Journal of Mines, Metals and Fuels, 71(11): 2116-2125; 2023. DOI: 10.18311/jmmf/2023/36270

Print ISSN : 0022-2755

Journal of Mines, Metals and Fuels

Contents available at: www.informaticsjournals.com/index.php/jmmf

Experimental Investigation of Red Soil Blended with Bentonite and Lime as a Landfill Liner

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Abstract

To control the migration of contaminants generated from the leachate, the liners are used in landfills. Compacted clay liners are widely used as liner materials due to the low value of hydraulic conductivity and large attenuation capacity. In the present work, an experimental study on red soil which is locally available is amended with bentonite use as a liner material for efficient leachate containment in landfills. The primary objective of this work is to determine the geotechnical properties of red soil blended with bentonite as a material for liners. The clay liners performance primarily depends on hydraulic conductivity. The hydraulic conductivity of the red soil is higher than the recommended limit (i.e.>10^{-7}cm/s). Commercially available bentonite was blended with red soil to decrease the hydraulic conductivity. The permeability tests and falling head tests were conducted on 5%, 10%, 15%, and 20% bentonite by weight blended with red soil to evaluate hydraulic conductivity. From the experimental studies, it is clear that the red soil blended with 15% bentonite has a hydraulic conductivity value less than the requirements of landfill clay liner(i.e.<10^{-7}cm/s). However, the Compressive Strength (CS) of blended red soil with 15% bentonite was less than 200 kPa, which is less than the minimum CS required for liner material. Lime was added to enhance the CS of the soil mixture and further studies were carried out. Swelling behavior is the major problem that is to be addressed during and after the construction of landfills. This study also presents the swelling behavior of red soil blended with bentonite and other additives.

Keywords: *Bentonite, Compressibility, Hydraulic Conductivity, Landfill, Red Soil*

1.0 Introduction

In developing nations, safe disposal of solid waste is a very complicated problem. Due to improper waste management, there will be disease transmissions, direct risks to those who come in contact with solid waste, proliferation of pathogens that are carriers of microorganisms such as bacteria, viruses, etc. indirect risks, deterioration of aesthetic, deprivation of the natural landscape, air, soil, and water pollution. The common practical scientific method for the disposal of solid wastes is landfill[1]. Around the world most widely used technique of solid waste disposal is by landfills. This disposal solid waste process has been practiced for centuries and will continue to be a vital component of municipal solid waste management across the entire globe.

Leachate is the pollutant liquid produced from municipal waste that contaminates nearby soil or

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groundwater[2]. It has been discovered that water sources close to waste dumps are also contaminated with microbes that have serious negative effects on the public's health. The sanitary landfills which are unlined produce leachate in a wet climate having lead, and toxic chemicals in contents above the drinking water standards for thousands of years. Even after more than 2000 years of construction landfill generates leachate[3].

Therefore, there is a requirement for a scientific method of waste disposal, namely depositing the waste in a landfill. Environment and human health should not be impacted by constructing landfills. So the landfills should be engineered[4-5]. Additional safeguards to inhibit the pollution of groundwater are usually achieved by liner systems of Landfills. The chemical compatibility of materials used for liner is studied with various pore fluids, and leachate to evaluate the liner material durability[6-7].

The present paper presents the evaluation of the geotechnical properties of the soil and its suitability as a liner material when soil is blended with bentonite and behavior to leachate interaction. In this regard, the following laboratory tests have been conducted. Atterberg limits, hydraulic conductivity, compaction characteristics, UCS, and particle size distribution were carried out on blended soil to assess the capabilities of the proposed soil as liner materials. To assess the swelling behavior consolidation tests were performed.

2.0 Materials and Methods

2.1 Materials

Red soil which is available locally, commercially available bentonite, and its blends with red soil were chosen as study material to determine the potential use as "landfill liner" materials. The natural red soil has been found in Ramanagar district of Karnataka state. Commercially available Bentonite, utilized in the work procured from the Bengaluru market. Lime (CaO) used in the present study was purchased from "Thermo Fisher Scientific India Pvt. Ltd.," Mumbai. The Bengaluru city some portion of MSW is being dumped at Seegehalli village, Magadi road. Randomly collected Leachate samples from 3 different locations at the dumping yard base are used in the present analysis.

2.2 Methods

Standard methods, and procedure suggested by the "Bureau of Indian Standards" is followed to evaluate the index as well as engineering properties of test soils.

3.0 Results and Discussions

Figure 1, gives the red soil and bentonite grain size distribution curve. From Table 1, it was found that mainly 47.53% of fines passed through 75 microns, and 52.47% were retained on 75 microns in the red soil. The particle

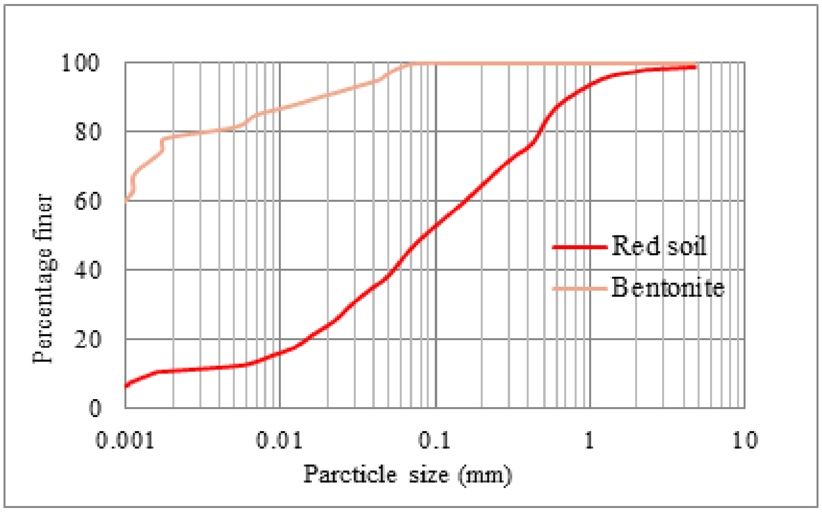

Figure 1. Red soil and bentonite's particle size distribution curve.

Table 1. Index and Engineering properties of the test soils

Parameters	Red soil	Bentonite
Specific gravity	2.62	2.48
Atterberg's limits (%)		
Liquid limit	36.0	247.0
Plastic limit	23.0	56.0
Shrinkage limit	12.3	9.2
Plasticity index	13.0	191.0
Particle size distribution (%)		
Gravel content	0.97	--
Sand content	51.50	--
Silt content	35.18	20.83
Clay content	12.35	79.17
Soil classification	SC	CH
Activity	1.1	2.4
Engineering properties		
Max. dry density (kN/m^3)	17.95	13.51
OMC (%)	15.17	30.63
Unconfined Compressive Strength (kPa)	407	185
Hydraulic conductivity (cm/s)	4.2 $\times 10^{-5}$	Impermeable

size distribution curve of bentonite contains 79.17% clay, remaining 20.83% is silt content.

3.1 Compaction Characteristics of Test Soils

From Figure 2, it is found that the maximum dry unit weight along with OMC ("Optimum Moisture Content") for red soil is 17.95 kN/m^3 and 15.17% respectively, and from Figure 3, it is found that the maximum dry unit weight and OMC for bentonite clay are 13.51 kN/m^3 and 30.63% respectively.

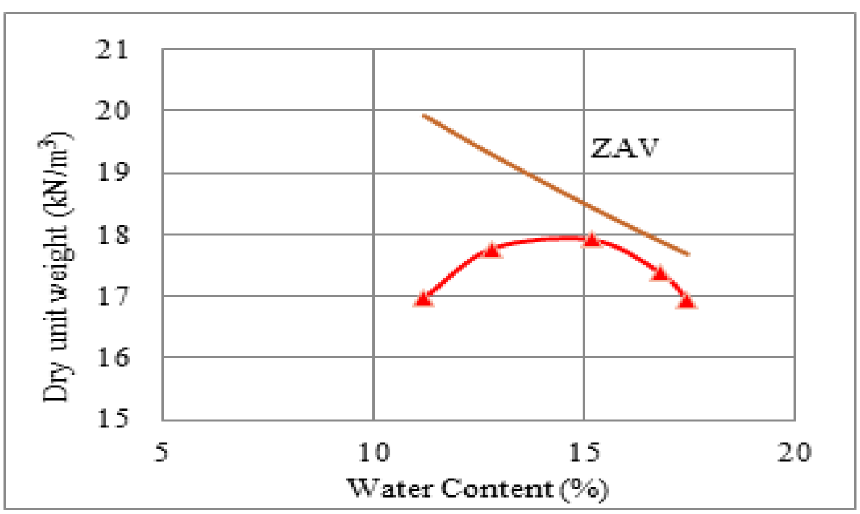

Figure 2. Standard compaction curve for red soil.

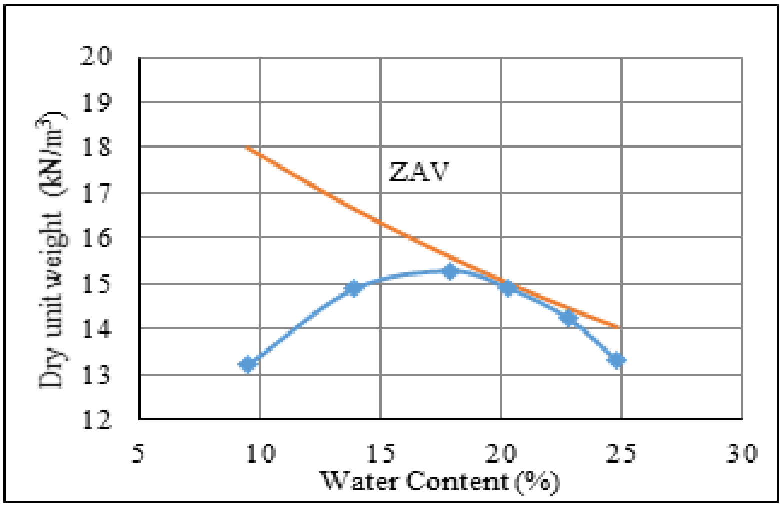

Figure 3. Standard compaction curve for red soil and bentonite.

3.2 Hydraulic Conductivity of Soils

The laboratory test resulted in a red soil hydraulic conductivity value that was higher than the standard for liner material (1×10^{-7}cm/s)[8]. To lower the hydraulic conductivity ($\leq 1 \times 10^{-7}$cm/s), At different proportions, the red soil was blended with bentonite. Red clayey soil was blended with 5,10,15, and 20% of bentonite.

Figure 4 displays the hydraulic conductivity variation with the bentonite percentage added to red soil. From the graph, it is obvious that red soil combined with 15% bentonite meets the conditions for hydraulic conductivity of landfill clay liner. Hence the red soil mixed with 15% bentonite was considered for further examination.

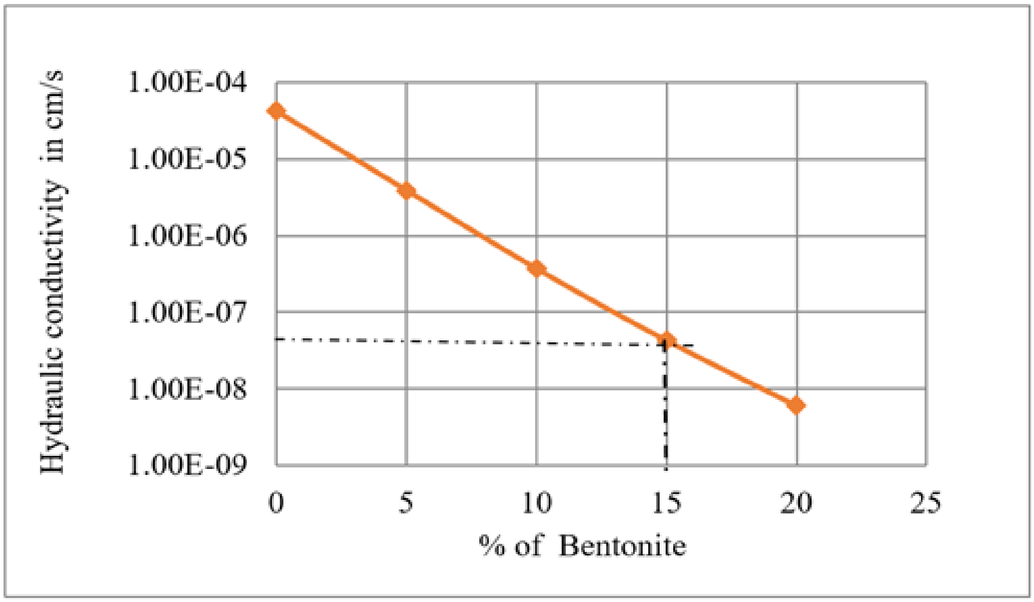

Figure 4. Hydraulic conductivity Variation of red soil blended with varying bentonite percentages.

3.3 Index Properties of Modified Red Soil

Table 2. Index Properties of Modified Red Soil

Parameters	Red soil + 15% Bentonite
Specific gravity	2.56
Analysis of grain size (%)	
Clay size	20.60
Silt	36.50
Sand	42.34
Gravel	0.56
Atterberg's limits (%)	
Activity	1.1
IS classification	CI
Plasticity index	21.80
Shrinkage limit	12.10
Plastic limit	25.00
Liquid limit	46.80

In comparison with unblended soil, a small rise in % fines and plasticity index was found in blended soil. There is an increment in plasticity index to a value of 21.80% for red soils blended with 15% bentonite clay and an increment of fines (silt and clay) to 57.10%. The plasticity index and the proportion of particles are crucial factors in the selection of soil for the construction of landfill liner. They are important properties to achieve low hydraulic conductivity. It is suggested that a plasticity index of more than 10% with very low in-situ hydraulic conductivity has been adopted successfully to construct soil liners. Lesser shrinkage can be anticipated if the plasticity index is lower than 35%. At least 50% fines are recommended for attaining a low value of hydraulic conductivity[9]. The shrinkage limit of the red soil blended with 15% bentonite was found to be 12.10%. The plasticity index value is more than 15 percent which shows that the soil is workable. Therefore, blended soil processes the desirable quality of the liner material that can be used for landfill liners.

Atterberg's limits of red soil mixed with 15% bentonite were tested and it shows a liquid limit value of 46.80%, plastic limit value of 25.00%, and plasticity index value of 21.80%. On the basis of test findings, the soil is categorized as intermediate Compressibility Inorganic Clay (CI). Red soil (Sandy Clay-SC) is altered into intermediate compressibility Inorganic Clay (CI) by the addition of bentonite. Inorganic clay of Intermediate Compressibility (CI) has lesser hydraulic conductivity compared to Sandy Clay (SC), therefore inorganic clay of Intermediate Compressibility (CI) could be broadly utilized as a liner material. Hence further tests are done to appraise the engineering properties of red soil blended with 15% bentonite.

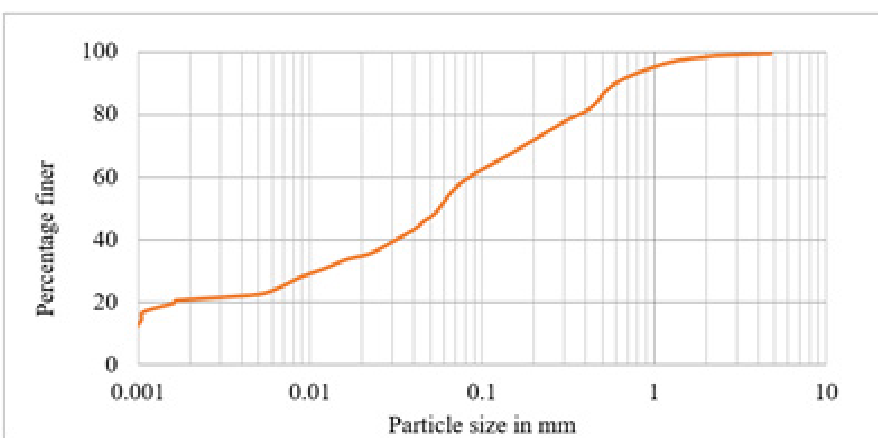

Figure 5. Particle size distribution curve for red soil blended with 15% bentonite.

3.4 Compaction Behaviour of Modified Soils

From Figure 6, it is seen that the maximum dry unit weight and OMC for red soil blended with 15% bentonite are 17.65 kN/m^3 and 17.90% respectively.

3.5 Unconfined Compressive Strength (UCS) of Blended Soil

Figure 7, illustrates the UCS produced with various levels of molding water content. The compacted soil liners utilized for waste containment should have the necessary strength for stability and to withstand the compressive stress produced by waste material on the liner system. Landfill Height and the unit weight of waste govern the compressive stress acting on the liner structure. Therefore, to sustain the maximum compressive stress exerted on a landfill a minimum UCS of 200 kPa must be possessed by the soil which is used for clay liners[8]. From Figure 7 it is seen that UCS decreases with the rise in the moulding water content. At contact points, the frictional resistance between soil particles is decreased due to the rise in clay size particles that fill voids between soil particles due to this shear strength. In the current work, it is observed that OMC blended soil possesses lower strength (<200kPa) as compared to the suggested minimum compressive strength. So, further experimental work is carried out with the blending of lime to obtain the anticipated compressive strength.

3.6 UCS of Blended Soils Mixed with Lime

The CS of red soil mixed with optimum 15% bentonite is around 187 kPa. There was a rise in strength when

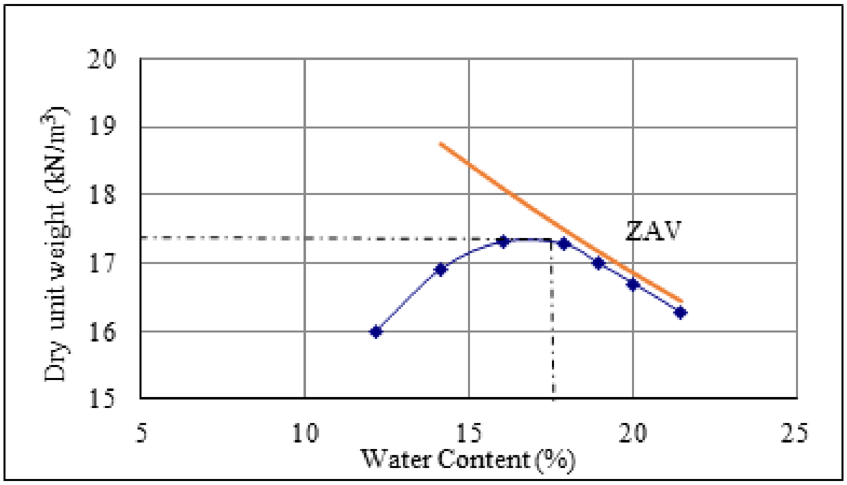

Figure 6. Standard compaction curve for red soil blended with 15% bentonite.

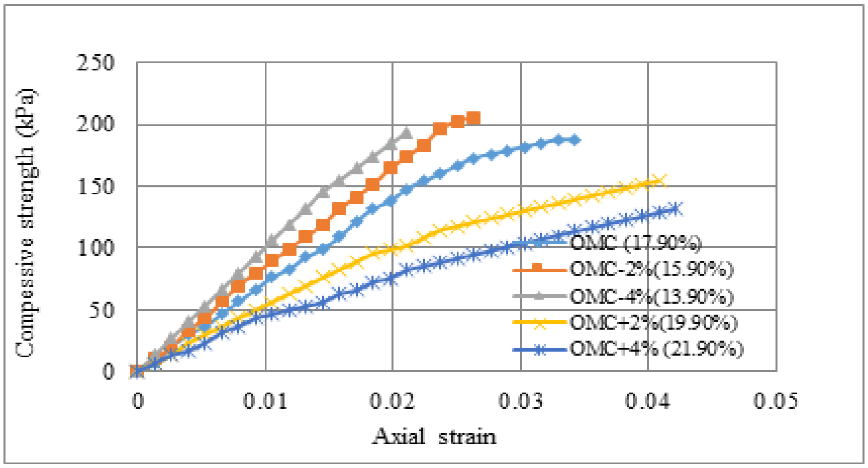

Figure 7. UCS variation with axial strain for red soil blended with 15% bentonite.

1% lime was added to 210 kPa from 187 kPa for 3 days of curing as shown in Figure 8. A similar tendency is observed at 7-, 14-, and 28-day curing periods. Due to pozzolanic reaction compounds the rise in strength up to 3% addition of lime is obtained. New cementitious products like C-S-H ("Calcium Silicate Hydrate") and C-A-H ("Calcium Aluminium Hydrate") are produced and effective penetration of lime and, binds the soil particles together.

3.7 Swelling Characteristics of Red Soil with Water

Figure 9 indicates the pressure void ratio relation for unblended red soil with water. The Sample had an initial void ratio of 0.44. 6.25 kPa Seating pressure is applied on the sample to swell initially. The soil is swollen into a "void ratio" of 0.48 and therefore swell potential and swell pressure of 2.78% and 60 kPa respectively.

3.8 Swelling Characteristics of Bentonite with Water

Figure 10 displays the pressure void ratio relation for bentonite with water. The initial void ratio is 0.95 for the test sample. 6.25 kPa Seating pressure is applied on the sample to swell initially. The soil is swollen to a void ratio of 1.31 and therefore swell potential and swell pressure of 18.46% and 370 kPa respectively.

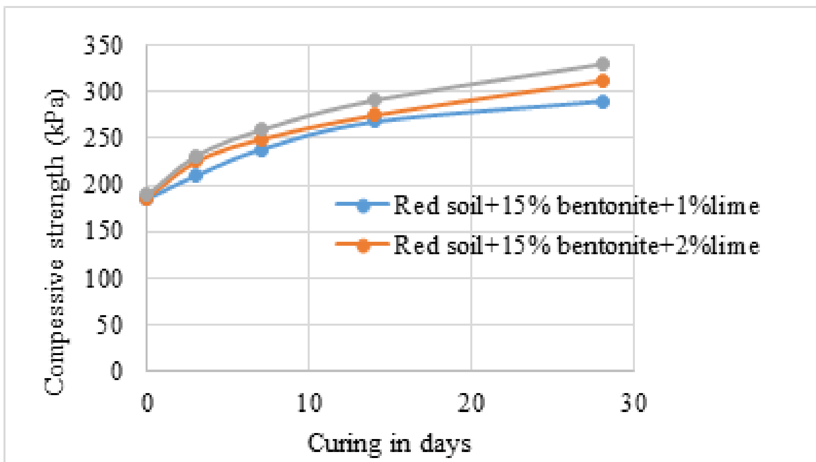

Figure 8. UCS of red soil blended with 15% bentonite with various percentages of lime.

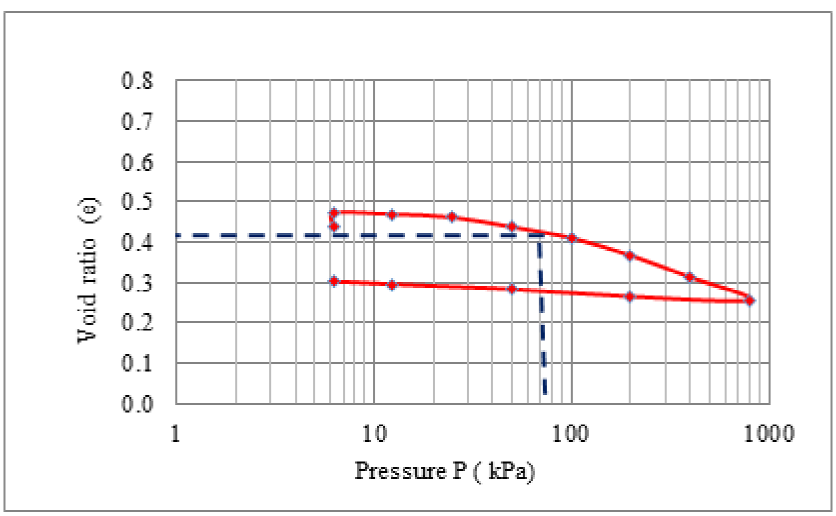

Figure 9. Relationship between pressure and void ratio in red soil.

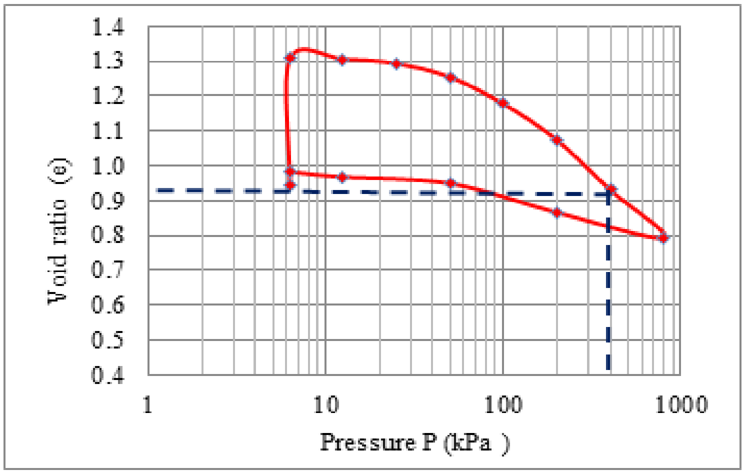

Figure 10. Relationship between pressure and void ratio in bentonite.

3.9 Swelling Characteristics of Red Soil Blended with Variation in Bentonite

A consolidation test was performed for soil samples of red soil with variations in bentonite to evaluate the behavior of compressibility. With the addition of bentonite, the swelling of red soil is increased. There is a rise in swelling owing to the rise in the proportion of clay particles in the soil. The curve of e-log P from the test outcomes is revealed in the Figure 11. As the addition of bentonite increases the initial void ratio increases due to the rise in clay minerals in the blended soil. It is seen that red soil blended with 15% bentonite exhibits an initial void ratio of 0.543. 6.25 kPa seating pressure was applied to swell initially. The void ratio increased to 0.624 and thus swell potential is 5.25% and swell pressure is 280kPa. Figure 10 shows the impact of bentonite content in bentonite-red soil mixture on swelling behavior. It has been seen that bentonite content in bentonite red soil mixture is the main factor for swelling deformation. Minerals like montmorillonite from the smectite group, which are predominant in bentonite have a structural gap in their mineral structure. Expansion of the whole mineral structure is due to the staking of water molecules entered in the gaps[10].

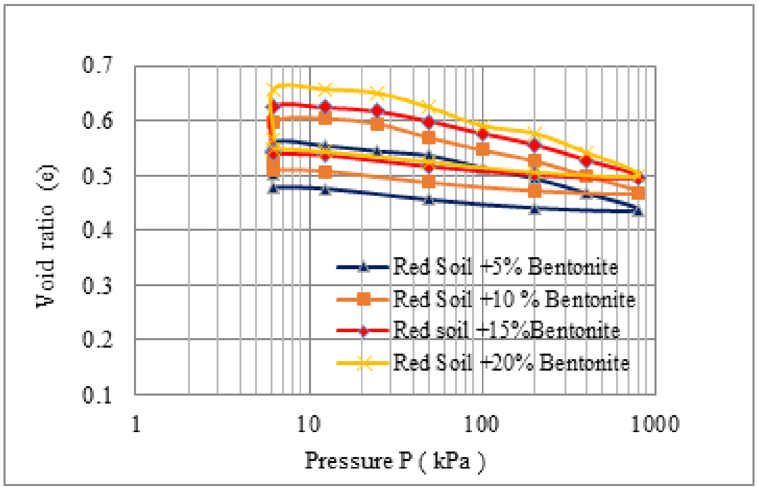

Figure 11. Relationship between pressure and void ratio for red soil with variation in bentonite.

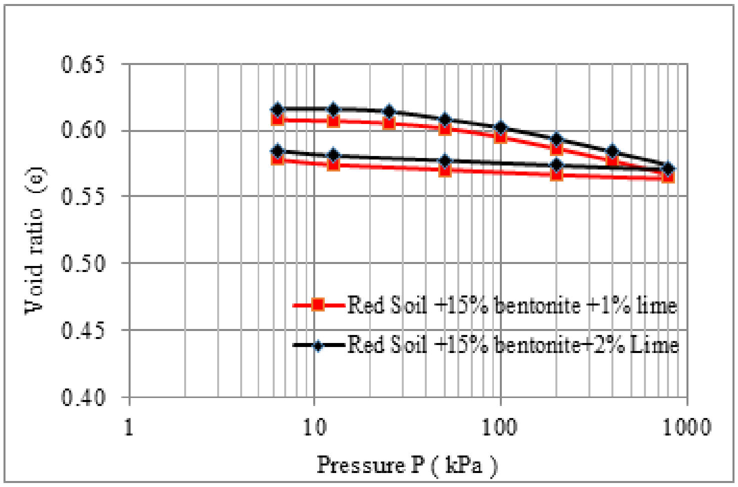

Figure 12. Relationship between the pressure-void ratio for red soil treated with 15% bentonite and treated with varying content of lime.

3.10 Swelling Characteristics of Modified Red Soil Treated With Varying Content of Lime with Water

A consolidation test is performed on red soil with 15% bentonite treated with 1% and 2% lime to assess the compressibility behavior. The sample's initial void ratio was 0.608 for the lime-stabilized samples at 1 percent and 0.616 at 2 percent, as shown in Figure 12. The sample is initially allowed to expand at a sitting pressure (6.25 kPa). The soil's void ratio is 0.610 and 0.618, respectively, indicating a swell potential of 0.13 percent and 0.12 percent. From this, it can be observed that adding lime reduces the soil's ability to swell, whereas, without lime, the soil mixture's swelling potential was 5.25 percent. The swelling pressure is also negligible in the addition of lime as shown in Figure 12. Calcium silicate and aluminum hydrates are formed due to the substitution of calcium in bentonite cations. This cementitious matrix results in lesser affinity to water and thus reduces swelling[11].

4.0 Conclusions

The following conclusions could be drawn based on findings of the current investigation.

- Hydraulic conductivity of red soil blended with 15% bentonite is about 4.20×10^{-8} cm/s at OMC, which satisfies the criteria for "hydraulic conductivity" of landfill clay liner.
- The hydraulic conductivity value declines with the rise of flow period, liquid limit, as well as plasticity index of red soil blended with 15% bentonite clay. There is an increase in UCS to a value of 312 kPa when 2% lime is added to the red soil with 15% bentonite.
- The red soil blended with 15% bentonite clay has normal activity i.e., Activity=1.1, which indicates that the soil is less affected by contaminants or leachate.
- The plasticity index of red soil blended with 15% bentonite clay is 21.80%, It lies from 10% to 35%, which satisfies the criteria of landfill clay liner and it possesses low shrinkage.
- The low value of hydraulic conductivity, required and lesser potential to shrinkage properties possess a red soil blended with 15% bentonite and 2% lime is a potential material that can be used as compacted clay liners inside landfills for environmental protection.

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