Desiccation Cracking Behaviour of Landfill Clay Liner Materials

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ABSTRACT : Due to formation of shrinkage cracks in landfill clay liners in dry zone of Sri Lanka leads to infiltration of leachate into ground during the rainy season. Therefore, in this research study, shrinkage behaviour of expansive soil available in dry zone of Sri Lanka, which is used to develop compacted clay liners, were evaluated using laboratory desiccation plate tests. Digital image processing technique has been used to determine the Crack Intensity Factor (CIF), which is the ratio of crack area to total surface area. Higher desiccation rate was observed for smaller thickness of soil specimen. In addition, higher CIF was recorded for the bentonite and oleic acid amended soil. It was noted that shrinkage cracks can be significantly controlled by amending soil with coconut coir fibres.

1 INTRODUCTION

Solid waste, especially Municipal Solid Waste (MSW), is a growing problem in urban areas of Sri Lanka and management of waste, both liquid and solid has become a critical environmental concern. The absence of engineered methods for disposing waste and the open dump approach adapted has created major environmental and social problem of waste within most of the cities. Especially, the attention given to the solid waste management in dry zone of the country is very less due to the fact that almost all major cities in Sri Lanka are situated in wet zone. However, solid waste management in dry zone is very important as people in this area depend very much on ground water for their drinking purposes and therefore, the contamination of ground water especially by the leachate generated in waste disposal sites should be kept at a minimum by following engineered waste disposal methodologies.

Engineered landfilling is one of the best options to overcome the problems associated with contamination of ground water with leachate. The liner system in an engineered landfill acts as a barrier for leachate and prevents the transportation of contaminants to the surrounding pollution prone environment. Hence liner system in a landfill becomes one of the critical design considerations. A landfill liner is intended to be a low permeable barrier which is generally involves with the application of clay or synthetic material layer. Since, synthetic materials are very expensive, Compacted Clay Liners (CCL) is the most suitable liner system for developing countries (Priyankara et al, 2013).

However, it was realized that a lot of cracks have been developed during the dry season in most of the clay liners in dry zone of Sri Lanka. This is basically due to the shrinkage behaviour of landfill liner material, which leads to infiltration of leachate into the ground during the rainy season. Thus, there is a possibility of contamination of ground water in this area due to development of shrinkage cracks in compacted clay liners.

Shrinkage cracking is a complex phenomenon in soil. It is a natural process involving weathering, chemical and biological changes. Shrinkage cracks significantly affect the soil performance. Cracks create zones of weakness in soil and reduce its overall strength and stability. Occurrence of shrinkage cracks may due to several factors, such as clay content, mineralogy, soil thickness, surface configuration, rate of drying and total drying time etc (Alvis and Marcelo, 2011).

Even though a lot of shrinkage cracks have been recorded in landfill clay liners in dry zone of Sri Lanka, so far no research has been conducted in order to control the shrinkage cracks. As such, in this research study, an attempt was made to study the shrinkage behaviour of clay which is commonly available in dry zone of Sri Lanka. Laboratory desiccation plate test was used to study the shrinkage behaviour of clay and by applying digital image processing technique, geometric and kinematic characteristics of the surface crack patterns were described quantitatively.

2 MATERIALS AND METHODOLOGY

2.1 *Materials*

In order to study the shrinkage behaviour of clay available in dry zone of Sri Lanka, soil samples were collected from Buttala area.The physical properties of the soil are presented in Table 1. It was found that soil is medium swelling potential material and rich of illite mineral, which makes the soil highly attracted to absorb water causing expansion of the material. These kinds of soil develop significant change of volume during drying.

Table 1. Physical properties of soil

Property	Value
Liquid Limit (LL)	35 %
Plastic Limit (PL)	20 %
Plasticity Index (PI)	15 %
Linear Shrinkage (LS)	3.9 %
Sand Content	58 %
Silt Content	14 %
Clay content	28 %
Maximum Dry Unit Weight	17.5 kN/m^3
Optimum Moisture Content	15.5 %
Specific Gravity	2.56

2.2 *Desiccation plate test*

Four number of circular type desiccation moulds with diameter of 20 cm were prepared using Perspex sheets. The thicknesses of the mould were 5 mm,10 mm, 20 mm and 50 mm. Soil has been air dried and sieved through 0.425 mm sieve to prepare the sample. The test sample was prepared by mixing sieved soil with water in such a way that initial water content of the soil is slightly higher than the liquid limit of the soil. Then samples have been manually placed into the moulds using a spatula. Samples were placed in the moulds by ensuring that air is not entrapped within the soil layers. Then samples were allowed to air-dry under room temperature. The weight of the samples was recorded at predefined intervals (1 hourly). At the same time, high resolution digital camera has been mounted at top of the setup to capture pictures at predefined intervals(1 hourly). Hence, crack initiation time, crack propagation information and crack pattern were investigated.

According to Priyankara et al, 2013, engineering properties of soil can be improved by the addition of commercially available bentonite to build a low hydraulic conductivity barrier in engineering landfills. Therefore, a series of tests have been carried out with unamended soil and soil amended with 5 % and 10 % of bentonite in order to study the shrinkage behaviour of proposed liner materials. Further, the effects of oleic acid and coconut coir fibres on control of shrinkage behaviour were studied using desiccation plate tests. The bentonite amended soils were mixed with oleic acid (1g of oleic acid per 1kg of soil) and with coconut coir fibres (5% by volume) in this research study.

3 RESULTS AND DISCUSSION

3.1 *Soil-water evaporation process*

In order to study the soil-water evaporation process, variation of soil moisture content with time for different sample thicknesses are presented inFig. 1. The experimental results indicate that all samples have similar initial moisture content, which is slightly above the liquid limit of the soil. It can be seen that moisture content has been decreased with time irrespective sample thickness. A significant reduction of moisture content can be observed in thinner samples (5 mm and 10 mm). Further, it can be noticed that thinner samples have been reached to constant moisture content with time. The 5 mm thick sample has been reached to constant moisture content before that of other samples. This behaviour can be further explained using soil-water evaporation rate.

The variation of soil-water evaporation rate with time for different sample thicknesses are illustrated in Fig. 2. Based on the data presented, two evaporation stages can be easily identified irrespective of sample thickness, namely;

(a) Initial constant evaporation stage
(b) Falling evaporation stage

This evaporation behaviour can be explained with respect to the heat and mass flow between soil and air (Tang et al, 2011). Based on the test results as shown in Fig. 2, it can be noted that thinner sample has a higher soil-water evaporation rate than that of others. The moisture in the deeply seated pores can be easily drawn to surface when the sample is thinner; as a result higher evaporation rate can be expected. In addition, soil-water content has been gradually diminished with time(Fig. 1) and soil suction has been increased under constant evaporation rate. The constant evaporation rate period has come to an end once the Air Entry Value (AEV) is reached. It can be seen that all samples have the same AEV (9%) irrespective of the sample thickness as AEV is a property of the material. However, when the sample is thicker, it takes longer time to reach to the AEV. At this point, air starts to penetrate into the soil pore spaces due to increase of suction, as a result soil transition from a saturated state to an unsaturated state.

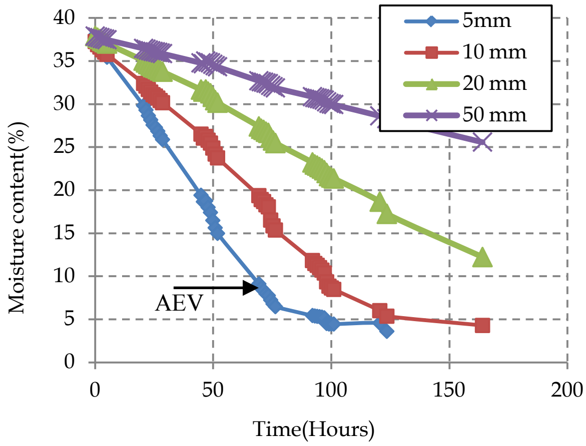

Fig. 1 Variation of moisture content with time with respect to different sample thicknesses

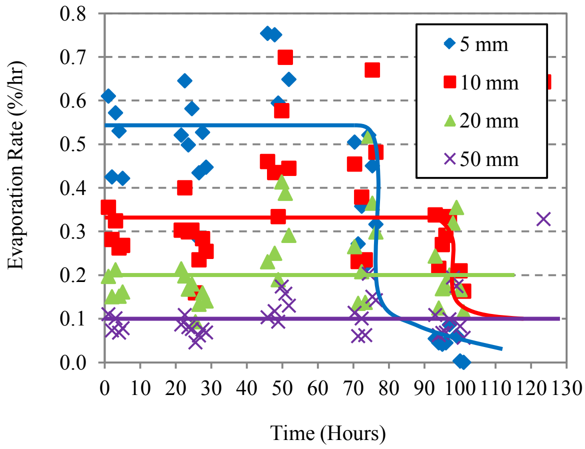

Fig. 2 Variation of evaporation rate with time

3.2 *Quantitative analysis of shrinkage cracks*

In order to quantitatively evaluate the development of shrinkage cracks during drying, a term Crack Intensity Factor (CIF) was defined, which is the ratio of crack area to total surface area. The variation of CIF with time for unamended soil is depicted in Fig. 3. It can be seen that CIF has been increased with time in thinner samples. However, there was no shrinkage cracks have been developed in 20 mm and 50 mm thick samples during the test period. Based on these observations, it can be concluded that development of shrinkage cracks are highly depended on the sample thickness; thicker the sample lesser the crack area.

In order to study the effect of moisture content on development of shrinkage cracks, CIF has been plotted against moisture content as shown in Fig. 4. The figure clearly illustrated that CIF has been increased with the decrease of moisture content irrespective of sample thickness. It can be noted that under particular moisture content, CIF is same for both 5 mm and 10 mm samples. This implies that even though thinner samples have higher desiccation rate, crack area is directly proportional to the moisture content of soil. Based on these observations it can be concluded that cracks have been developed irrespective of the Compacted Clay Liner (CCL) thickness. However, if the CCL is thicker, the crack development rate is less. Also by controlling the moisture present in the soil, crack development rate can be controlled.

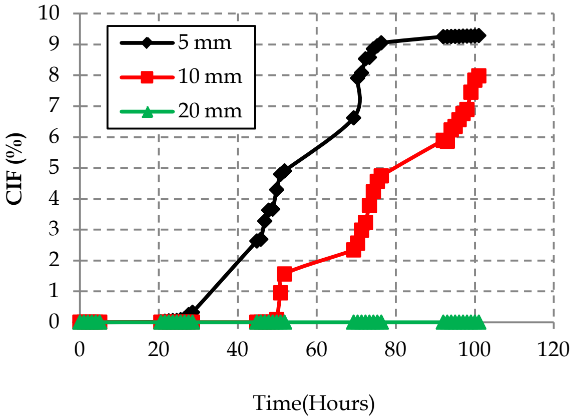

Fig. 3 Variation of CIF with time

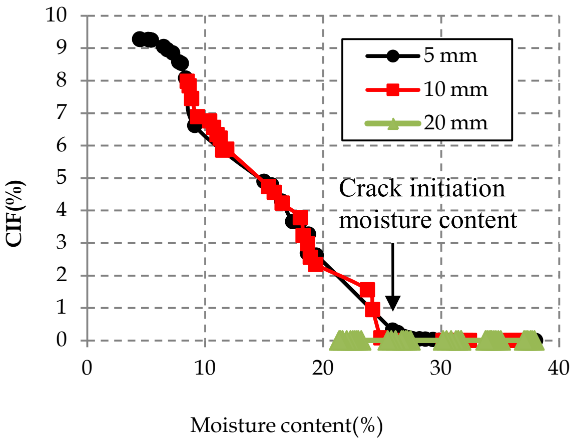

Fig. 4 Variation of CIF with moisture content

3.3 *Effect of Bentonite on shrinkage behaviour*

Since bentonite has been successfully utilized to improve hydraulic characteristics of CCL material (Priyankara et al, 2013), it is very important to investigate the effect of bentonite on shrinkage behaviour of clay liner material. The variation of CIF with time for 5 mm thick sample is presented in Fig. 5. It can be seen that CIF has been increased with the bentonite content. With the increase of bentonite, which mainly consists of montmorillonite mineral, the diffused double layers surrounding the clay particles are getting thicker. The diffused double layers create repulsive forces along the sides of the clay particles making it difficult for individual clay particles to stay closer to each other. As a result, cracks can be developed.

Further, based on image analysis, it was noted that when a new crack is propagating close to an existing crack, the new crack is attracted by the existing crack towards it, and new crack is at right angle to the existing crack. As a result, the final crack pattern is mostly square shaped clods.

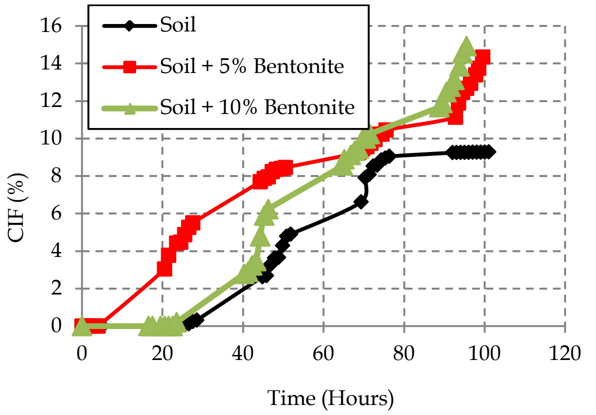

Fig. 5 Variation of CIF with bentonite content

3.4 *Effect of Oleic acid and Coconut coir fibres on shrinkage behaviour*

In order to reduce the shrinkage behaviour of clay liner material, oleic acid and coconut coir fibres were used in this research study. Oleic acid is a product of olive oil, and which is an environmental friendly product. The effect of oleic acid and coconut coir fibres on shrinkage behaviour is presented in Fig. 6. Even though oleic acid was added to control the shrinkage behaviour, it can be seen that with the addition of oleic acid, shrinkage behaviour of soil has been significantly increased. However, it is very clear that development of shrinkage cracks have been significantly reduced with the addition of coconut coir fibres. Coir fibres act as reinforcements and resist the tensile stresses to develop during soil-water drying process, as a result crack formation can be reduced. In other words, due to inclusion of coconut coir fibres into soil, plasticity characteristics of soil gets reduced controlling the volume change behaviour of soil.

4 CONCLUSIONS

Based on laboratory experimental results, it can be concluded that,the soil-water evaporation process composed of two stages namely initial constant evaporation stage and falling evaporation stage. Thinner samples have higher soil-water evaporation rate than that of others. During soil-water evaporation process, the constant evaporation rate period comes to an end once the moisture content of the soil reaches to AEV of the soil, at which soil transition from saturate state to unsaturated state. All samples have the same AEV irrespective of the sample thickness. However, when the sample is thicker, it takes longer time to reach to the AEV.

Desiccation cracking highly depends on the moisture presence in the soil. Formation of desiccation cracking is increased with the decrease of moisture content irrespective of sample thickness. This indicates that development of desiccation cracks in CCL can be minimized by increasing the liner thickness. In addition, coconut coir fibres can be effectively used to control the desiccation cracking behaviour of CCL.

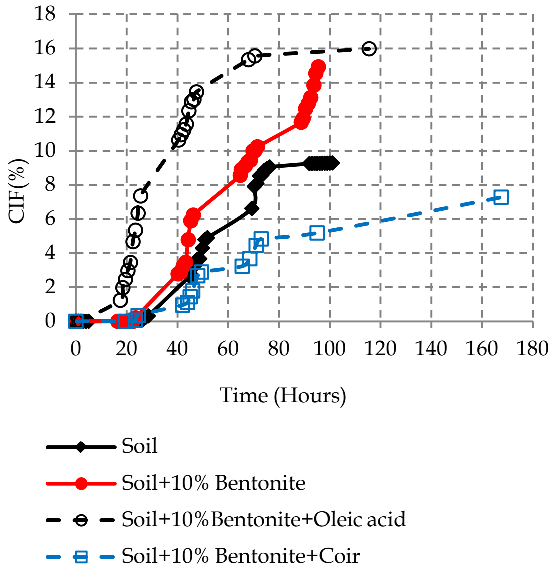

Fig. 6 Effect of oleic acid and coir on CIF

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