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Development of Ilmenite Mud as Liner Material

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Abstract. Industrialization has resulted in the rapid improvement of standards of living however it has also resulted in the generation of huge quantities of waste. In India, the sources of industrial waste are food industry , thermal power plants, pulp and paper industry, chemical industry, etc. In the current work an effort is made to useIlmenite mud which is a by product of the titanium industry, in the development of liner. By doing so it provides double advantage of waste management and the development of cost effective liner.The safe disposal of waste material in landfills with the separation of the waste from the surroundings needs engineered solutions. Generally, low permeability soil is used as liner for landfills thereby it could withstand infiltration of the developed leachate to the surrounding area. Adding an adequate amount of bentonite to soil will decrease the permeability and can enhance mechanical stability of the soil. By mixing ilmenite mud and locally available soil along with bentonite in various proportion a desired liner with low permeability and sufficient unconfined compressive strength is developed. The Atterberg limit of the developed mix is also determined.

Keywords: Ilmenite mud, UCC, Permeability

1 Introduction

In the last decades, the recycling of waste materials generated in the industries is being the matter of great concern. One well-known potential use of some industrial wastes is through their incorporation as secondary raw materials in the manufacture of construction materials. Earlier studies have shown Ilmenite mud to be a good additive for concrete production [2] also it improves the physical properties of bitumen binder in asphalt industry [15]. It can also be used in the production of sulphur polymer cement [10]. Globally 1.1 million tonnes of ilmenite mud is produced[12].In this study ilmenite mud is used for the development of a liner as per the EPA guidelines.

The safe disposal of waste materials requires exhaustive engineered solution this includes the confinement of the waste material. These materials could be recycled into construction materials which can be cost effective. Using ilmenite mud in the development of liner mix will be a double advantage of waste management along with

the development of a cost effective liner. An impermeable liner with k< 10^{-9} m/s is required to prevent the infiltration of hazardous leachate from landfill into the surroundings. Movement of contaminants in leachate is retarded by the low permeability and also due to sorption characteristics of the liner mix. Bentonite is found have good adsorption characteristics[13], so the addition of bentonite to the liner mix also improves the adsorption charateristics.

2 Materials Used

2.1 Soil

The soil used for the research work is kaolinite clay collected from Coromendal Clay Limited, Veli. Laboratory tests were conducted on the soil to determine the basic properties such as Atterberg limits, specific gravity, optimum moisture content, maximum dry density, unconfined compressive strength and permeability. Fig. 1 shows the grain size distribution of ilmenite mud, bentonite and soil. Properties of the soil used in the study and their respective IS code procedures are tabulated in Table 1. It is found that the percentage finer in ilmenite mud is less than that of soil and bentonite.

Table 1. Properties of soil and their respective IS code procedures.

Test	Results	Code reference
Liquid limit, LL(%)	50	*IS 2720-Part 5*
Plastic limit, PL(%)	28	*IS 2720-Part 5*
Plasticity index, PI(%)	22	*IS 2720-Part 5*
Shrinkage limit	27	*IS 2720-Part 5*
Specific gravity	2.75	*IS 2720-Part 3*
% clay fraction	53	*IS 2720-Part 4*
% silt	47	*IS 2720-Part 4*
Max. dry density (g/cc)	1.57	*IS 2720-Part 8*
OMC (%)	26	*IS 2720-Part 8*
UCC (kPa)	115	*IS 2720-Part 10*
Permeability (m/s)	1.49 x 10^{-8}	*IS 2720 - Part 17*
Unified Soil Classification	CI	*IS 1498:1970*

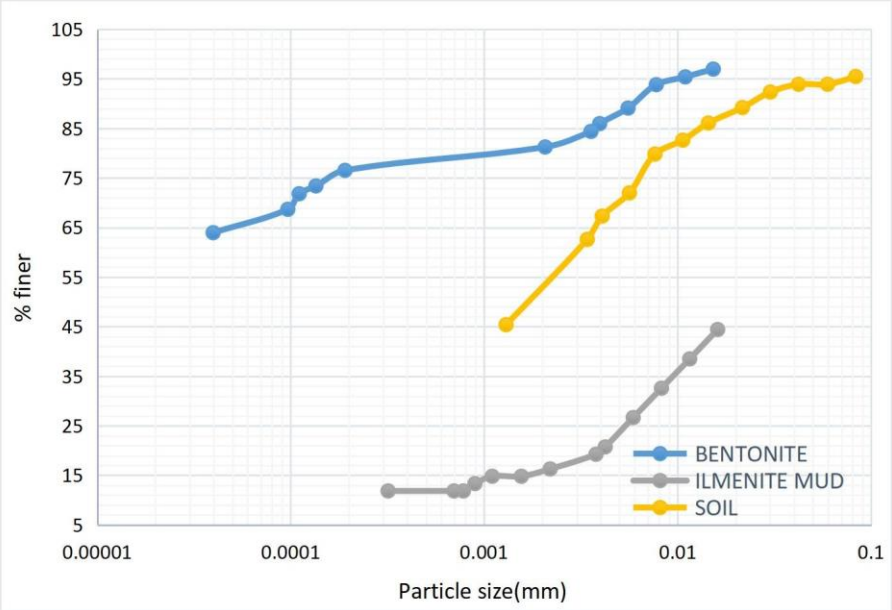

Fig.1 Particle size distribution curves

The properties required for liner material as per EPA, 2013 guidelines is represented in Table 2. From the test outcomes it is perceived that the soil alone will not satisfy the UCC strength and permeability characteristics of a liner material.

Table 2. EPA 2013 guidelines for the design of liner

Properties	Values
Permeability	$< 10^{-9}$ m/s
Plasticity Index	≥ 12-30 %
Unconfined compressive strength	≥ 200kPa

2.2 Ilmenite mud

The waste mud used for the study is collected from Travancore Titanium Products Ltd., Veli. which is is manufacturer and supplier of Titanium Dioxide and Sulphuric acid. Ilmenite mud is a by product that is obtained from the treatment of ilmenite ore with sulphuric acid. The chemical composition of ilmenite mud was analyzed using XRF (X-ray Fluorescence Spectroscopy), it is seen that the major constituents of ilmenite mud are TiO_2, SiO_2 , Fe_2O_3 etc. The chemical constituents and properties of

ilmenite mud are represented in Table 3 and Table 4. Ilmenite mud can be classified as Non-Plastic according to Geotechnical Design Manual as per Geotechnical Engineering Bureau, New York.

Table 3. Chemical composition of ilmenite mud

Constituents	Values
SiO_2	17.80%
TiO_2	54.40%
Al_2O_3	4.72%
MnO	0.14%
Fe_2O_3	15.90%
CaO	0.29%
MgO	0.45%
Na_2O	873 PPM
K_2O	717 PPM
P_2O_5	0.13%
LOI	2.14%
SUM	95.96%
Zr (PPM)	84
Cr	68
Zn	77
Co	20
Ni	35
Cu	97

Table 4. Properties of ilmenite mud

Property	Results
Specific gravity	3.12
Liquid limit	23.2
Plasticity index	NP
% clay-like fraction	16
% silt-like fraction	84
LOI (%)	2.14

2.3 Bentonite

The type of bentonite used for the work is sodium bentonite. It was collected from Harisons Minitech Pvt. Ltd., Jaipur. Table 5 shows the properties of bentonite used in the study.

Table 5. Properties of Bentonite

Test	Results
Liquid limit, LL(%)	166
Plastic limit, PL(%)	51.2
Plasticity index, PI(%)	114.8
Shrinkage limit	18
Specific gravity	2.16
% clay fraction	79.8
% silt	20.2
Unified Soil Classification	CH

3. Methods

3.1. Development of liner mix

The soil is mixed with ilmenite mud and bentonite in different proportions. Different tests like compaction, permeability, unconfined compressive strength characteristics etc. were conducted in order to determine the most suitable mix. The different proportions tested using soil is presented in Table 6. Since the percentage finer in ilmenite is less compared to soil and bentonite, the addition of ilmenite mud to soil bentonite mud increases the permeability. Therefore the percentage of ilmenite is varied from lower percentage until the liner properties is satisfied.Since ilmenite mud has 84% silt fraction the percentage of bentonite addition is decided to be varied from 0-15 % with reference to work done by Sobti et al[14].

Table 6 Trial test proportions with Soil (S:I:B)

Soil	Ilmenite mud	Bentonite
90	0	10
70	20	10
60	30	10
50	40	10

3.2 Compaction test

The compaction was carried out on different mix proportions to obtain a mix with desirable properties as per the EPA guidelines, 2013. The compaction test is carried on as per IS 2720-Part 8.

3.3 Unconfined Compressive test

UCC test on the soil samples were conducted at different mix proportions. The test was done as per IS 2720-Part 10.

3.4 Permeability test

The permeability of the soil,bentonite and ilmenite mud at different proportions are carried out as per IS 2720 - Part 17.

If the chosen mix does not satisfy the required liner properties then the composition is varied accordingly to get a satisfactory result. The main aim is to reduce the amountof bentonite added to the mix and thereby decreasing the overall cost of the construction. From the compaction test on the mix, maximum dry density and optimum moisture content is found out and using that, the unconfined compressive strength and the permeability of the mix is determined.

4. Results and Discussions

In order to obtain a desired proportion of the liner mix the compaction, permeability and unconfined compressive strength were conducted at different percentage of bentonite and ilmenite mud. From the results a liner is selected based on the hydraulic conductivity and unconfined compressive strength.

4.1 Trial test using soil and additives

Variation of compaction characteristics of different mixes

The compaction, permeability and UCC tests were conducted with soil and additives. Variation of MDD and OMC is shown in Figure 4 and Table 7. It is seen that as the OMC decreases MDD increases and the maximum value is obtained for 50:40:10 soil mix. There is an increase in MDD of the mix on addition of ilmenite mud as it has higher specific gravity of 3.12.

Table 7. Properties of mix at different composition

Property	90:0:10 S_2 :I : B	70:20:10 S_2 : I : B	60:30:10 S_2 : I : B	50:40:10 S_2 : I : B
Max. dry density (g/cc)	1.527	1.56	1.66 g/cc	1.782 g/cc
OMC (%)	28.02	24.06	22.23	20.2
Permeability (m/s)	1.25×10^{-11}	2.12×10^{-11}	2.68×10^{-10}	1.72×10^{-9}
UCC (kPa)	232	225	212	203

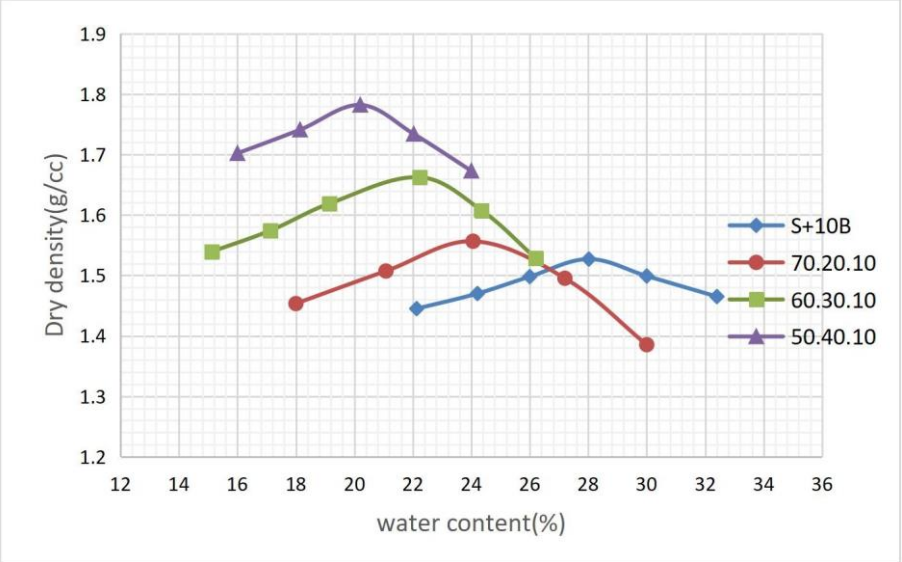

Fig. 4 Compaction curve of soil at different liner mix

Variation of hydraulic conductivity of different mixes

From the permeability test on the developed different liner mixes, the mix 70:20:10 and 60:30:10 (S : I : B) showed the desired values of hydraulic conductivity for a liner mix. An addition of 10 % bentonite was needed to satisfy the permeability characteristics. Table 8 shows the values of hydraulic conductivity of mixes prepared with soil, ilmenite mud and bentonite.

Table 8. Hydraulic conductivity of mix at different proportions

Proportion S : I : B	Hydraulic conductivity(m/s)
70:20:10	2.12×10^{-11}
60:30:10	2.68×10^{-10}
50:40:10	1.72×10^{-9}

Unconfined compressive strength of of different mixes with soil

The stress-strain curve obtained from the UCC test shows satisfactory UCC strength for the three mix proportions using soil shown in Figure 5. The strength value of soil

and bentonite mix which was initially 232.71kPa reduced to 203.52kPa on the addition of 40% ilmenite mud to the mix. Further addition of ilmenite mud would reduce the desired strength of the liner mix, so no further addition is possible. It canbe observed that all the mixes are suitable liner based on the strength characteristics as per the EPA, 2013 standards.

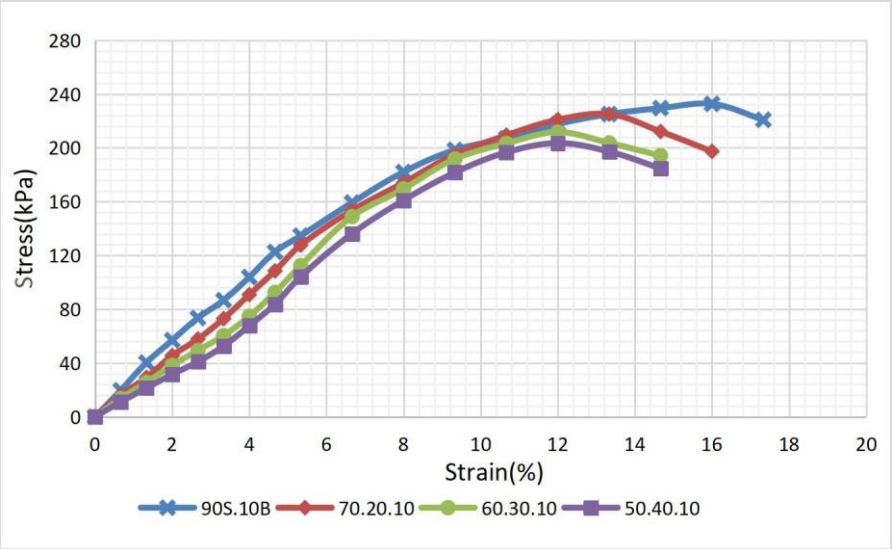

Fig. 5 Stress-strain curve of soil 2 for different mix proportion

Since the aim of the work is to incorporate maximum amount of the ilmenite mud into the liner for better waste management, the liner mix with the proportion 60:30:10 is chosen as the desired liner.

Atterberg limits of the developed mixes

The liner mix with 90 :10 (S :B) and 60:30:10 (S : I: B) are tested for the Atterberg limits to study the change in properties, with the addition of ilmenite mud. The Atterberg limits decreases on the addition of 30% ilmenite to the soil-bentonite mix as shown in Table 9. From the results it could be observed that the mix 60:30:10 satisfy the EPA, 2013 standards.

Table 9. The Atterberg limits of the liner mix

Atterberg Limits (%)	90 :10 (S :B)	60:30:10 (S : I: B)
Liquid Limit	84	48.2
Plastic Limit	57.34	27.16
Plasticity Index	26.66	21.04
Shrinkage Limit	25.18	23.57

5. Conclusions

1. Ilmenite mud along with soil and bentonite can be developed into a liner material which satisfies the EPA guidelines.

2. CI soil having an initial unconfined compressive strength of 115kPa and permeability 1.49 x 10^{-8} can be used for ilmenite mud liner development.

3. The addition of ilmenite mud to soil decreases the OMC, UCC strength and increases the dry density and permeability of the soil since the percentage finer is less in case of ilmenite mud compared to the soil and bentonite used in the study.

4. The liner mix 60:30:10 (S: I: B) is chosen as the suitable ilmenite mud liner mix proportion from the various proportions tested. This mix has a permeability of 2.68 x 10^{-10} m/s and unconfined compressive strength of 212 kPa.

5. The plasticity index of the developed liner, 21.08 % also satisfies the plasticity index standard for a liner material as per the EPA, 2013 guidelines.

Ilmenite mud could replace 30% of soil in case of CI soils. In-situ implementation would require further analysis of the leachate formation needs to be studied which also depends on the type and purpose of the landfill. The developed liner has a UCC strength less that the soil bentonite mix so the load on ilmenite mud liner will be less however this could be suggested as one effective and sustainable way of managing thedeveloped industrial waste.Further analysis has to be done to find out the design parameters of the liner such as height and load on the liner.

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