Visakhapatnam Chapter

Proceedings of Indian Geotechnical Conference 2020
December 17-19, 2020, Andhra University, Visakhapatnam

Design of Compacted Clay Liner with Black Cotton Soil and Micro Silica Fume

Anjuraj C. and Soumya Jose

Department of Civil Engineering
Thejus Engineering College, Vellarakkad
[1]anjurajc@gmail.com
[2]soumyacjd@gmail.com

Abstract. Waste liquids are arising in our environment from various sources like uncontrolled dumping of oils, pure solvents, municipal and hazardous waste, infiltration through waste deposits etc. This may lead to the formation of contaminated leachates, which are very harmful to environment and human being because of their mobile and soluble nature. Hence it is very necessary to prevent them. For that purpose we are using clay liners and compacted clay liners etc. The properties of clay liner materials are Hydraulic conductivity, Unconfined Compressive Strength and Volumetric Shrinkage Strain. Here we are introducing a new material for compacted clay liner using Black Cotton Soil and Micro Silica Fume. It was found to be an effective material as a hydraulic barrier with required properties of design specifications. Also developing an Overall Acceptable Zone based on the above properties.

Keywords: Silica Fume, Black cotton Soil, Overall Acceptable Zone

1 Introduction

Clays are essential materials to reduce the hydraulic conductivity of natural clay liners in landfill sites. Impermeable compacted clay liners are needed for the landfills. It is known that clays with high plasticity absorb water several times as much as their weights. The clay liners subjected to water pressure in landfills generate high permeability in time and instability problems in their body due to their expansive capacity [Craig H. Benson, 1999]. Though the compacted clay liners possess many advantages such as low permeability and large capacity of attenuation, they have high shrinkage and high expansive potential causing instability problem. The chemical analysis, which has positive effects to improve the properties of composite samples, also indicated that it could be a chemical reaction between silica fume and clay particles. When compacted wet of the line of optimums soils that are more plastic and have a greater quantity of fines yield lower hydraulic conductivity. Quality control of hydraulic barrier construction soils is usually based on some compaction criteria. Typically, the hydraulic conductivity must also be less than or equal to $1x10^{-7}$cm/s for soil liners and covers which are used to contain hazardous waste, industrial waste and municipal waste [David E. Daniel, 1990]. Various ratios of silica fume to clay were tested to obtain the most desirable mixture ratio of the ideal liner material for waste containment systems.

2 Objectives and Scope

- To evaluate the suitability of compacted Black Cotton Soil treated with Silica Fume as a hydraulic barrier in waste contaminant applications.
- To develop overall acceptable zones on the compaction plane to meet design objectives for Hydraulic conductivity, Volumetric Shrinkage Strain, and Unconfined Compressive Strength.

- Liner in waste containment facilities
- Disposal of municipal solid waste in most developing countries
- Use of engineered landfill liners for waste containment
  Minimization of pollutant migration
- Construction of dams and embankments
- Ecofriendly method

3 Materials Used

Black cotton soil and Micro Silica fume. Silica fume the byproduct of the reduction of high-purity quartz with coal in electric furnaces in the production of silicon and ferro-silicon alloys ferrochromium, ferromanganese, ferromagnesium, and calcium silicon. It consists of very fine vitreous particles with a surface area 20,000 m^2/kg. Particles approximately 100 times smaller than the average cement particle. Because of its extreme fineness and high silica content, Silica Fume (SF) is a highly effective pozzolanic material. Silica Fume is used in concrete to improve its properties. SF improves compressive strength, bond strength, and abrasion resistance; reduces permeability. Table 1 gives the chemical composition of SF.

Fig. 1. Black cotton soil

Fig. 2. Micro silica fume

Table 1. Chemical Composition of Silica Fume

Compostion	Percentages
SiO_2	98.87%
Al_2O_3	0.01%
Fe_2O_3	0.01%
CaO	0.23%
MgO	0.01%
K_2O	0.08%

Na_2O	0.00%

4 Experimental Programme

4.1 Determination of Volumetric Shrinkage Strain (IS 2720 (Part 5) 1985)

For the calculation of Volumetric Shrinkage Strain (VSS), the soil sample required for liquid limit is used. The sample is filled in an evaporating dish. The initial volume of sample is calculated by measuring the diameter and height of evaporating dish. After completion of 24 hours oven drying the final volume of dish was taken.
Volumetric shrinkage strain = Initial volume of evaporating dish/
Final volume of evaporating dish

4.2 Determination of Compaction Characteristics (IS 2720 (Part 7) 1980)

IS 2720 (Part 7) 1980 give procedure for determination of the relation between water content and dry density of soils using light compaction test. For the test 3 kg of air dried soil was taken and passed through 4.75mm IS sieve. A reasonable value of water content was assumed. The mould and the base plate were cleaned and greased. The mould and base plate were weighed to the nearest 1gm. Then the collar was attached to the mould and placed it on a solid base. The soil filled in the mould in 3 equal layers and gave each layer 25 blows with rammer. After compaction, removed the collar and trimmed off excess soil using a straight edge. Cleaned the base plate and mould from outside and weighed to the nearest 1gm and ejected the soil from the mould. Soil sample was taken from the middle portion for water content determination. The procedure was repeated by increasing the water content about 5% than the preceding one. The graph between the water content as abscissa and the corresponding dry density as ordinate was plotted. The plotted line indicates theoretical maximum density. Table 2 shows various compactive efforts used for this study.

Table 2. Compaction Test Procedures

Test Procedure	Weight of rammer (kg)	Number of blows per layer	Number of layers
Reduced Compation	2.5	15	3
Light Compaction	2.5	25	3
Heavy Compaction	4.5	56	5

4.3 Determination of Permeability of soil (IS 2720 (Part 17)-1986)

In the falling-head permeability test, the soil specimen was placed inside a tube, and allowed a flow through the specimen. The initial head difference h1 at time t = 0 was recorded, and water was allowed to flow through the soil in order to obtain h2 in the final head at time t = t. The hydraulic conductivity K was calculated by the following equation:

$$K = 2.303 \frac{aL}{At} \log \frac{h_1}{h_2}$$

where K is the hydraulic conductivity, in centimeters per second, h is the head difference, in centimeters, at any time t, A is the area of specimen, in square centimeters, a is the area of standpipe, in square centimeters and L is the length of specimen, in centimeters. The permeability apparatus had a plastic mould 10 cm wide, 20 cm high and 2 mm thick. The test apparatus consisted of a mould with lids and a stand pipe 10 mm in diameter and 100 cm high.

4.4 Determination of Unconfined Compressive Strength (IS 2720 (Part 10)-1991)

Place the sampling soil specimen at the desired water content and density in the large mould. Push the sampling tube into the large mould and remove the sampling tube filled with the soil. For undisturbed samples, push the sampling tube into the clay sample. Saturate the soil sample in the sampling tube by a suitable method. Coat the split mould lightly with a thin layer of grease. Weigh the mould. Extrude the sample out of the sampling tube into the split mould, using the sample extractor and the knife. Trim the two ends of the specimen in the split mould. Weigh the mould with the specimen. Remove the specimen from the split mould by splitting the mould into two parts. Measure the length and diameter of the specimen with vernier calipers. Place the specimen on the bottom plate of the compression machine. Adjust the upper plate to make contact with the specimen. Adjust the dial gauge and the proving ring gauge to zero. Apply the compression load to cause an axial strain at the rate of ½ to 2% per minute. Record the dial gauge reading, and the proving ring reading every thirty seconds up to a strain of 6%. The reading may be taken after every 60 seconds for a strain between 6%, 12% and every 2minutes or so beyond 12%.Continue the test until failure surfaces have clearly developed or until an axial strain of 20% is reached. Measure the angle between the failure surface and the horizontal, if possible. Take the sample from the failure zone of the specimen for the water content determination.

5 Results and Discussions

Table 3. Properties of Black Cotton Soil sample

SL.NO.	Properties	Results
1	Specific Gravity	2.66
2	Differential Free Swell Index	70%
3	Swelling Potential	19%
4	Shrinkage index	59%
5	Liquid Limit	75%
6	Plastic Limit	53%
7	Plasticity Index	22%
8	Shrinkage Limit	16%
9	Compaction Characteristics	OMC-27% MDD-1.44g/cc
10	Clay Fraction	85%

11	Sand Fraction	15%
12	Unconfined Compressive Strength	63kN/m^2
13	Natural Moisture Content	26%

5.1 Compaction test results

Reduced, Light and Heavy compaction were done on both raw Black Cotton Soil and Silica Fume- Black Cotton Soil composite to determine their Optimum Water Content (OMC) and Maximum Dry Density (MDD) relationships. The addition of silica fume to Black Cotton Soil samples increased the OMC and reduced the MDD for the same compaction effort. The significance of these changes depends upon the amount of silica fume added and the chemical composition of the clay minerals. Silica fume, depending on its content, increased the total particle surface of the mixture as compared with that of raw clay sample. Therefore, the OMC increased in the composite samples. Of course, depending on an increase in OMC, MDD decreased in the composite samples gradually. When the compactive effort increases MDD value increases and OMC value decreases. Hence MDD is maximum for heavy compaction and minimum for reduced compaction. OMC is maximum for reduced compaction and minimum for heavy compaction. The low optimum water contents and the high dry unit weights occurred in raw clay samples, while the high optimum water contents and the low dry unit weights occurred in 20% silica fume–clay composite samples. Different compaction tests were done on black cotton soil with 0, 5, 10, 15 and 20% of silica fume. The results are shown below:

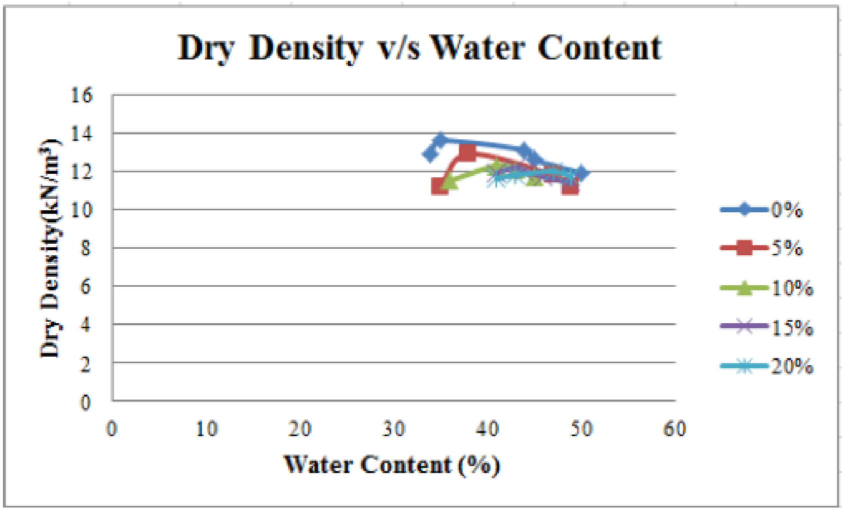

Fig. 3. Reduced compaction test results with different percentages of SF

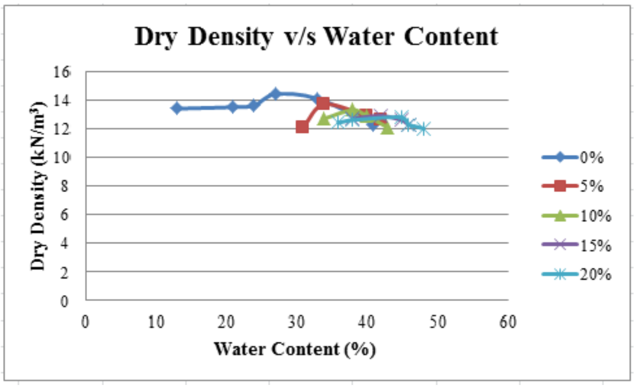

Fig. 4. Light compaction test results with different percentages of SF

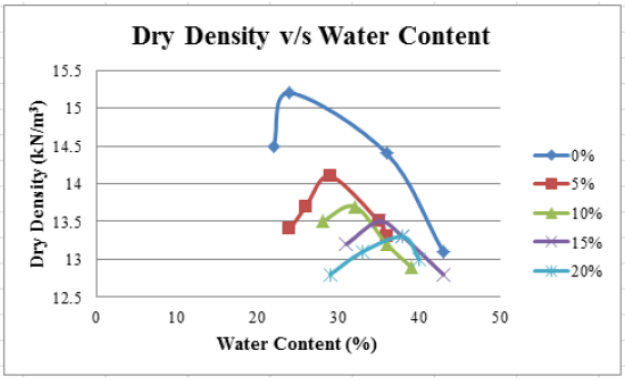

Fig. 5. Heavy compaction test results with different percentages of SF

5.2 UCC test results

The variations of unconfined compression (UCC) test values with water content are shown below. The strength of the untreated black cotton soil decreases with increasing molding water content. As the molding water content increases electrolyte concentration is reduced, leading to an increased diffused double layer expansion and the distance between clay particles as well as the distance between the alumina-silicate unit layers increases, resulting in a reduction of both the internal friction and cohesion [Ekrem Kalkana, 2004]. The unconfined compressive strength (UCS) of stabilized samples significantly increases with increasing silica fume content from 0% to 20%. However, after that, the unconfined compressive strength is slightly affected by additional silica fume content. The maximum unconfined compressive strength of the stabilized soil samples is found to be at the 15% silica fume content. The increase in the unconfined compressive strength is attributed to the internal friction of silica fume particles and chemical reaction between silica fume and soil. An increase in silica fume content in soil has made the stabilized soil samples more brittle than the natural soil samples, which is ductile as compared to all the stabilized samples. The unconfined compression test is widely used as a quick, economical method of obtaining the approximate compressive strength of the cohesive soils. The UCC test results for different compactive efforts are shown below.

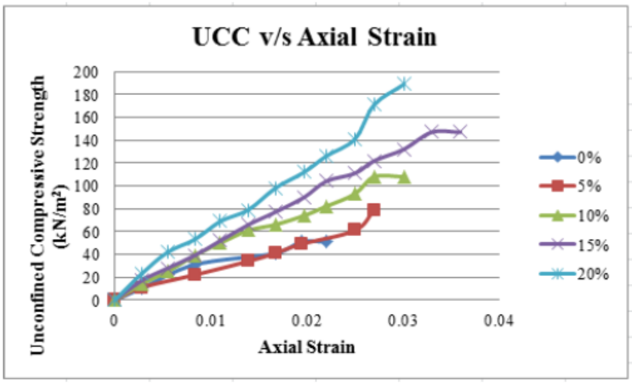

Fig. 6. UCS for reduced compaction test with different percentages of SF

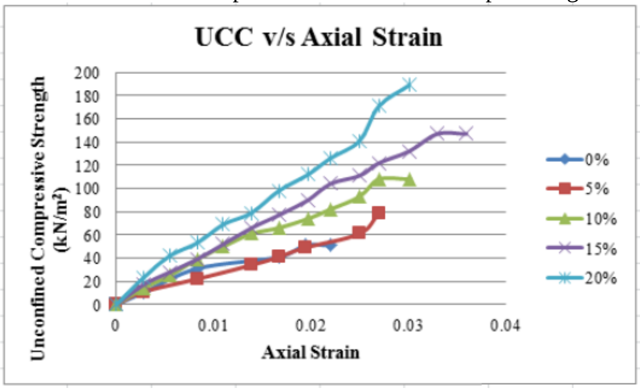

Fig. 7. UCS for light compaction test with different percentages of SF

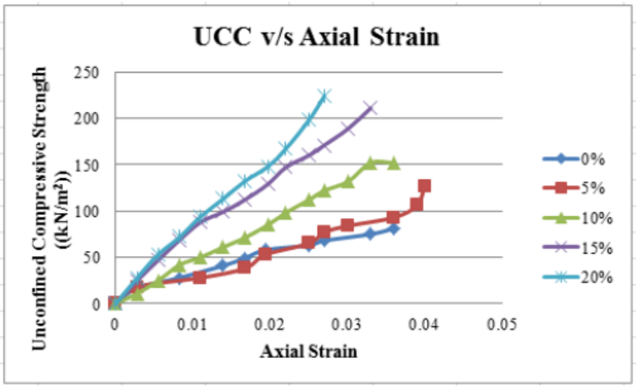

Fig. 8. UCS for Heavy compaction test with different percentages of SF

5.3 Effect of silica fume on Atterbergs Limits

The effects of silica fume on the consistency limits are given below. Liquid limit, Plasticity Index and Shrinkage limit values increased with increasing silica fume content for all stabilized samples. The plasticity index of soil decreases with increase in

SF content. The reason of this could be explained depending on the soil type, the relative amount of silicate clay mineral in the samples and associated exchangeable cations.

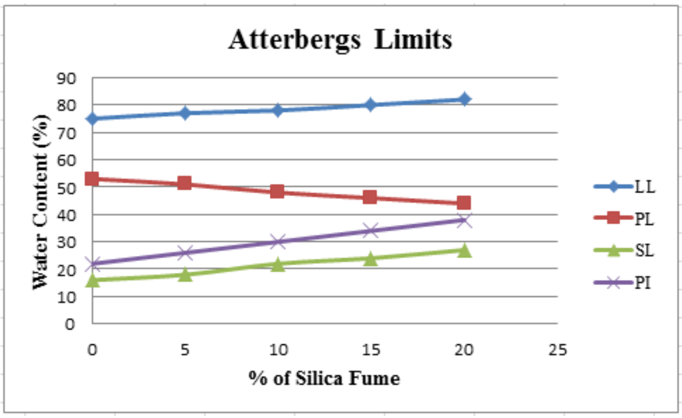

Fig. 9. Atterbergs Limits of black cotton soil with different percentages of SF

5.4 Effect of Silica Fume on Specific Gravity

The effect of silica fume content on specific gravity is presented in figure 10. It shows that as the silica fume content increases, the specific gravity of soil decreases .This indicates that the soil-silica fume mixture is lighter than that of the natural conditions because the silica fume fills the voids between soil particles.

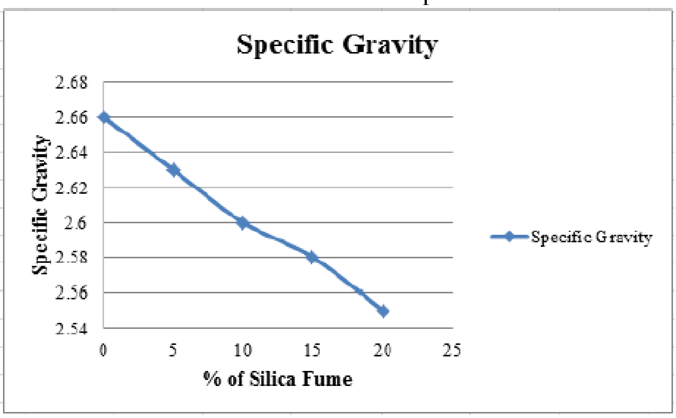

Fig. 10. Specific Gravity of black cotton soil with different percentages of SF

5.5 Effect of SF on VSS

The cracking do not likely occur in soil liners when compacted cylinders of the same soil undergo less than about 4% VSS upon drying. The most severe cracking occurred in specimens with the highest volumetric shrinkage strain The test results showed that, the natural clayey soil cracked severely, whereas the samples of soil-silica fume mixtures suffered little cracking. In each sample, it was observed that reduction in the development of desiccation cracks with 75% occurred with increasing silica fume content between 0 and 20%. So the addition of silica fume minimized the effects of volumetric shrinkage strain. When the compactive effort increases VSS values decreases. The results are shown in the table below.

Table 4. Effect on VSS of black cotton soil with different percentages of SF

Type of Compaction	0%	5%	10%	15%	20%
Reduced	42	27	11	6	4
Light	38	22	9	3	2
Heavy	32	19	7	2	2

5.6 Effect of SF on Coefficient of Permeability

Hydraulic conductivity is the key parameter affecting performance of liners and covers. The relationship between hydraulic conductivity and molding water content is shown in Fig 11. Generally the hydraulic conductivity obtained its lowest value on the wet side of compaction, conductivity values [Ekrem Kalkana, 2004]. The increasing molding water content facilitates deflocculating of the particle structure, reducing the void. At 15% SF treatment satisfactory hydraulic conductivity were obtained values indicating that SF has filled the air voids present in the black cotton soil. The increase in the permeability is attributed to the changes in soil sample structure due to particle rearrangements and the initiation of cracks. The Coefficient of permeability decreases with increase in compactive effort. The results are shown below:

Table 5. Coefficient of Permeability in cm/s for different compactive effort

Percentage of Silica Fume	Reduced Compaction	Light Compaction	Heavy Compaction
0	4.3E-07	1.6E-07	9.4E-08
5	9.4E-08	4.5E-08	1.2E-08
10	1.7E-08	6.5E-09	6.3E-09
15	4.9E-09	1.2E-10	5.7E-10
20	1.2E-09	0.6E-10	0.4E-10

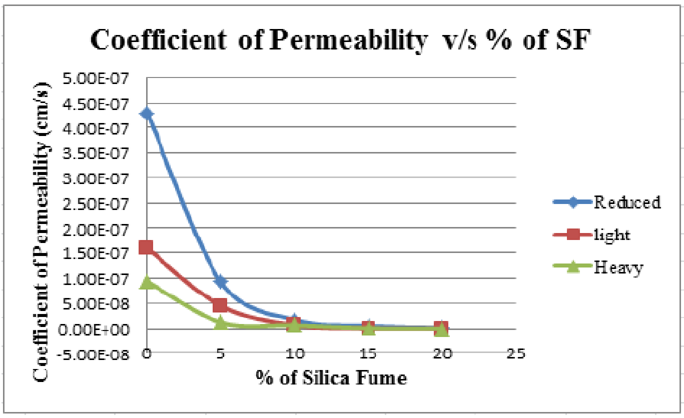

Fig. 11. Coeff. Of Permeability of Black Cotton Soil with various % of SF

5.7 Design of Overall Acceptable Zone

The design of liners and cover in waste containment facility involves arriving at a convergence of molding water content of three important design parameters. At this range of molding water content the regulatory specified values of the hydraulic conductivity, unconfined compressive strength and volumetric strain shrinkage must be met [David E. Daniel, 1990]. Thus, an overall acceptance zone of molding water content and maximum dry density satisfactory for all the design parameters is produced. The required design conditions are

1. Black cotton soil liners and covers should have hydraulic conductivities less than or equal to $1x10^{-9}$ cm/s
2. Volumetric shrinkage strain should not exceed 4%.
3. Compacted black cotton soil liners and covers should have adequate strength to ensure structural integrity.

4. Minimum unconfined compressive strength value of 200kN/m^2 defined as the lowest value for stiff clays was used.

Finally, the recommended overall acceptance zone that produced a convergence of the specification requirements of the three most important parameters for the design of liners and covers were achieved at15%SF and 20% SF treatment of black cotton soil at Heavy compactive effort, and at molding water content ranges of 35-40% and 38-43%

respective

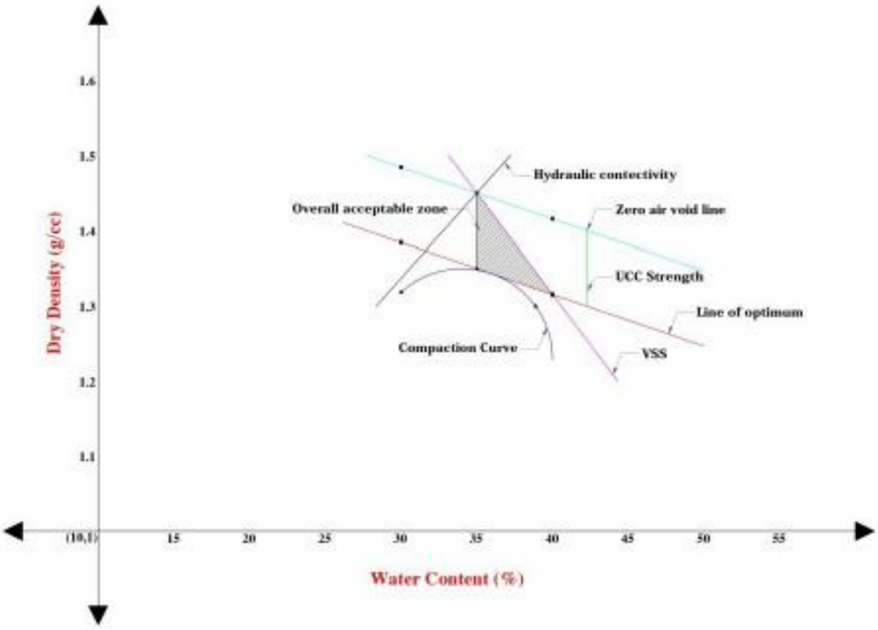

Fig. 12. Overall Acceptable Zone for 15%SF

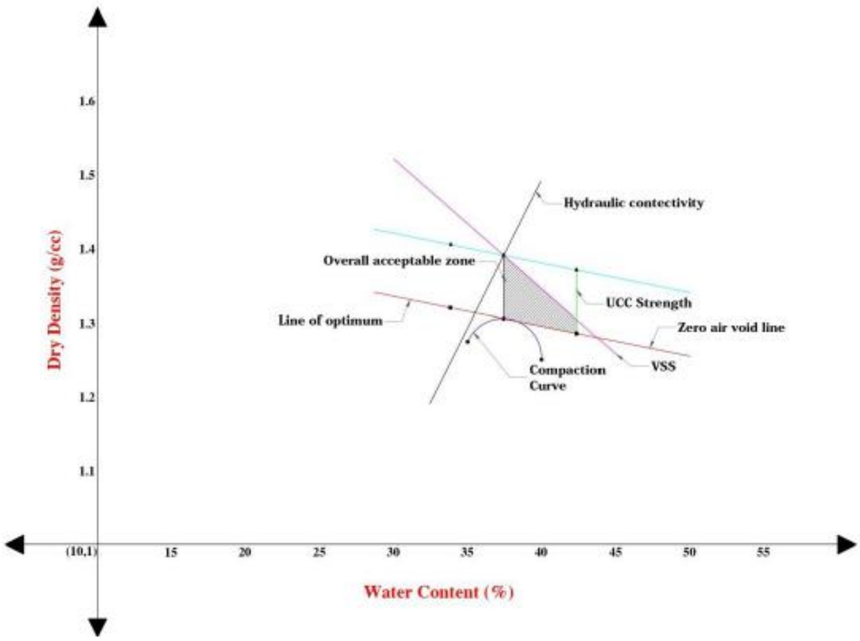

Fig. 13. Overall Acceptable Zone for 20%SF

6 Conclusions

1. There were changes in the index properties of the SF treated black cotton soils specimen. However, the MDD generally decreased with increasing SF content while the OMC increased with increasing SF content
2. Specimens were compacted at the energy levels of Reduced, Light and Heavy compactive effort in to determine a suitable acceptance zone for the three important parameters (Hydraulic conductivity, Unconfined compressive strength and volumetric shrinkage strain)
3. An assessment to produce a converging MDD and OMC that will produce covers and liner that meets the specification requirements of widely accepted standards of the three important parameters were designed
4. Hydraulic conductivity produced acceptable results at both light and heavy compactive efforts
5. Generally, a decline of hydraulic conductivity with increasing molding water content and increasing compactive energy level were observed
6. For the UCS, the result shows a general improvement in strength with increase in SF content. This is largely as a result of the pozzolanic input of SF which produced stronger bonds
7. Treated black cotton soil produced improved volumetric shrinkage strain values at both Light and Heavy compactive efforts. the minimum VSS values were achieved at 15% SF for Heavy and 20% for heavy and light compactive effort.
8. Finally, the recommended overall acceptance zone that produced a convergence of the specification requirements of the three most important parameters for the design of liners and covers were achieved at15% SF and 20% SF treatment of black cotton soil at Heavy compactive effort, and at molding water content ranges of 35-40% and 38-43% respectively.

References

1. Arora, K. R, Soil mechanics and foundation Engineering, Standard publishers Delhi. (2008).
2. A. Naseem et.al., Stabilization of expansive soil using tire rubber powder and cement kiln dust,Soil Mechanics and Foundation Engineering, Springer Science+Business Media, LLC Vol-14, 105-113,(2016).
3. Benson, C., Hardianto, F., and Motan, E., Representative specimen size for hydraulic conductivity assessment of compacted soil liners, ASTM STP 1142, 3–29,(1994).
4. Benson, C., and Boutwell, G., Compaction control and scale dependent hydraulic conductivity of clay liners,Proc., 15th Annu. Madison Waste Conf., University of Wisconsin, Madison, 62–83,(1992).
5. Braja M. Das, Principles of foundation Engineering, Tata McGraw- Hill Publishing company Limited, 7th Edn, (2011).
6. Blotz, L., Benson, C., and Boutwell, G., Estimating optimum water content and maximum dry unit weight for compacted clays, J.Geotech. and Geoenvir. Engrg, ASCE, 124(9), 907–912,(1998).
7. Brian A. Albrecht et.al., Effect of Desiccation on Compacted Natural Clays, Journal of Geotechnical and Geoenvironmental Engineering, ASCE,Vol-127, 67-80,(2001).
8. Craig H. Benson et.al.,Field Performance of Compacted Clay Liners, Journal of Geotechnical and Geoenvironmental Engineering, ASCE Vol-125, 390-403,(1999).

9. Craig H. Benson et.al., Estimating Hydraulic Conductivity of Compacted Clay Liners, Journal of Geotechnical Engineering, ASCE Vol-120, 386-400,(1994).
10. David E. Daniel et.al., Water Content-density Criteria for Compacted Soil Liners, Journal of Geotechnical Engineering, ASCE Vol-116, 1811-1830,(1990).
11. Daniel, D., and Wu, Y., Compacted clay liners and covers for arid sites, J. Geotech. Engrg, ASCE, 119(2), 223–237,(1993).
12. Dr. Adel A. Al-Azzawi et.al., Journal of Engineering and Development, ResearchGate Vol-16, 90-105,(2011).
13. Ekrem Kalkana et.al., The positive effects of silica fume on the permeability, swelling pressure and compressive strength of natural clay liners, Journal of Engineering Geology, Science direct, Vol-73, 145-156,(2004).
14. F.O.P. Oriola et.al., Compacted black cotton soil treated with cement kiln dust as hydraulic barrier material, American Journal of Scientific and Industrial Research, Vol-2(4), Pg 521-530,(2011).
15. George Moses et.al., Desiccation-induced volumetric shrinkage of compacted metakaolin-treated black cotton soil for a hydraulic barriers system, Slovak Journal of Civil Engineering Vol-24, 1-5,(2016).
16. IS: 2720 (Part IV)-1985, Specification for Grain Size Analysis, Bureau of Indian Standards, New Delhi.
17. IS: 2720 (Part III)-1980, Determination of Specific Gravity of Soil, Bureau of India
18. IS: 2720 (Part II)-1973, Determination of water content of Soil, Bureau of Indian Standards, New Delhi.
19. Kawther Al-Soudany et.al., Remediation of Clayey Soil Using Silica Fume, MATEC Web of Conferences 162, 1-7,(2018).