Chapter 1
Enhancement of Soil Properties by Using Red Mud and Lime

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Introduction

The term red mud (RM) is used synonym of bauxite tailing. Annually over 150 million tons of RM produced internationally out of which India is producing 9 million tons per year (Ministry of Mines, Government of India, 2019). Red mud is produced from the refining process of bauxite in to alumina followed by Bayer's process, which is not disposed satisfactorily. According to Yang and Xiao [1] the RM is highly alkaline in nature and stored either in a red mud pond with low solid content about 15–40% by volume or in dry form more than 65% [2]; either way, it uses large amount of land. The properties of RM like chemical composition typically depend on the extraction of alumina from bauxite which influences the overall properties of RM. The primary composition of RM is Fe_2O_3 (48–54%), Al_2O_3 (17–20%), SiO_2 (4–6%), Na_2O (3–5%), TiO_2 (3–4%), and CaO (1–2%) [3]. Various methods have been adopted to find out the properties and its utilization [4–6] but, due to very less utilization rate, huge quantity of RM leftovers in ponds. Numerous methods have been implemented by the different organizations to utilize the RM in an effective way. Due to its cohesive property, the RM is considered as an effective material to improve the engineering properties of the soil. Many methods have been implemented by the different organizations to dispose the waste material which will cause benefits to the society. Due to the cohesive property, RM is the efficient material for enhancing the engineering properties of soil. Parekh [7, 8], studied the behavior of RM and suggested that it is highly alkaline in nature and have clay fraction (20–30%). Also,

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he reported that major particles are silt (CaCo3, goethite, hematite, sodalite, and gibbsite. Vick [9] found out its low plasticity property and found out LL to be 45% and PL to be 10% with high specific gravity ranging from 2.8 to 3.3. Kalkan [10] had explained stabilization of expansive clay with red mud and cement-RM. He observed that strength is increasing and permeability and swelling pressure are decreasing. Sundaram [11] studied the behavior of RM and suggested that it can be used as foundation material in in situ condition itself. He also found that the RM is highly alkaline in nature ranging from 9.3 to 10.2. The Atterberg limits range from 39 to 45%, 27 to 29%, and 19 to 22% as liquid limit, plastic limit, and shrinkage limit, respectively. Rout et al. [12] used RM for the road embankment design based on its geotechnical properties. They observed that specific gravity, MDD, and soil friction angle values are more compared to soil without addition of RM. Satyanarayana et al. [13] studied the characterization of lime stabilized red mud mix for feasibility in road construction. RM was stabilized with 2–12% of lime at an increase rate 2%, and tests like UCS, split tensile strength, and CBR were conducted at 1, 3, 7, and 28 days curing periods, respectively. It has been detected that 10% of lime shows higher values when compared with other percentage. Singh et al. [14] stabilized the RM using cement kiln dust (CKD). The percentage of CKD varies from 2 to 12% with an increment of 2%. The strength criteria like MDD and UCS values have been checked. The optimum percentage of CKD is 8%. After the optimum value, further addition of CKD has no effect on strength criteria. Deelwal et al. [15] did the characterization of RM (both index and engineering properties). They concluded that RM is suitable for base and subbase course of road where the traffic is less. They also suggested that it is suitable for some geotechnical work. Pandey and Jawaid [16] did the stabilization of disturbed soil by adding fly ash and RM. The optimum value of RM is found to be 30% with 3% of fly ash which shows the higher CBR values. Lakshmi et al. [17] had stabilized red mud with cement in different proportions and obtained increase in OMC and UCS and decrease in MDD value with increased dosage of cement. Cement and RM mixture changed the dispersed structure of RM to flocculated structure; hence, it increased the strength of cement-RM mixture. Aswathy et al. [18] studied the behavior of clay by adding RM and found that addition of 20% RM with 2% of lime gives more strength compared to only addition of RM (15%).

This study involves the utilization RM, which can be used for stabilization of weak clay soil which has been collected from NALCO, Odisha. The strength criteria (i.e., compaction, UCS, direct shear tests, CBR) of have been studied for the maximum utilization of RM. The RM and soil mix are then treated with lime to obtain the optimum utilization of RM with lime treatment. All the tests have been executed confirming to IS 2720.

Table 1.1 Different properties of RM and soil

Properties		Soil	Red mud
Maximum dry density (g/cc)		1.66	1.73
Optimum moisture content (%)		19	24
Specific gravity		2.36	3.27
Grain size Distribution (%)	(a) Sand	5	12
	(b) Silt	72	36
	(c) Clay	23	52
Liquid limit (%)		48.72	33
Plastic limit (%)		26.12	24
Plasticity index		22.6	9
Classification		CI	ML
Cohesion (kN/m^2)		29.42	20.59
Soil friction angle (in degree)		19	36.5

Materials and Research Methodology

Soil

The soil is collected from Godavaga village, Sambalpur. To make the soil free from vegetation, pebbles, gravel, etc., a depth of 0.3 m from ground level is chosen for sample collection. After collection, the soil lumps are broken into small pieces and passed through 4.75 mm IS sieve. Based on the index properties, the soil is called CI conferring to IS classification system. The geotechnical properties are mentioned in Table 1.1.

Red Mud

Red mud is collected from NALCO which is located in the district of Odisha called. RM is a multifaceted material that varies due to the dissimilar types of bauxites rummage sale and has diverse parameters. Test results are shown in Table 1.1; it shows that RM is subjugated by silt elements and also high plasticity features. The basic geotechnical characteristics of RM are stated in the Table 1.1. Table 1.2 shows the chemical elements. The chemical compositions and metal content of the red mud were determined using energy dispersive spectroscopy (EDS) in Fig. 1.1.

Table 1.2 Chemical elements of RM and lime

Red mud		Lime	
Element	Weight (%)	Element	Weight (%)
$CaCO_3$	0.72	$CaCO_3$	3.12
SiO_2	31.95	SiO_2	36.12
Al_2O_3	7.10	Al_2O_3	0.12
Fe	45.38	Fe	0.26
Ti	2.33	Ca	52.52
Na	6.24	MgO	0.71
Ca	1.34	YbF_3	6.21
P	0.17	–	–
K	0.13	–	–

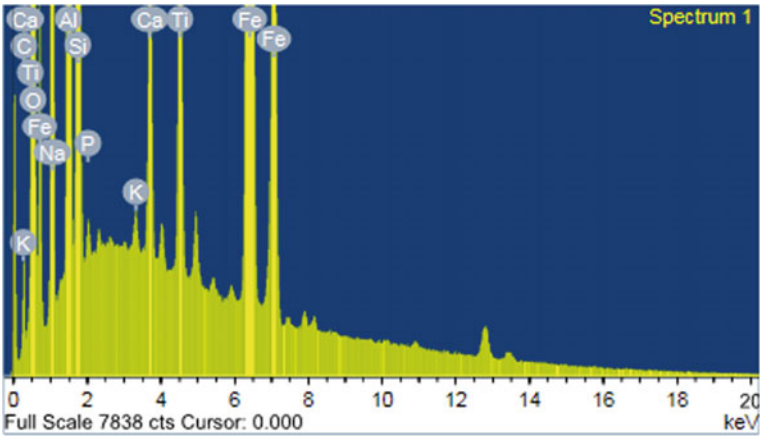

Fig. 1.1 EDS breakdown of RM

Lime

Lime is collected from nearby market in Sambalpur. The chemical composition (elements) is mentioned in Table 1.2, and chemical compounds present in lime are shown in Fig. 1.2 using EDS test.

Sample Preparation

The soil used in this study is clay. It is oven dried at 105 °C approximately and grounded before use to get uniform mixture. First, the desired proportion of clayey

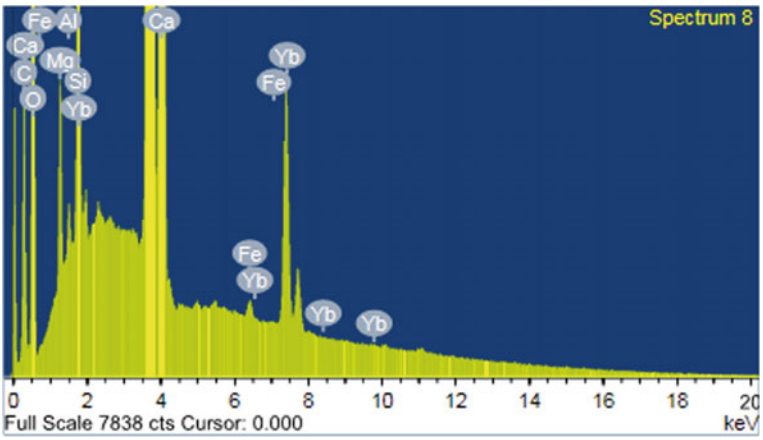

Fig. 1.2 EDS breakdown of lime

Table 1.3 Experimental program for different proportions of soil with dissimilar proportion of RM and lime

Sl. No.	Symbol	Soil (%)	Red mud (%)	Lime (%)
1	R1	100	0	0
2	R2	70	30	0
3	R3	60	40	0
4	R4	50	50	0
5	RL1	60	40	2
6	RL2	60	40	3
7	RL3	60	40	4
8	RL4	60	40	5

soil, red mud, and lime has been blended together under dry condition. The percentages of red mud are 30, 40, and 50% of the total weight of soil. Lime was taken as 2, 3, 4, and 5% by weight of total volume of mixture (soil and RM) (Table 1.3).

Results and Discussion

Compaction Characteristics

Proctor test (standard) has been conducted to determine the compaction characteristics of the red mud and soil and RM stabilized soil through lime with reference IS:

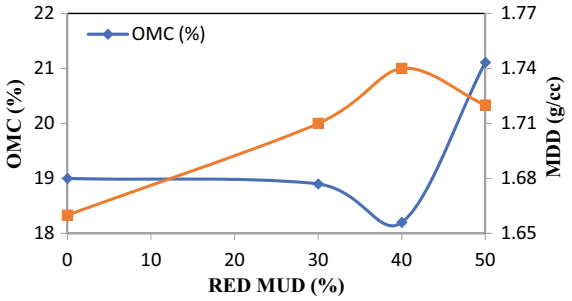

Fig. 1.3 OMC and MDD values for soil with red mud

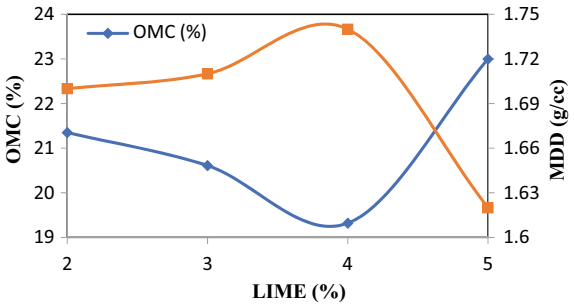

Fig. 1.4 OMC and MDD of RM stabilized soil with lime

2720 (Part 7). The variations of diverse combinations of OMC and MDD are plotted in Figs. 1.3 and 1.4.

The test result in Fig. 1.3 shows that, OMC of soil reduces significantly with the intensification of red mud percentage up to 40 after which the OMC value increases with increase in RM content. Simultaneously, the MDD of red mud mix soil increases significantly with red mud content (increase) up to a certain percentage after which there is decrease in MDD value. Originally, the OMC value and MDD value of virgin soil were 19% and 1.66 g/cc, respectively. But after adding red mud in different proportions, the optimal value of MDD and OMC was 18.2% and 1.74 g/cc, respectively.

Figure 1.4 shows that the optimum red mud mixed soil was again treated with different proportions of lime in order to get the best result. It has been observed that, the addition of $Ca(OH)_2$, the OMC decreases about 4% then it is increasing and the vice versa pattern is observed in case of MDD. The OMC and MDD values obtained in addition with 4% lime were 19.32% and 1.74 g/cc.

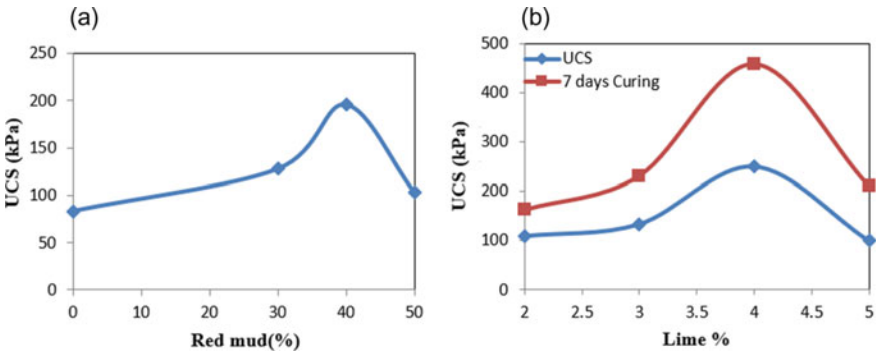

Fig. 1.5 Variation of UCS **a** with red mud, **b** with lime

Uniaxial Compression Test

The uniaxial compression test was conducted with strain rate of 1.25 mm/min as per IS: 2720 (Part 10), and static compaction method has been used to reach MDD and OMC. Figure 1.5 shows that the UCS is improved by 1.5 times in comparison with the soil without reinforcement and occurred at RM content of 40%. In addition, the lime has considerable effect on UCS when stabilized with RM. The UCS of soil increased to 249.58 kN/m^2 from 195.83 kN/m^2 when lime was added to RM stabilized clayey soil. The accumulation of lime more than 4% decreases the value (UCS) to 99.63 kN/m^2. The UCS value hits the peak with addition of 4% lime and 40%, or RM attains the maximum value when the lime is 4%. The UCS values of the virgin soil increases three times by the combined effect of RM and Ca $(OH)_2$. The cause of this consequence is the pozzolanic reactions of Ca $(OH)_2$ with soil and red mud. After addition of 5% lime, the strength decreases because of the availability of extra lime.

California Bearing Ratio (CBR)

The CBR test is used to evaluate the strength of sub-grade of road embankment. This test has been conducted as per IS: 2720 (Part 16).

The CBR value of RM mixed soil rises significantly through increasing the RM content up to 40% after which there is a decreasing trend. The CBR of RM stabilized soil increases to 4% from 2.8% of virgin soil in unsoaked condition and 2.69% from 1.7% of virgin soil in soaked condition.

By adding different percentages of lime show significant properties on the CBR (soaked and unsoaked) of the RM alleviated soil. Adding different percentage of lime, the unsoaked CBR values of RM stabilized soil increased to 19.43% from 6.32%, at 4% lime, by an increasing factor of 1.75; further the addition of lime decreases

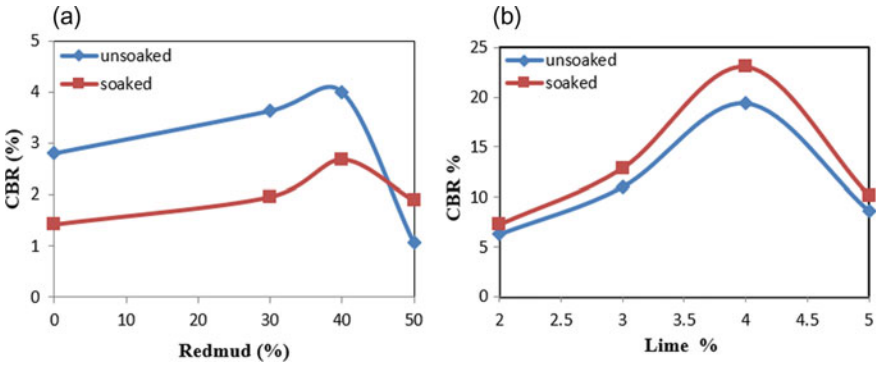

Fig. 1.6 Variation of CBR **a** with red mud, **b** with lime

the CBR value (soaked) of soil. Likewise, the CBR value (soaked) of RM stabilized soil increased to 23.07% from 7.27%, when 4% lime was added, by an increasing factor of 1.78 and further decreases (Fig. 1.6).

Shear Strength Parameters

Soil shear strength properties include the cohesion (c) and the soil friction angle. The test is conducted by putting the sample at OMC and MDD inside the shear box. The sample has been compacted in the box (shear) of (60 × 60 × 60) by tamping at MDD to obtain the specimens. The samplings were tested at stresses of 50 kN/m^2, 100 kN/m^2, and 150 kN/m^2 in UU conditions confirming to IS code 2720 (Part 13) 1986. The load is applied at a strain rate 0.002 mm/s. The readings were noted down at a fixed interval of horizontal dial gauge readings to study the displacement performance of soil RM mix and soil–RM–lime mix.

The observed shear parameters are c and φ in the Fig. 1.7 specifies that the stabilized soil shows an increase in the cohesion (c) and the soil friction angle (φ) up to 40% of RM content then decreases. The soil friction angle is increased considerably from 19º to 30º, and the cohesion increases from 29.42 to 49.03 KN/m2.

Figure 1.8 illustrates that there is a rise in the cohesion (c) and soil friction angle (φ) up to 4% of lime content. The soil friction angle increased significantly from 19º to 40º at 4% of lime and then decreased. Similarly, cohesion increased from 33.33 to 58.82 kN/m2 and after that it decreased.

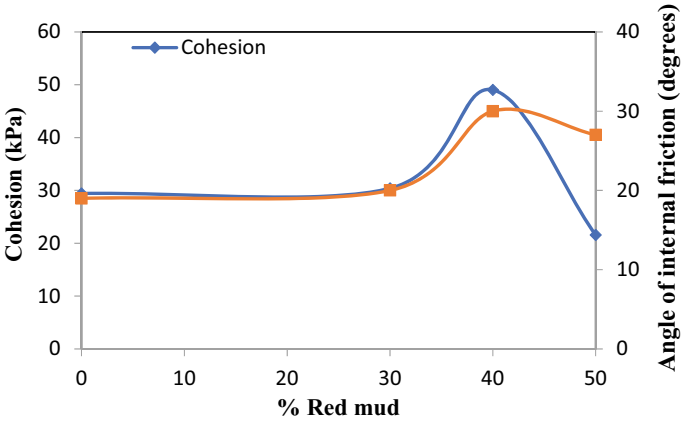

Fig. 1.7 Effect of red mud on shear strength parameters

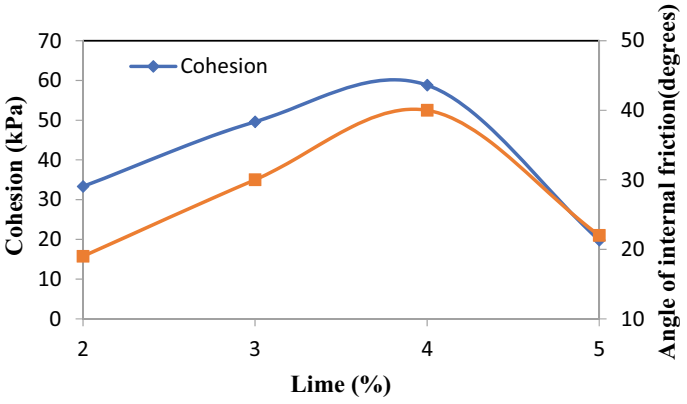

Fig. 1.8 Effect of lime on shear strength parameters

Analysis of EDS

The EDS analysis of particles is shown in Figs. 1.9 and 1.10 for RM stabilized soil and RM-soil mix with lime. The Ca content was increased with addition of lime that is 1.55%–5.78%. The iron content decreases from 45.38 to 29.0% in RM stabilized soil and 26.57% in lime stabilized red mud-soil mix.

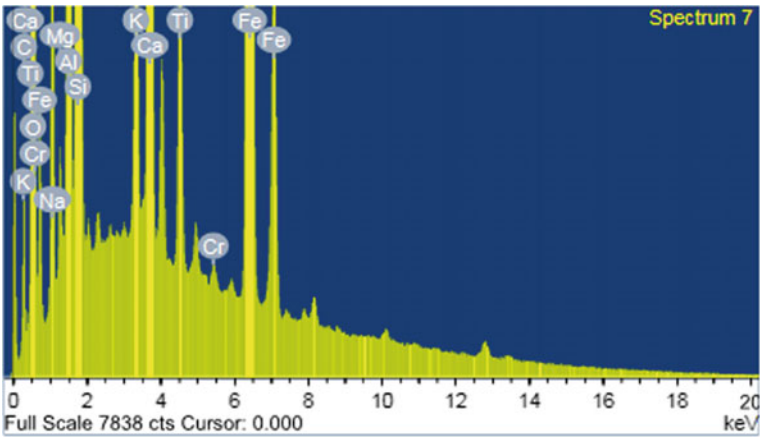

Fig. 1.9 EDS analysis of sample (red mud 60% + soil 40%)

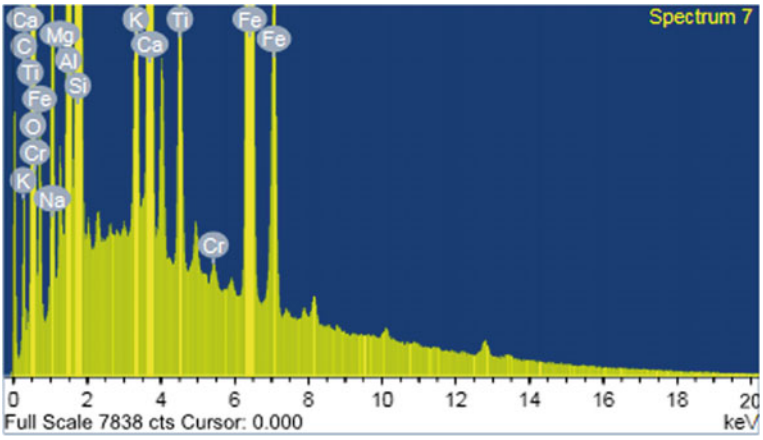

Fig. 1.10 EDS analysis of sample (red mud 60% + soil 40% + lime 4%)

Conclusion

Based on shear strength parameter, UCS results, and CBR results, the optimum proportion of soil to RM was 60:40 by weight. Addition of lime (up to 4%) to the stabilized clayey soil with optimal ratio of RM, the OMC value decreased with intensification in MDD. Further addition of lime results in decreasing in MDD and increasing in OMC. The soaked CBR of RM stabilized soil added with lime increased by a factor of 1.78 at 4% lime and further decreased. In unsoaked condition, the CBR value of RM stabilized soil added with lime increased by a factor of 1.75 at 4% lime and then decreased. The UCS achieves the maximum value when 4% of lime is added

with RM stabilized soil. The UCS value of the virgin soil increases 3 times by the combined effect of RM and lime. After curing, the maximum value of UCS was found at 4% Lime. So, the optimum percentage of Soil: Red mud: Lime was found to be 60:40:4. The red mud is utilized with lime to enhance the behavior of soil strata for better results. Hence, it may be concluded from this study that the RM may be used in soil enhancement of poor clayey soil in its place of simply being predisposed on the land.

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