Utilization of Red Mud as a Stabilizer to Enhance the Geotechnical Properties of Expansive Soil

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Abstract - *In order to construct any structure on expansive soil we need to stabilize the weak soil. The objective of this study is to strengthen the expansive soil which lacks the essential engineering properties and also to maximize the utilization of industrial waste; Red Mud. It is a residue generated from bauxite while producing alumina through Bayer process. The major concern regarding this material is that, it's simply disposed without any major application, despite having high strength. By utilizing wastes as stabilizer the usage of natural resources can be minimized. This study is about investigating the effect of red mud on the behavior of expansive soil by carrying out compaction tests, UCS and CBR tests for different percentages of soil-red mud admixture. Soil is stabilized with red mud varying from 10% to 40% with increment of 10%. The test results show a considerable increase in MDD, UCS and CBR values. The MDD and OMC are increasing and maximum at 20% of red mud by weight of dry soil while optimum UCS and CBR value is observed at 30%. This admixture improves geotechnical properties of soil and it also ensures that desired strength can be gained by replacing more soil which will be beneficial for pavement subgrades and as a foundation supporting layer under buildings.*

***Key Words*:** Compaction characteristics, Compressive strength, CBR, Stabilization, Expansive soil, Red Mud.

1. INTRODUCTION

Insufficiency of land due to growth in population is the major constructional draw back in the present circumstances. The lands which are available for construction these days contain weak and expansive soil, such as montomorilonite and bentonite clay, and that exhibits high shrinkage and swelling characteristics. When the soil absorbs water, swelling appears tremendously and after water dries out it starts shrinking and then cracks develop. In order to overcome these situations the stabilisation method need to be adopted, which will improve the geotechnical characteristics of weak and expansive soil for the safe construction.

Here Red Mud is taken as the stabilizing material. Red mud is a residue which generates in the digestion of Bauxite with sodium hydroxide under the Bayer process while producing alumina. It consists of caustic soda and other minerals. Iron oxide present in it gives red color to the material. The pH of red mud ranges from 10 to 13, hence it's highly basic. India generates approximately 9 million tons of red mud per year and its disposal is a major apprehension for bauxite industries. Due to its toxic nature it has adverse effect for the environment without any essential circumspection.

1.1 Stabilization

Soil stabilization is the procedure for improving the condition of soil by enhancing their physical properties; shear strength and CBR characteristics, thus increasing the load bearing capacity of a sub-grade for pavements and foundation by mixing with other materials.

The basic methods involve in soil stabilization are physical, chemical, and biochemical stabilization methods. Stabilizers are divided into three groups. These are:

- Conventional stabilizers (lime, cement, etc.)
- By-product stabilizers (red mud, fly ash, quarry dust, slag, etc.)
- Non-conventional stabilizers (sulfonated oils, potassium compounds, polymer, enzymes, ammonium chlorides, etc.)

2. LITERATURE REVIEW

Several researches are accomplished on usage and application of red mud. Kalkan [2006][1] investigated about the implementation of red mud as a stabilizer for the construction of clay liner. According to the study there is an increase in compressive strength and decrease in hydraulic conductivity and swelling percentage. Manoj Bhaskar et al. [2014][2] studied about the initial setting time and compaction characteristics to create bricks from red mud. Newson et al. [2006][3] analyzed about the physical, chemical and mechanical properties of red mud. Compressional and frictional characteristics are similar to clayey and sandy soil respectively. Desai and Herkal [2010][4] examined on red mud as a substitute, for a low cost building material.

3. MATERIALS AND PROPERTIES

3.1 Expansive soil

As a part of this investigation, the soil used is acquired from the site of Ananta Sayana, Sarang, Dhenkanal, Odisha state, India. According to plasticity, the soil is classified as CH

(Highly plastic Clay). The geotechnical properties are given in Table 1.

3.2 Red Mud

The Red Mud used for this investigation is collected from NALCO, Damanjodi, Koraput, Odisha state, India. The physical and chemical properties of red mud are given in Table 1 and 2 respectively.

(a) Wet Red Mud collected from Damanjodi, Koraput Odisha, India

(b) Oven Dried Red Mud

Fig -1: Red Mud used for various laboratory Purposes

Table -1: Geotechnical properties of soil & Red Mud

Sl No.	Name of Properties	Soil	Red Mud
1	Specific Gravity	2.62	3.1
2	Liquid Limit	56.608	32
3	Plastic Limit	25.580	24
4	Plasticity Index	31.028	08
5	Free Swell Index (%)	30	_
6	Grain size Distribution Fine Sand (%) Silt & Clay (%)	 24.182 75.818	 17 83
7	OMC (%)	17.252	_
8	MDD (gm/cm^3)	1.642	_
9	UCS (kPa)	49.192	_
10	CBR Value at 2.5 mm 5 mm	 4.763 4.176	 _ _

Table -2: Chemical properties of Red Mud

Sl No.	Name of Properties	Values
1	Fe_2O_3	51
2	Al_2O_3	18
3	SiO_2	9.8
4	Loss due to Ignition	9.05
5	Na_2O	5.3
6	TiO_2	4.6
7	CaO	1.8
8	P_2O_5	0.15

4. PREPARATION OF THE SAMPLE

Samples were prepared by following the specifications and instructions of Indian Standard code. The tests were conducted on expansive soil as well as soil-red mud admixture. Red mud was dried properly before use for preparing samples as it was in the semi-solid form. The samples prepared for UCS and CBR tests were cylindrical. The specimens were moulded in their respective moulds cautiously. In both the tests soil samples were compacted by using rammer. After that the rammer was removed and the samples were trimmed to make flat surface at both ends, so that it can be placed on the machine properly to have an appropriate result.

For this study red mud was added to the soil in a desirable manner. In this experimental investigation red mud was added to the expansive soil by 10%, 20%, 30% and 40% by weight of dry soil. Initially the optimum moisture content (OMC) was found from the standard proctor test by mixing red mud with soil and water added at an increasing percentage of 10%, 13%, 16%, 19%, 22%, 25%, and 28%. The consistency limits, unconfined compression tests and CBR tests were conducted on expansive soil as well as soil-red mud admixture.

4.1 Standard Proctor Compaction test

In the year 1933 R.R. Proctor showed that the dry density of a soil for a compactive effort depends on the amount of water the soil contains during soil compaction. This test is conducted to determine the relationship between the moisture content and dry density of soil, according to IS: 2720 (Part 7)-1980. Then compaction curve is obtained by plotting the value of water content and dry density on a graph. From the peak point of the compaction curve the maximum dry density and the optimum moisture content is determined.

Wet density = Mass of wet soil by Volume of mould

Moisture content (w) % = (Mass of Water by Mass of Dry soil) × 100

Dry density, ρ_d (kN/m^3) = Wet density by (1+ Moisture content)

4.2 Unconfined Compressive Strength (UCS) test

The unconfined compressive strength test conducted as per IS: 2720 (Part 10)-1991. The aim is to determine the UU (unconsolidated undrained) shear strength of cohesive soil. The compression device and dial gauge are there in the set up to evaluate the load and deformation. The load has taken for altered readings of strain dial gauge starting from ε = 0.01 and further increased by 0.05 at each step. The proving ring is used depending upon the soil strength. Soil specimen is prepared by using OMC and MDD and compacted in a mould; having 8.6 cm height and 3.8 cm diameter. The soil sample is removed and placed on the compressive test machine without any confinement.

Then the stress-strain values are recorded. In the present study 2.5 kN proving ring has taken for the test to determine the UCS for expansive soil.

Strain (ε) = Δ/L_o
Corrected Area (A) = $A_0/(1-\varepsilon)$
Compressive Stress (σ) = P/A
Shear strength = $q_u/2$
Here,
Δ = Total Deformation
L_0 = Initial length of the specimen
A_0 = Initial area of the specimen
P = Axial load at failure

4.3 California Bearing Ratio (CBR) test

The California bearing test (CBR) test is conducted as per IS: 2720 (Part 16)-1987. The aim is to evaluate the subgrade strength of roads and pavements. The penetration test machine is set up to determine the load and penetration from 0.5 mm to 12.5 mm at an interval of 0.5 mm. Then volume of the mould is calculated. By using OMC and MDD sample is prepared and the soil is compacted in the mould; having height and diameter 17.5 cm and 15 cm respectively. The sample is then placed on the penetration test machine with the mould and baseplate properly. A penetration piston is placed at the center of the sample without putting any extra load. After placing all the arrangements carefully, the load is applied. The proving ring reading and corresponding penetration is noted. By using proving ring reading and penetration the load and load intensity is calculated from which the CBR value is found. The CBR value is usually calculated for penetration of 2.5 mm and 5 mm.

In the present study 5 kN proving ring has taken for the test to determine the CBR for expansive soil.

Load intensity = Load/ Area of Plunger
Area of Plunger = $(\pi/4) \times D^2$
CBR at 2.5 mm = (Load intensity/70) ×100
CBR at 5 mm = (Load intensity/105) ×100

5. RESULT AND DISCUSSIONS

5.1 Effect of Red Mud on Compaction Characteristics of Expansive soil

Standard Proctor's compaction test were conducted according to IS: 2720 (Part 7)-1980 on varying percentages of red mud as mentioned above to determine the optimum moisture content (OMC) and maximum dry density (MDD) of the sample.

Table -3: Data sheet of OMC & MDD for soil samples

Samples	OMC %	MDD (gm/cm^3)
Soil	17.252	1.642
Soil + 10% RM	25.147	1.573
Soil + 20% RM	23.574	1.651
Soil + 30% RM	26.677	1.608
Soil + 40% RM	26.808	1.576

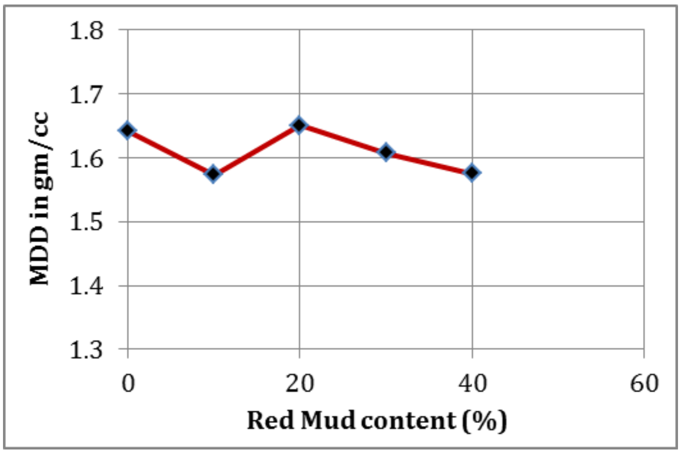

Chart -1: Comparison of MDD for Expansive soil & soil-red mud admixtures

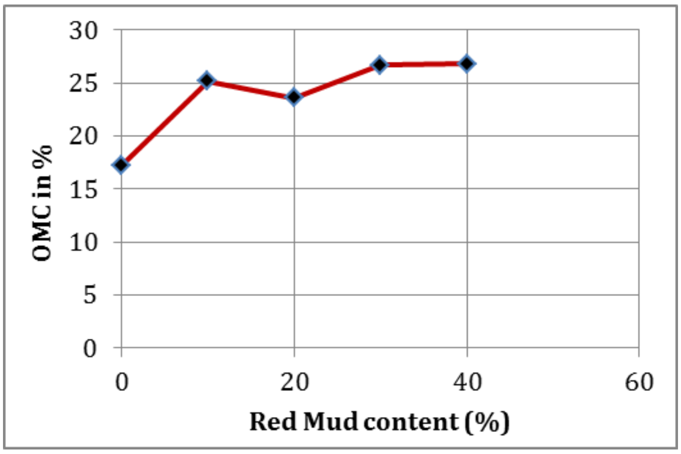

Chart -2: Comparison of OMC for Expansive soil & soil-red mud admixtures

From chart-1 it can be seen that there is an increase in maximum dry density (MDD) with the combination of expansive soil and red mud from virgin soil. Initially at 10% of red mud it was decreased from virgin soil but after increment at 20% of red mud in the soil mixture the MDD increased from 1.642 gm/ cm^3 to 1.651 gm/cm^3 and further it gradually decreased with increment of red mud percentage. The increase in density is may be due to the better binding of material for which floc is created to fill the voids; hence void space reduces which leads to increase in dry density. The OMC of soil-red mud mixture also increases with increase in admixture content can be seen from the chart-2. But at 20% where the MDD is optimum, the OMC reduced as compared to other admixtures thus shows MDD and OMC has inverse relation. The increase in fineness of red mud may be the reason for increment in the value of OMC.

5.2 Effect of Red Mud on Unconfined Compressive Strength (UCS) of Expansive soil

As per IS: 2720 (Part 10)-1991 the unconfined compressive strength (q_u) is the load per unit area at which the cylindrical specimen of cohesive soil fails in compression. This test is conducted on varying percentages of red mud without any curing period. The soil samples are prepared by using respective OMC and MDD.

Table -4: Data sheet of UCS values for soil samples

Samples	UCS in kPa
Soil	49.192
Soil+10% RM	42.081
Soil+20% RM	89.414
Soil+30% RM	102.317
Soil+40% RM	75.135

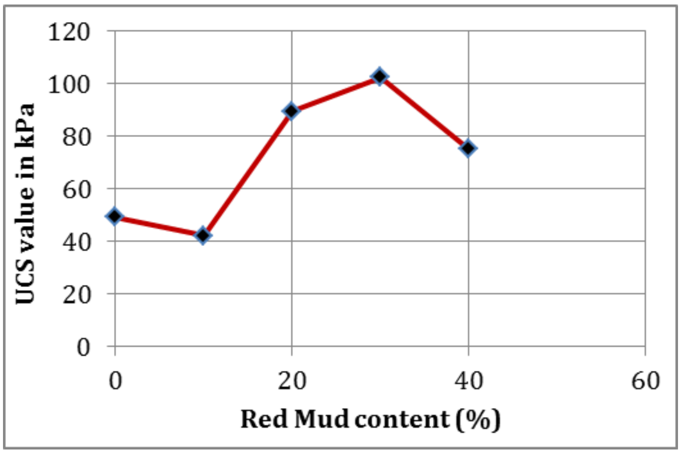

Chart -3: Comparison of UCS values for Expansive soil & soil-red mud admixtures

The test was conducted to study about the efficacy of red mud. The chart-3 represents the comparison of UCS value for untreated soil and soil-red mud admixture. From the graphical representation it can be clearly visible that the unconfined compressive strength (UCS) value of soil increases with addition of red mud in the admixture. Initially it increases up to 30% but after that there is a slight reduction in UCS value. The value of untreated soil is 49.192 kPa, which increases to 102.317 kPa after the addition of red mud at 30% by weight of dry soil. This incrimination shows a significant improvement in the strength of soil.

5.3 Effect of Red Mud on California Bearing Ratio (CBR) of Expansive soil

California Bearing Ratio test is conducted according to IS: 2720 (Part 16)-1987 on varying percentages of red mud to determine the CBR value of the samples at 2.5 mm and 5 mm penetration. The soil samples are prepared under varying percentages by using respective OMC and MDD.

Table -5: Data sheet of CBR values for soil samples

Samples	CBR value at 2.5 mm	CBR value at 5 mm
Soil	4.763	4.176
Soil+10% RM	3.913	3.075
Soil+20% RM	7.516	7.018
Soil+30% RM	8.670	7.118
Soil+40% RM	4.670	3.275

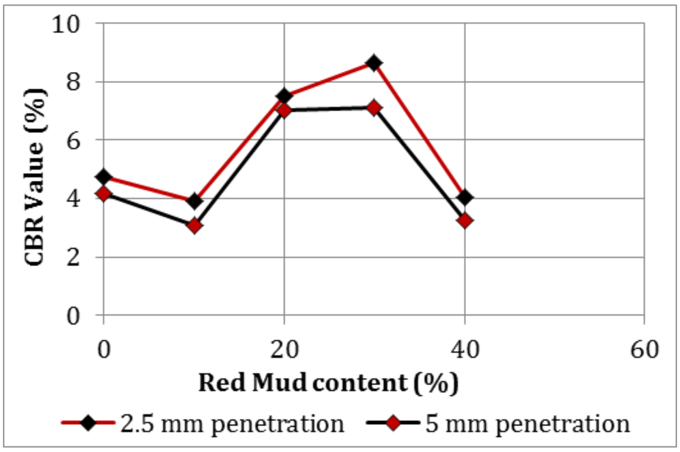

Chart -4: Comparison of CBR at 2.5 mm and 5 mm penetration for Expansive soil & soil-red mud admixtures

In the chart-4 the variation of unsoaked CBR values with different red mud content for the load penetration of 2.5 mm and 5 mm is given. This test is conducted to demonstrate the effectiveness and usability of red mud with expansive soil as the subgrade material for the pavement. From the comparison, enhancement of CBR value is clearly visible for both 2.5 mm and 5 mm penetration. The CBR value for 2.5 mm penetration increased till 30% beyond which it reduced with excessive addition of red mud. At 2.5 mm the CBR value of soil-red mud admixture increased from 4.763 to 8.670. The increment with 5 mm penetration is also seen. It increased till 30% i.e. 7.118 and after that it continued to decline.

6. CONCLUSIONS

Addition of red mud impacts on compaction characteristics of expansive soil. The OMC and MDD increases with the replacement of soil by red mud. For soil-red mud admixture, the maximum MDD was obtained at 20% by weight of dry soil.

The UCS value was improved significantly. A moderate increase in UCS value has seen up to 20% addition of red mud. After which an instantaneous increment can be seen with addition of 30% red mud by weight of dry soil beyond which a sharp reduction in UCS value was measured.

A noticeable enhancement in the CBR value was observed with the addition of red mud to the soil. The admixture containing 30% red mud increased the CBR value of 2.5 mm penetration as compared to untreated expansive soil.

Thus, from this comparison, it is concluded that clayey soil mixed with 30% red mud by weight of dry soil exhibits improved geotechnical properties in terms of compaction characteristics, UCS and CBR. Such improvements show that the industrial waste is highly effective in stabilization of weak expansive soil instead of simply being disposed on the land.

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