Effect of Clay-Embedded Zeolite as Landfill Liner

P. A. Amalu and Ajitha B. Bhaskar

Abstract This study investigates the characteristics of natural zeolite amended kaolin clay, to be used as an impervious liner in the landfill. A landfill liner or composite liner is a low permeable barrier, which is laid down under engineered landfill sites. The ingredient zeolite was chosen due to its high absorption capacity for heavy metals as well as pozzolanic properties. A *B*/*Z* ratio of 0.5 was found to be an ideal landfill liner material considering its low hydraulic conductivity. Hydraulic conductivity tests on zeolite-embedded clay liner systems show that the hydraulic conductivity of all the mixtures prepared with varying proportions of zeolite, meet the common regulatory requirements. The micro-porous structure of natural zeolite results in a very high absorption rate, which in turn reduces the hydraulic conductivity. In order to estimate the optimum dosage of zeolite to the clay mixture, an extensive study on the strength and compaction characteristics was done.

Keywords Zeolite · Bentonite · Landfill liner

1 Introduction

Landfill liners are barriers, made of materials with very low hydraulic conductivity. Liner functions as a separator between the waste and outside soil, protecting the ground water from being contaminated. In practice, the clay liners are widely adopted due to its lower permeability and flexibility. Among the criteria required for design of landfill liner, one of the most important constrains is the hydraulic conductivity. In Kerala, a lot of environmental issues are occurring due to the absence of proper liner systems in landfills. Developing a liner system with locally available materials could resolve the issue of finding the cost-effective liner system in engineered landfills. This study focuses on the usage of locally available kaolin clay as landfill liner. Experimental analysis on the kaolin clay pointed out that, the hydraulic conductivity

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of the material is higher than the required values. Therefore, additives were added into kaolin clay for modifying its engineering properties to meet the liner criteria. The selected external ingredients were bentonite and zeolite. These ingredients have higher specific surface areas which in turn results in more absorption of liquid.

Bentonite is the type of clay which is abundant with montmorillonite clay minerals. Based upon the dominant element present within bentonite, different types of bentonites are available. Among these various types, calcium bentonite was used in this study. Calcium bentonite could absorb water several times its dry weight and hence widely used as an absorbent. Through chemical reactions, calcium bentonite can be converted into sodium bentonite. This process is called as sodium beneficiation. As the predominant mineral in calcium bentonite is montmorillonite, it is widely used as a filler as well as absorbent. Due to these properties, a wide spectrum of industries is using calcium bentonite for various purposes such as for the production of cosmetics, pellets of materials, and many more, a percentage of bentonite was added to the locally available clay.

Zeolite is advantageous with natural clay as landfill liner mixture because of its high adsorption capacity. Zeolite is commonly known for its industrial application as absorbents. These are naturally occurring minerals with considerably larger specific surface area.

Thus, clay-embedded zeolite with different zeolite content was developed for possible use as a barrier material. Zeolites are micro-porous, alumino-silicate minerals that can act as a filter in case of leachate through liner. Furthermore, the pozzolanicity characteristic of zeolite provides remarkable increase in compaction characteristics. Bentonite is also an effective absorbent consisting mostly of montmorillonite in a landfill liner mixture. Na-bentonite expands when absorbing as much as several times its dry mass in water.

In this study, bentonite and zeolite were mixed with clay in various proportions in order to find out the optimum mixture as landfill liner.

Most of the research work has been focused in understanding the change in behavior of zeolite-embedded clay liner system on various mix proportions. Limited knowledge is available on the influence of zeolite, on the properties of locally available Kaolin clay. In addition, the optimum percentage of zeolite dosage was not studied generally and thereby compressive strength as well as compaction characteristic was evaluated for various mix proportions. Also, the influence of zeolite on locally available Kaolin clay has rarely been considered by researchers. Hence, the motivation behind the present study is to understand the effect of zeolite in the clay available from nearby locality and its implementation as landfill liners in order to propose an economic and efficient solution for landfill liner systems.

Table 1 Properties of Kaolin clay

Particulars	Values
Specific gravity	2.37
Liquid limit (%)	53
Plastic limit (%)	33
Plasticity index (%)	20
Maximum dry density (g/cc)	1.5
Optimum moisture content (%)	27.8
Sand (%)	17
Silt (%)	48
Clay (%)	37
Compressive strength (kPa)	117

1.1 Soil

In this study, kaolin clay was purchased from English India Clay Ltd. Thiruvananthapuram. The properties of this clay are summarized in Table 1.

1.2 Bentonite

Bentonite is a montmorillonite rich clay mineral which possesses high swelling and absorption capacities. There are different types of bentonite, namely sodium bentonite, potassium bentonite, and calcium bentonite. This study considered the effects of calcium bentonite mixed with kaolin clay and zeolite.

1.3 Natural Zeolite Powder

Natural zeolite occurs on the earth crust in different forms of deposits. These deposits are identified and mined using heavy machineries and blasting equipment. The extracted zeolite ore is then pulverized into finer forms for commercial purpose. The basic properties of natural zeolite purchased from Intercity Chemicals, Chennai, are tabulated in Table 2.

Table 2 Properties of natural zeolite

Particulars	Values
Liquid limit (%)	44
Plastic limit (%)	24
Plasticity index (%)	17
Specific gravity	2.23

2 Methods

Various experiments were conducted on the sample mixture of liner system. The sample mixture consists of Kaolin clay, a fixed 10% calcium bentonite and varying percentages of natural zeolite powder. The test results were aimed to converge at the optimum mixture of a zeolite-embedded clay liner system that could provide the highest strength and lowest permeability characteristics.

2.1 Consistency Limits

The consistency limits, invented by Albert Atterberg, classified soils based on the extend of water it can contain at each stages. When added with water, soil shifts from solid state to semi-solid and liquid states. Precisely, the shift in each state occurs at a specific water content that depends on the type of soil. These water contents are experimentally calculated and are termed as shrinkage limit, plastic limit, and liquid limit. The moisture content above which the soil will behave as a liquid of feeble shear strength is termed as liquid limit. This limit could be determined by using a standard penetrometer. The plastic limit test was performed under fixed conditions. The water content that separates the plastic and semi-solid states of soil is the plastic limit, whereas while reducing the moisture content in a soil, there will be a point beyond which the reduction in water content will not change the volume of soil. This limit is defined as shrinkage limit of the soil. The tests were conducted under fixed conditions compiling to IS 2720-part 5 and part 6.

2.2 Specific Gravity

Specific gravity indicates how much heavier a material is when compared with water of equal volume. It is property related to that of soil formation and is independent of particle size. The tests were conducted under fixed conditions compiling to IS 2720-part 3.

2.3 Grain Size Analysis Using Hydrometer

Particle size distribution of soil particles, having sizes less than 75-μm, is often determined by a sedimentary process using a hydrometer, based on the analysis by Stoke's law. The fraction of clay and silt plays a vital role in determining the properties of fine-grained soil. This test is mainly carried out to obtain the percentage silt and clay size particles in the given soil sample. This method could not be adopted if less than 10% of material passes through 75-μm sieve. The tests were conducted under fixed conditions compiling to IS 2720-part 4.

2.4 Compaction Test

Engineering properties of the soil, such as its strength, stiffness, resistance to shrinkage, and imperviousness of soil, etc., can be improved by increasing the soil density. The terminology "*compaction*" defines the process of reduction in volume of soil by the reduction of air void in it under sudden impact loading. The compaction test is used to determine the right quantity of water to be used, during field compaction and the resulting degree of denseness. The test is performed as per IS 2720-part 7-1980.

2.5 Unconfined Compressive Strength Test

The test determines the maximum stress a cylindrical soil specimen can bear without failure, when kept unconfined and subjected to axial loading. The rate of strain was maintained at 1 mm/min. The results obtained from the unconfined compressive strength test could be used to determine the unconsolidated undrained shear strength of the clayey soil. The experiments were conducted as per IS 2720-part 10-1986.

2.6 Permeability

In this study, the permeability is calculated from consolidation test. The permeability characteristics of a soil sample are determined by using an oedometer. The main parameter obtained from this test will be coefficient of consolidation which will be used for further determination of permeability. The test is performed based on IS 2720-part 5-1986.

Table 3 Variation of dry density with zeolite content

Sample specification	Maximum dry density (g/cc)	Moisture content (%)
Clay	1.50	27.80
Clay + 10% B	1.47	28.88
Clay + 10% B + 10% Z	1.39	34.64
Clay + 10% B + 20% Z	1.44	35.75
Clay + 10% B + 30% Z	1.42	33.52
Clay + 10% B + 40% Z	1.39	36.48
Clay + 10% B + 50% Z	1.36	34.95

3 Results and Discussions

3.1 Variation of Dry Density with Zeolite Content

On the clay sample mixed with 10% of bentonite, the natural zeolite content was varied from 10 to 50%. Compaction tests were conducted as per standards on each of the mixtures. The value of maximum dry density obtained had a slight improvement with the increase in natural zeolite content up to 20%, after which there was a considerable reduction in dry density. This might be due to the increase in proportion of natural zeolite which adsorbs more moisture and thereby reduces the dry density. The compaction test result showed that clay bentonite mix with 20% of natural zeolite content has got a maximum dry density. The details of compaction test are summarized in Table 3. The graphical representation of variation in maximum dry density with change in moisture content and change in percentage of zeolite is shown in Figs. 1 and 2, respectively.

3.2 Influence of Zeolite Content on Atterberg Limits

The values of consistency limit obtained from the study by changing the proportion of natural zeolite were observed. It could be concluded from the observation that a liquid limit, plastic limit as well as plasticity index properties of the prepared sample tend to increase with the increment in zeolite percentage. The details of variation in these consistency limits are tabulated in Table 4. The graphical representations of these variations in Atterberg's limit are shown in Figs. 3 and 4.

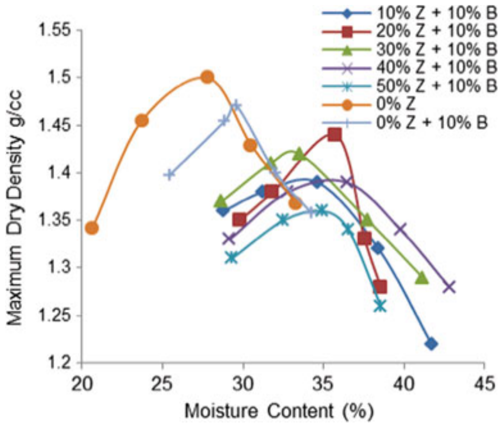

Fig. 1 Compaction characteristics of Kaolin clay, bentonite mixture with different zeolite content

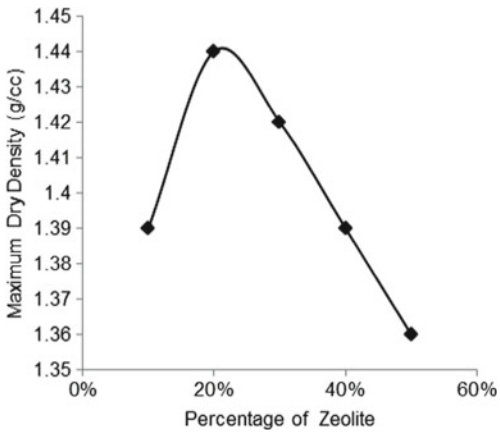

Fig. 2 Variation of dry density with zeolite content

3.3 Influence of Zeolite Content on Unconfined Compressive Strength

The increase in the percentage of zeolite content in the bentonite clay mix resulted in the improvement of unconfined compressive strength values. It could be inferred from the results obtained that the maximum strength was 280 kPa. This was obtained when 20% of natural zeolite was added to the bentonite clay mixture. The variations in compressive strength characteristics have been tabulated in Table 5. The stress–strain curves for various natural zeolite contents are graphically illustrated in Fig. 5.

The results obtained for changes in unconfined compressive strength indicated that beyond 20% of zeolite, there was a slight reduction in the compressive strength values. It is also evident that all the samples have met the minimum compressive strength requirement of liner criteria.

Table 4 Variation of consistency limits with zeolite content

Sample specification	Liquid limit (%)	Plastic limit (%)	Plasticity index
Clay + 10% Bentonite + 10% Zeolite	55.63	45.32	22.31
clay + 10% Bentonite + 20% Zeolite	59.00	36.50	22.50
clay + 10% Bentonite + 30% Zeolite	61.50	37.80	23.70
clay + 10% Bentonite + 40% Zeolite	62.92	38.64	24.28
clay + 10% Bentonite + 50% Zeolite	64.32	39.87	24.45

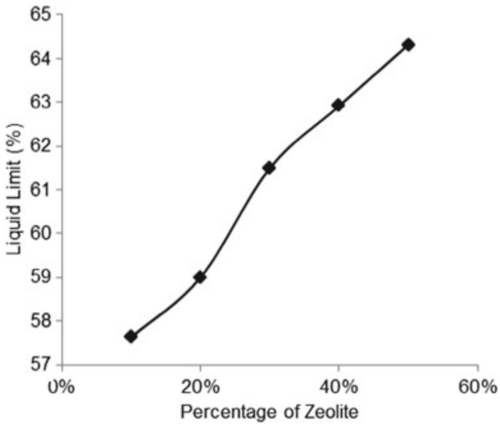

Fig. 3 Changes in liquid limit characteristics on addition of zeolite

3.4 Variation of Hydraulic Conductivity with Zeolite Content

The hydraulic conductivity values obtained for zeolite-embedded clay liner mixtures of various proportions denoted that the increase in zeolite percentage decreases the permeability of the liner system. This reduction in conductivity characteristics is mainly due to the porous molecular structure of the zeolite. Thereby, the zeolite entraps water molecule as well as other metal contaminants of sizes in coherence

Fig. 4 Changes in plastic limit characteristics on addition of zeolite

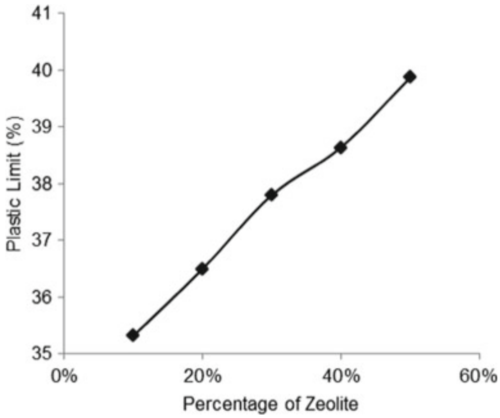

Table 5 Variation of unconfined compressive strength with zeolite content

Sample specification	Unconfined compressive strength value (kPa)
Clay + 10% Bentonite + 10% Zeolite	265
Clay + 10% Bentonite + 20% Zeolite	280
Clay + 10% Bentonite + 30% Zeolite	260
Clay + 10% Bentonite + 40% Zeolite	242
Clay + 10% Bentonite + 50% Zeolite	230

Fig. 5 Stress–strain behavior of different clay samples treated with zeolite

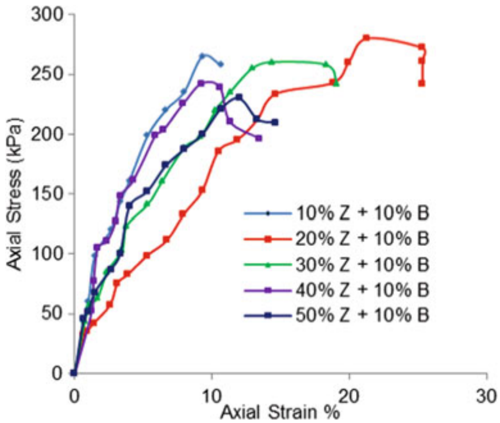

Table 6 Variation of hydraulic conductivity with zeolite content

Sample specification	Hydraulic conductivity (m/s)
Clay + 10% B + 10% Z	3.65×10^{-11}
Clay + 10% B + 20% Z	2.30×10^{-11}
Clay + 10% B + 30% Z	2.15×10^{-11}
Clay + 10% B + 40% Z	1.95×10^{-11}
Clay + 10% B + 50% Z	1.80×10^{-11}

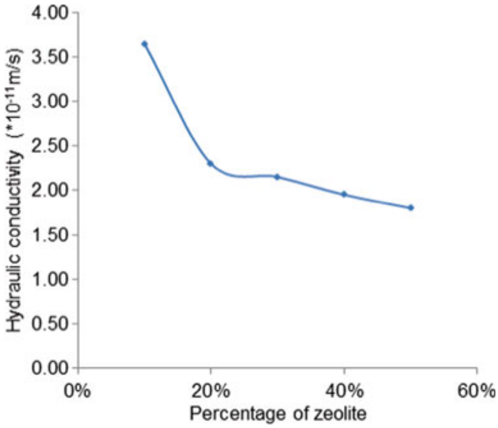

Fig. 6 Variation of hydraulic conductivity at different zeolite content in clay mixture

with inter-molecular pore spaces. This absorption of more water causes a reduction in hydraulic conductivity. In order to draw a conclusive statement regarding the optimum percentage of zeolite addition, the effect of 20% zeolite in the bentonite clay mixture was giving satisfactory results regarding the regulatory values for the liner system which is not more than 1×10^{-7} cm/s. These variations in hydraulic conductivity has been tabulated and graphically represented in Table 6 and Fig. 6, respectively.

4 Conclusions

It was intended to find out the optimized sample mixture which could render maximum strength with minimum hydraulic conductivity. The increase in zeolite content with Kaolin clay and fixed percentage of bentonite imparts an increase in the maximum dry density values up to 20%. Further increment in the zeolite percentage caused a reduction in the maximum dry density values which was an effect of the high moisture absorption characteristics of zeolite. The graphical representations of the unconfined compressive strength values point out that, the changes of strength characteristics resemble the similar trend in compaction properties. Thus the peak compressive strength was obtained for 20% zeolite content in the bentonite clay mix. From the results of consistency limit values, the increase in zeolite content causes a proportional increment in the consistency limits. The increment in consistency limit is the impact of the high absorption capacity per unit volume of natural zeolite. It could be inferred from the hydraulic conductivity values that when zeolite was added the hydraulic conductivity decreased significantly. But the addition of zeolite showed the reduction in hydraulic conductivity is due to the molecular sieve-like structure of zeolite that helps in the absorption considerable volume of water within its subatomic structure. Therefore, considering both strength as well as hydraulic conductivity criteria, the sample with zeolite content 20% mixed with 10% bentonite and 70% Kaolin clay can be taken as an optimum mixture for the liner system.

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