in soil. This content may vary with respect to time since cementitious process is a long time chemical reaction. Variation of $CaCO_3$ with addition of bottom ash is shown below.

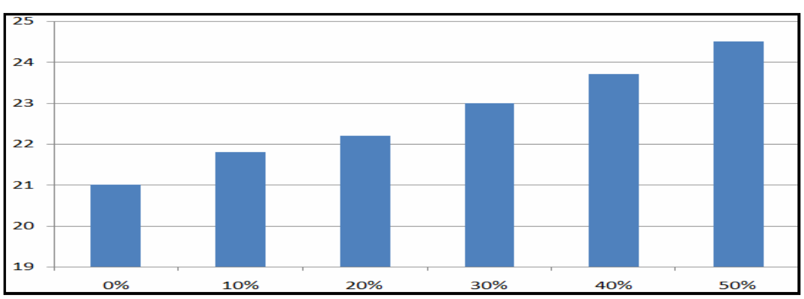

Figure.7 Calcium Carbonate In %

5.3 Effect of Bottom Ash on pH of Soil

The pH of soil is an indirect measure of Cation Exchange Capacity of soil. pH is directly proportional to CEC in alkaline state. CEC and pH are indirectly proportional to strength of soil.

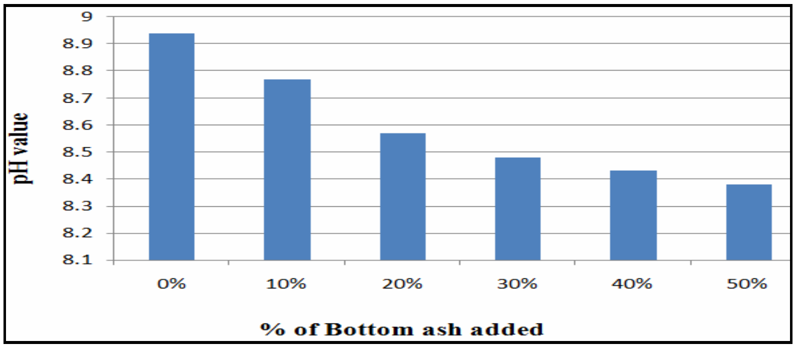

Figure.8variations of PH Values

5.4 Effect of Bottom Ash on Cation Exchange Capacity of Soil

Cation Exchange Capacity indicates amount of exchangeable ions adsorbed on clay surface, CEC fixes the double layer thickness of clay. A decrease in CEC is observed with the addition of bottom ash to soil.

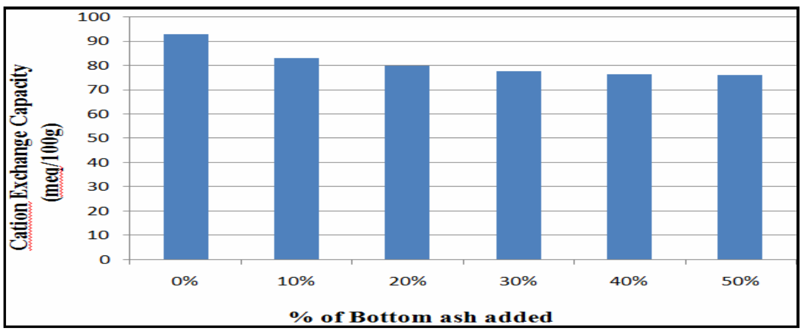

Figure.9 Cation Exchange Capacities

5.5 Variation of Atterberg's Limit with Addition of Bottom ASH

Variation of Atterberg's limits with addition of bottom ash can be observed from the table 5.1 Liquid limit, plastic limit, plasticity index are decreasing with the addition of bottom ash. Atterberg limits play an important role in soil identification and classification. It is known that the addition of bottom ash can reduce the thickness of the diffuse double layer clay particles, cause flocculation of clay particles and increase the coarser particles by substituting finer soil particles with coarser bottom ash particles. The immediate and long term effects combine together to bring out the beneficial changes in the plasticity characteristics. This reasons all together cause decrease in Liquid Limit (w_L), Plasticity Index and Plastic Limit (w_p).

Table.8 variation of Atterberg's Limit

% Of Bottom Ash Added	Liquid Limit %	Plastic Limit %	Plasticity Index %
0	48	18	30
10	41	14	27
20	32	12	20
30	27	10.2	16.8
40	24	9	15
50	22	8.1	13.9

5.6 Variations in OMC and MDD

Variation of optimum moisture content and maximum dry density with the addition of bottom ash can be observed. The cation exchange between additives and expansive soil decreases the thickness of electric double layer and promotes the flocculation. The flocculation of the solid particles implies that the water additives soil mixtures can be compacted with lower water content and the optimum water content is reduced. The decrease in the optimum water content indicates that expansive soil can be stabilized by adding bottom ash even for soils with low water content. The decrease of maximum dry unit weight with increase of percentage of bottom ash is mainly due to the lower specific gravity of bottom ash and compared with expansive soil, and the immediate formation of cemented products which reduce the density of the treated soil.

5.7 Variations in CBR

Variation of CBR with the addition of bottom ash is presented. Increasing the bottom ash content from 0 to 50% for the samples, the CBR values increase until 20% of bottom ash mix and then decreases with further addition of bottom ash. The optimum bottom ash content for improving the CBR of the treated soils under the presented conditions is 20%. This indicates that the quantity of bottom ash until optimum content can induce pozzolanic reaction and cemented materials effectively contributing to shear strength increase, while the additional quantity of bottom ash acts as unbounded silt particles, which has neither appreciable friction nor cohesion, thus causing decrease in strength.

Table.9 Variations in Soaked CBR

S.No.	% of Bottom ASH Added	Soaked CBR %
1	0	2.95
2	10	3.57
3	20	4.52
4	30	3.84
5	40	3.12
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Table.10 Variations in Unsoaked CBR

S.No.	% of Bottom ASH Added	Soaked CBR %
1	0	6.74
2	10	7.43
3	20	8.57
4	30	7.75
5	40	7.28
6	50	6.62

5.8 Variation in Unconfined Compressive Strength

VARIATION of UCS with the addition of bottom ash is presented. Increasing the bottom ash content from 0 to 50% for the samples, the UCS values increase until 40% of bottom ash and reduction in strength takes place after 40%. Presence of bottom ash increases the compressive strength.

Table.11 Variations in UCS

S.No.	% of Bottom Ash Added	Unconfined Compressive Strength (KN/m^2)	Cohesive Strength (KN/m^2)
1	0	85.4	42.7
2	10	118.71	59.35
3	20	160.88	80.44
4	30	216.08	108.04
5	40	286.54	143.27
6	50	260.16	130.08

6. Conclusion

Based on the experimental investigations on stabilization of soil, the following conclusions are drawn.

1. Total soluble solids increase from 104 ppm to 149 ppm by adding bottom ash until 50%.
2. $CaCO_3$ content is increased by adding 50% bottom ash to soil.
3. pH value of virgin soil is 8.94 which shows soil is slightly alkaline and pH is reduced to 8.38 with the addition of 50% bottom ash.
4. Only a trace of sulphate is present in soil.
5. CEC is decreased to 75.96 meq/100g with the addition of 50% bottom ash.
6. Liquid limit of untreated soil was 47%. It has decreased to 32% at 20% addition of bottom ash. On further addition of bottom ash, liquid limit has finally reduced to 22%.
7. Plasticity Index of untreated soil was 30%. It has decreased to 13.9% at 50% addition of bottom ash.
8. OMC decreases with increase in Bottom ash and MDD increases for 10% and decreases from 20 to 50%.
9. CBR increases until 20% addition of bottom ash and then it starts to decrease for every 10% addition of bottom ash.
10. Unconfined Compressive Strength increases with increase in Bottom ash until 40% and then decreases for 50%.

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