Analysis of Cracking Behavior of Composite Landfill Liners

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ABSTRACT: This study aims to quantify the cracking behaviour of composite landfill liners easily, quickly and in better mode using image analysis technique. The disturbed soil samples were collected from a selected waste disposal site at Rajbandh, Khulna, Bangladesh. The mixing proportions of 10, 20, 30, 40, 50 and 60% of brick dust as well as 20, 30, 40, 50, 60 and 70% of fly ash by dry weight with soil samples were used to prepare composite liners. Steel circular molds having 30 cm diameter with different thicknesses of 10, 20 and 30 mm were used. The amount of water content equal to liquid limit, plastic limit and optimum moisture content of mixing soil were considered. The wetting-drying cycles were subjected on specimens to simulate the field behavior of liners. The cracking behaviour such as crack intensity factor (CIF), crack density factor (CDF) and crack areas were measured through MATLAB and ImageJ technique. The maximum CIF, CDF and crack area were obtained in control soil. The CIF, CDF and crack area decreases with the increase of fly ash and brick dust content in liners. Result reveals CIF, CDF and crack area increase with the increase of water content. The liners with water content equal to liquid limit showed maximum CIF, CDF and crack area. Moreover, the CIF and crack area decrease with the increase of specimen thickness except for CDF. With the multiple wetting-drying cycles experiment, the amount of cracking did not significantly change after 2nd wetting-drying cycle.

KEYWORDS: Composite liners, Desiccation, Cracking behavior, ImageJ, MATLAB.

1. INTRODUCTION

The cap and base liners in landfill are required to reduce leachates from municipal solid waste (MSW) and protect surrounding environment, including groundwater, surface water and underlying soils (Rafizul and Alamgir, 2012). It is very important to design of base and cap liners appropriately in landfill for manage contaminated leachate that is generated from decomposed MSW in landfills (Carey et al., 2000). The characteristics of clay soil used for liners can be highly compromised when desiccation cracks start to propagate through soil. If surficial tensile stress exits, soil tensile strength and volumetric shrinkage become constrained, desiccation cracks promote its geometrical characteristics (Noman and Rafizul, 2021). Besides, temperature, confining pressures, moisture and density conditions, and wetting and drying cycles are also responsible for the formation of cracks in liners. In addition, the orientation of particles, colloidal content and the type and amount of exchangeable cation in the pore fluid also affects the cracking characteristics of soil (Singh et al., 2017). According to Daniel (1995), for any admixtures that are used as landfill liners, it should be low permeability i.e. $k < 10^{-9}$ ms^{-1}, the soil used as composite soil should have at least 30% fines, the plastic limit should be less than moisture content, plasticity index should be greater than 7%.

The commonly used admixtures to prepare composite landfill liners with soil such as cement, sand, lime, brick dust, bentonite, fly ash, etc. The addition of fly ash, brick dust, sand and cement content in soil helps to reduce the intensity of cracks and shrinkage. Mahajan and Parbat (2015) used fly ash with soils to investigate the effect of fly ash content on the plasticity, compaction properties, cracking behaviour, etc., of composite soils. Another researcher Tiwari and Prasad (2018), used brick dust with lime to study their combined effect on engineering properties of composite soil.

Cracks reduce the overall strength and stability of soil by creating a weak zone in soil mass (Yisiller et al. 2000). The crack formation also depends on surface configuration, soil thickness, rate of drying and wetting, etc. The propagation, initiation and impact of cracks on the geoengineering properties are needed to know for a better understanding of the cracking and shrinkage phenomenon. To achieve this objective, an accurate method for quantifying shrinkage and crack intensities is needed, along with the parameters that influence the same.

Nowadays, image-based techniques are gaining popularity to quantify crack development and characterization of landfill liners. In this context, the studies of Peng et al. (2006), Lakshmikantha et al. (2009), Auvray et al. (2014), Tiwari (2015) and Singh et al. (2017) are worth mentioning. With the help of this study, cracks are quantified in the form of CDF and CIF. Singh et al. (2017) defined CIF which is the ratio of crack area to the total surface area of a drying soil specimen. According to Lakshmikantha et al. (2009), CDF is the ratio of the summation of crack and shrinkage area to the initial specimen area. If directly measure the cracks parameters, larger error will fabricate in the actual result due to the irregular length, width, depth and shape of cracks as well as shrinkage (Tang et al., 2016).

In this present study, commonly available admixtures such as fly ash and brick dust were used to prepare composite landfill liners at varying mixing proportions. A MATLAB code was developed to quantify the behaviour of cracks in composite landfill liners. In addition, ImageJ and MS excel were also used to determine other relevant parameters so that geometrical characteristics of cracks can be easily described. The geometric parameters in terms of CIF were determined from MATLAB coding. In addition, the other features such as total CDF and crack area were measured based on ImageJ software and MS excel. In addition, the variation of CDF, CIF, and crack areas in relation to the changes of mixing water content in terms of liquid limit, plastic limit and optimum moisture content as well as liner thickness were investigated.

2. STUDY AREA

In this study, soil samples used to prepare composite landfill liners were collected from a waste disposal site at Rajbandh, Khulna, Bangladesh, which is approximately 20 km away from Khulna city.

Khulna is a district among the total of 64 districts in Bangladesh. Khulna city is in the northern part of the district, acknowledged as the third largest among the ten metropolitan cities of Bangladesh. Geographically, Khulna lies between 22°47'16" to 22°52'0" north latitude and 89°31'36" to 89°34'35" east longitude. This city on the Rupsha and Bhairab is by river-banks. At present, the city covers an area of 45.65 km^2 with a population of about 1.5 million (Rafew and Rafizul, 2021). The MSW of Khulna city is dumped in the Rajbandh disposal site to accumulate and dispose of it in the landfill. Therefore, open disposal site at old Rajbandh is chosen to collect soil for the experimental test. This site was selected because this is only an official open dumping site in Khulna city and for daily covering, the available soils at this site is used. Moreover, as this study aims to analyze cracking behaviors of liners that are used in landfill, the used soil samples were collected from this site. Figure 1 depicts the location of the waste disposal site at Rajbandh, Khulna, Bangladesh.

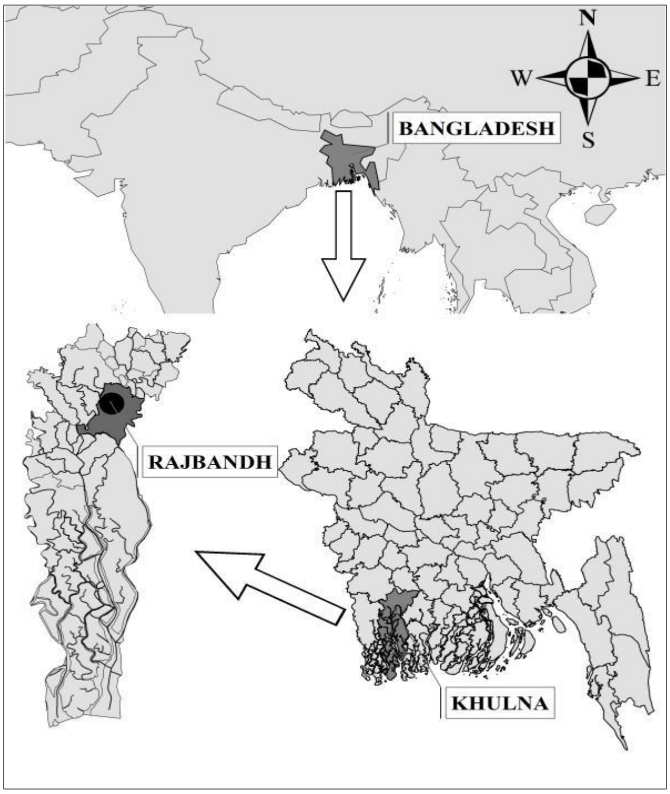

Figure 1 Location map of soil sampling disposal site at Rajbandh, Khulna city of Bangladesh

3. MATERIALS AND METHODOLOGY ADOPTED

3.1 Collection of Soil Samples

In this study, soil samples were collected from a waste disposal site at Rajbandh, Khulna, Bangladesh. The soil samples were first air-dried by oven and then powdered. The powdered samples were then sieved No. 4 and then the sieved samples were used to prepare composite liners. In the laboratory, the physical and index properties of soils were measured through the standard test methods. The values of initial moisture content, optimum moisture content, maximum dry density, specific gravity, liquid limit, plastic limit, plasticity index, shrinkage limit, sand, silt and clay were 37.65%, 20%, 1.59 gm/cc, 2.61, 54%, 31%, 23% and 35.11%, 4.6%, 64.7%, 30.7%, respectively.

3.2 Collection of Additives

To prepare composite landfill liners, different types of commonly used admixtures like fly ash (FA) and brick dust (BD) were collected from local market. In this study, FA and BD passing through 4 no. sieve were used. In the laboratory, the physical and index properties of admixtures were measured through the standard test methods. The values of optimum moisture content, maximum dry density, specific gravity and liquid limit of FA were found 34%, 1.52 gm/cc, 2.23 and 42.6%, respectively. In addition, the values of optimum moisture content and maximum dry density of BD were found 31%, and 1.46 gm/cc, respectively.

3.3 Preparation of Composite Liners

Experimental work was carried out by mixing of FA and BD separately with air dried soil samples in different mixing proportions. The mixing proportions of 20, 30, 40, 50, 60 and 70% of FA with soil were used to prepare composite landfill liner. Moreover, mixing proportions of 10, 20, 30, 40, 50 and 60% BD by dry weight with soil was used to prepare composite landfill liner.

In this study, to prepare soil slurry with different admixtures at varying mixing proportions, three different water content in terms of optimum moisture content (OMC), plastic limit (PL) and liquid limit (LL) of mixing composite soil were considered to ensure a uniform paste. A researcher Tiwari (2015) prepared composite liners with bentonite and fly ash at different percentages with distilled water at three water content in terms of OMC, PL and LL. In this study, for preparing composite liners with water content, the statement postulated by Tiwari (2015) was followed. The mixing soil pastes were kept in air-tight polythene bags for 2 hours due to uniform water absorption in wooden chamber. In this study, the diameter of steel circular mold of 30 cm was used. In addition, thickness of liners of 10, 20 and 30 mm were considered to prepare composite landfill liners.

3.4 Drying and Image Taking Process

After the preparation of composite liners, the desired amount of composite slurry was poured in mold and kept the mold in the wooden chamber, where six heat lamps of 100 W light bulbs were connected. For this system, desiccation crack would be formed due to evaporation of water from liner specimens shown in Figure 2. In this stage, it was ensured that each specimen could get equal heat. Moreover, a thermometer was connected to the chamber to measure the variation of temperature in a regular basis and the temperature was found approximately 38 ºC (Figure 2(a)). During the drying process, a digital camera (Nikon COOLPIX S2900) which was mounted at the top of sample soil through steel made camera stand, was used to take images of dying sample. 1.5 feet of constant height was always maintained for taking images of one-day interval shown in Figure 3.

3.5 Wetting and Drying Cycles

Initially, all soils were subjected to two cycles: a drying cycle and a wetting–drying cycle. Three cycles of wetting and drying were subjected on the prepared composite soil to simulate the field behaviour of liners in landfills. In the drying cycle, the formation of cracks was constant for both liners after seven days (168 hrs). After the end of first drying cycle with constant crack area at 168 hrs for both liners, desired amount of water was applied to start a wet cycle. In wetting cycle, approximately 250 ml/day of water for 4 days was used through spraying nozzle to simulate the percolation behaviour of clay shown in Figure 4. In wetting cycle, developed cracks became zero for both liners after 4 days. For this reasons duration of drying cycle was 7 days and that of the wetting cycle was 4 days.

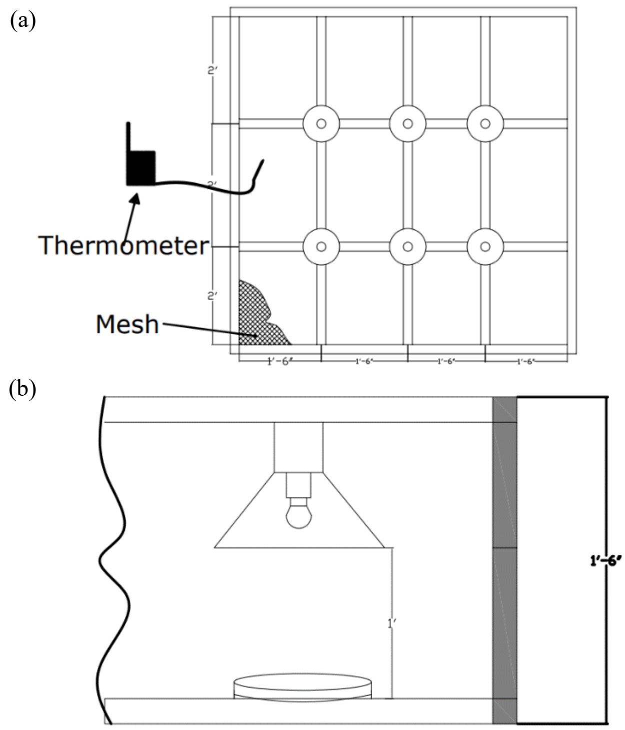

Figure 2 (a) Chamber system for drying of soils (top view) and (b) Chamber system for drying of soils (sectional view)

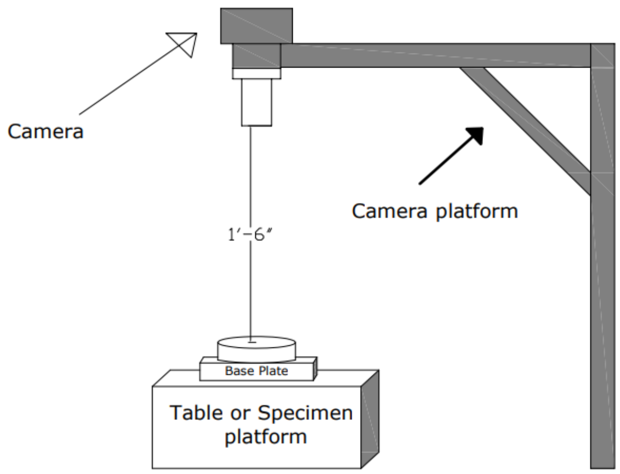

Figure 3 Camera setup for taking image

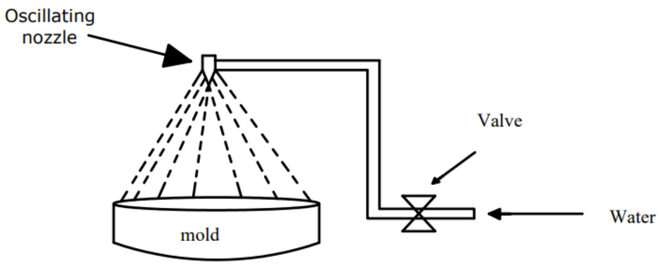

Figure 4 Spraying nozzle setup for spraying

3.6 Image Processing

Extraction of meaningful information from digital images clicked by a digital camera by means of image processing is known as image analysis which is performed in two basic steps.

The first step involves image processing, in which the image is prepared in various stages for further analysis. This includes cropping the unnecessary part of RGB image and then to a binary (black and white) image obtained by thresholding the RGB image shown in Figure 5 and Figure 6, respectively. The second step consists of the analysis of the processed image obtained from step 1 to calculate the parameters that characterize the CIF, total area of cracks and CDF.

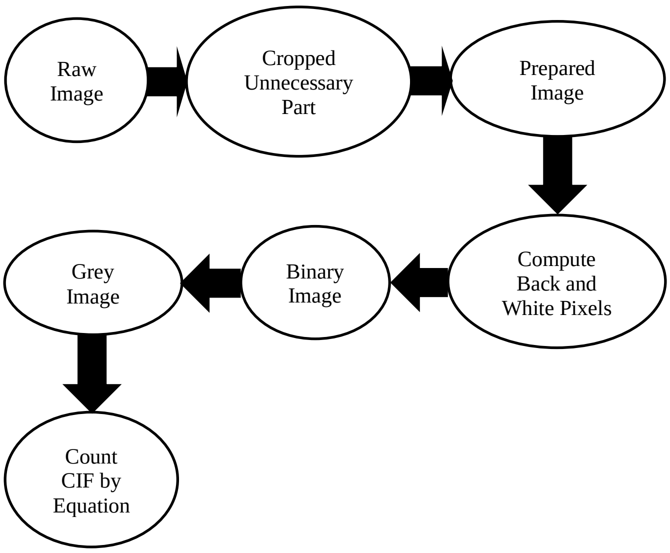

Figure 5 Flow chart of image processing

3.7 Image Analysis

RGB Image obtained from the camera was analyzed in MATLAB to gain some important information. MATLAB program was developed in such a way that it counts only the area of black pixels in the image of composite liners. These black pixels show the cracked area. In addition, summation of black pixels and white pixels was also calculated. Then set a program in MATLAB of the ratio of black pixels to the summation of black and white pixels which is known as CIF using the following Eq. (1). To determine other parameters ImageJ and MS excel software were used. For the determination of the diameter of reduced specimen, some known distance in the image like the diameter of mold is marked by straight line and scale is set in ImageJ by going to the option Analyse - Set Scale – give value 30 cm. In the same image length of the reduced specimen was calculated by measure command (Analyze – measure). Other parameters like total area of cracks were calculated through Microsoft excel. In addition, the value of crack density factor (CDF) was computed using Eq. (2).

$$CIF\ (\%) = \frac{Crack\ area * 100}{Reduced\ specimen\ area} \quad (1)$$

$$CDF\ (\%) = \frac{(Crack\ area + shrinkage\ area) * 100}{Reduced\ specimen\ area} \quad (2)$$

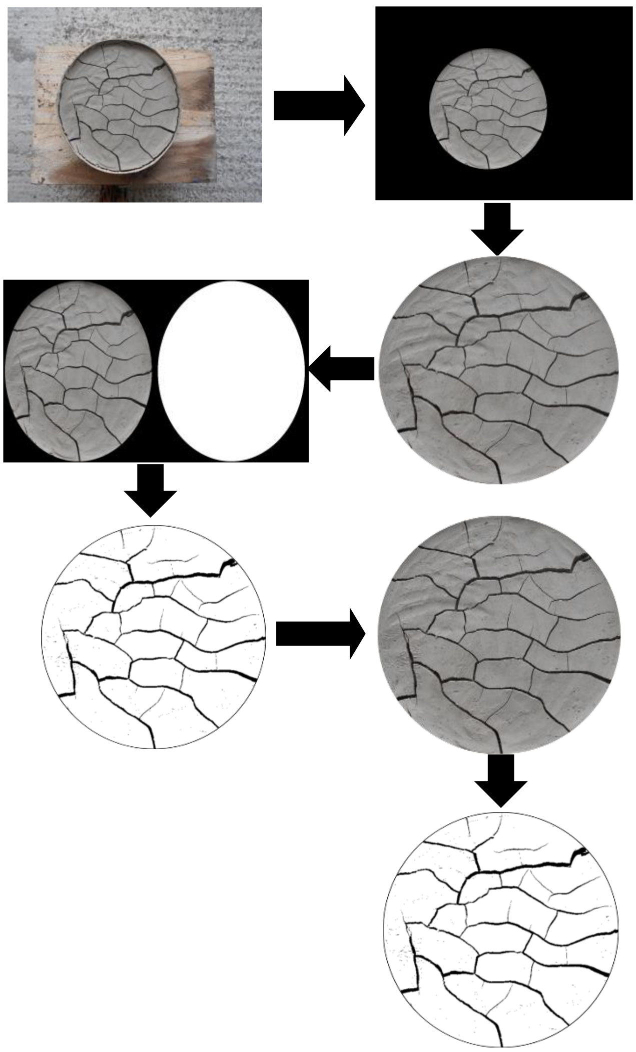

Figure 6 Image processing and analysis of a composite liner (20% fly ash with soil of 30 mm thickness at water content equal liquid limit)

4. Results and Discussion

The effects of liner thickness, mixing water content, drying and wetting cycles, Atterberg's limits, compaction properties and cracking behaviour of liners were analysed and hence discussed in the following articles.

4.1 Atterberg's Limit

The variation of Atterberg's limit in terms of liquid limit (LL), plastic limit (PL) and plasticity index (Pl) of composite soil with FA and BD are revealed in Table 1 and Table 2, respectively. From following figures, it was observed that LL, PL and PI of composite soil decreases with the increasing of admixture content like FA and BD. The value of LL for 10% BD was 52% and reduction of LL for 20, 30, 40, 50 and 60% BD were found 51, 49, 47, 46 and 43%, respectively (Table 2). In addition, LL for 20, 30, 40, 50, 60 and 70% FA were 53, 52 51, 49, 48 and 46%, respectively (Table 1). PI with 10, 20, 30, 40, 50 and 60% BD were 21.47, 20.96, 19.58, 18.23, 17.91 and 15.62%, respectively. In addition, PI with 20, 30, 40, 50, 60 and 70% FA were 22.89, 22.45, 21.57, 20.14, 19.68 and 17.98%, respectively (Table 1). The PL for 20, 30, 40, 50, 60 and 70% FA were found 30.11, 29.55, 29.43, 28.86, 28.32 and 28.02%, respectively. Moreover, PL of 10, 20, 30, 40, 50 and 60% BD were found 30.53, 30.04, 29.42, 28.77, 28.09 and 27.38%, respectively (Table 2).

Table 1 Atterberg's limits of soil slurry with fly ash

Soil slurry with fly ash (%)	Liquid limit (LL) (%)	Plastic limit (PL) (%)	Plasticity index (PI) (%)
S100, FA0	54	31	23
S80, FA20	53	30.11	22.89
S70, FA30	52	29.55	22.45
S60, FA40	51	29.43	21.57
S50, FA50	49	28.86	20.14
S40, FA60	48	28.32	19.68
S30, FA70	46	28.02	17.98

Table 2 Atterberg's limits of soil slurry with brick dust

Soil slurry with brick dust (%)	Liquid limit (LL) (%)	Plastic limit (PL) (%)	Plasticity index (PI) (%)
S100, BD0	54	31	23
S90, BD 10	52	30.53	21.47
S80, BD 20	51	30.04	20.96
S70, BD 30	49	29.42	19.58
S60, BD40	47	28.77	18.23
S50, BD50	46	28.09	17.91
S40, BD60	43	27.38	15.62

4.2 Compaction Characteristics

The variation of dry density in relation to the changing of moisture content of stabilized soil with FA and BD are presented in Figure 7 and Figure 8, respectively. The following figure clarifies that with increasing percentages of FA and BD, maximum dry density increases and optimum moisture content gets decreased. Due to the presence of FA and BD, the weight of soil specimen increases with the increasing of stabilization content. Therefore, dry density increases with the increasing of admixture content in composite soils with FA and BD. The maximum dry density for control soil was 1.59 gm/cc and it was increased with increasing percentage of admixture content. Maximum dry density for 70% FA and 60% BD were found 1.81 and 1.74 gm/cc, respectively (Figure 7 and Figure 8).

4.3 Crack Intensity Factor

4.3.1 Variation of CIF with Time and Admixture Content

The variation of CIF due to drying and wetting cycle with varying mixing proportions of BD and FA having 20 mm liner thickness, respectively with mixing water content equals to PL are shown in Figure 9 and Figure 10, respectively. During 1st drying cycle, CIF was very low. CIF for all liner in the 1st cycle was less than 2.5%. Maximum CIF was observed in control soil which was 2.17 and it decreases with the increasing of admixture contents. In addition, there was no crack found in the specimen of 70 and 60% FA and BD, respectively. After end of first drying cycle with constant crack area at 168 hrs for both liners with BD and FA, the amount of water was applied to start a wetting cycle at a rate of approximately 250 mm/day for four days (96 hours). In 1st wetting cycle, developed cracks became zero and CIF was also found zero for both liners with FA and BD. Cracks were developed rapidly at the beginning of 2nd drying cycle in days. Cracks progressed slowly after initial rapid period and became constant after 4 days. It can be observed that CIF at 2nd wetting-drying cycle was significantly greater than that of 1st drying cycle for both FA and BD.

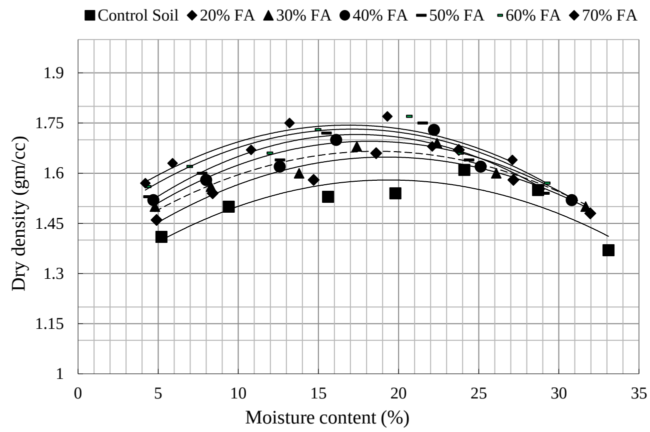

Figure 7 Variation of MDD with fly ash content

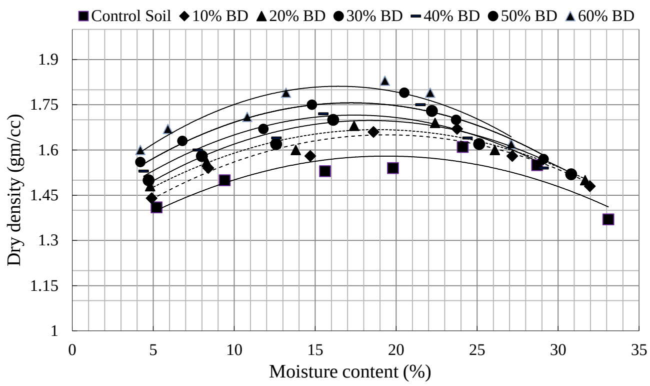

Figure 8 Variation of MDD with brick dust content

Figure 9 and Figure 10 reveals, maximum CIF for control soil which was 4.91% and decreases with the increasing of FA and BD content. FA and BD have very low capacity to shrink and swell. As a result, crack generally do not generate. It was observed that, PI is related to the CIF. Low CIF value was obtained in the specimen with low PI. Due to the increase of admixture content, PI of liner specimen was decreased. For this phenomenon with the increase of FA and BD content in the liners, the value of CIF is reduced. It is believed that rearrangement of soil fabric diminishes and eventually ceases subsequent to one or two wetting and drying cycle. Therefore, with the multiple wetting and drying cycles experiment, the amount of cracking did not significantly change after 2nd wetting and drying cycles.

According to Yesiller et al. (2000), at the initial stage of the drying cycle, CIF increased upto centain level then became constant as well as at the wetting cycle it goes to zero. In addition, CIF in 2nd wetting-drying cycle was significantly greater than the compaction drying cycle and CIF did not change significantly in multiple wetting-drying cycles. The findings of the present study are agreed well with the postulation stated by Yesiller et al. (2000).

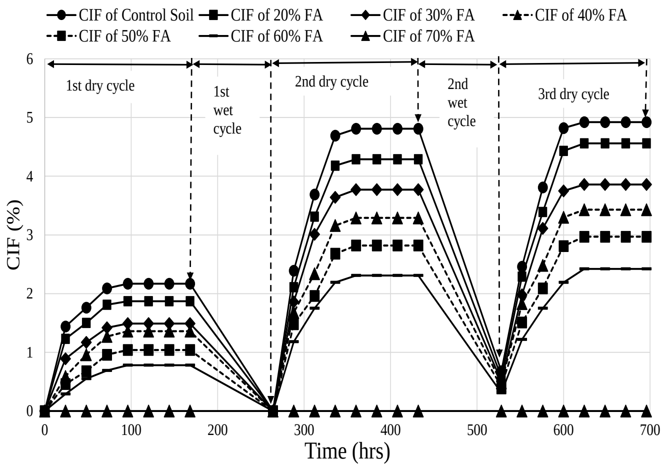

Figure 9 Variation of CIF with time of liners with FA having 10 mm thickness for dry and wet cycles at PL

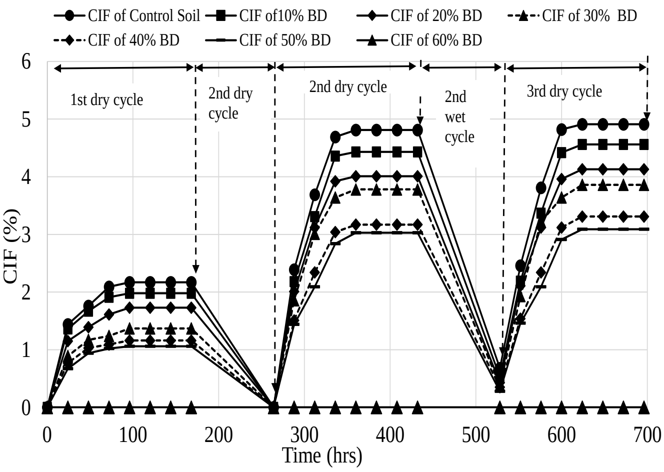

Figure 10 Variation of CIF with time of liners with BD having 10 mm thickness for dry and wet cycles at PL

4.3.2 Variation of CIF with Thickness and Moisture Content

Figure 11 and Figure 12 illustrate the comparison of CIF with liners specimen thickness moisture content equals to OMC, PL and LL for 40% FA and BD, respectively. The tendency of cracking is seen higher in thinner sample due to the high rate of desiccation. Therefore, the intensity of cracks decreases with the increase of specimen thickness. As a result, CIF of liner specimen at 10 mm thickness for both FA and BD liners were comparatively higher than that of 20 mm and 30 mm liners.

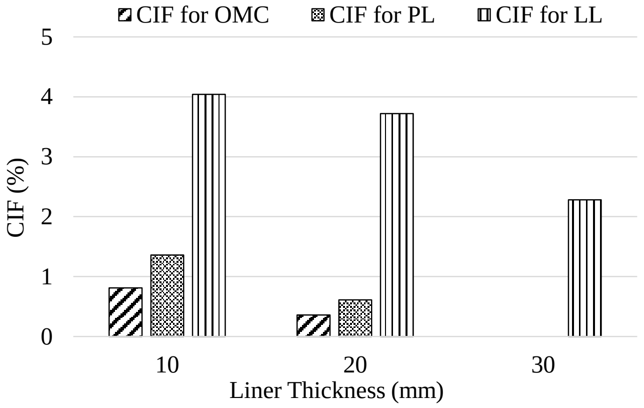

Figure 11 Variation of CIF with FA Content at OMC, PL and LL for all the liner thickness

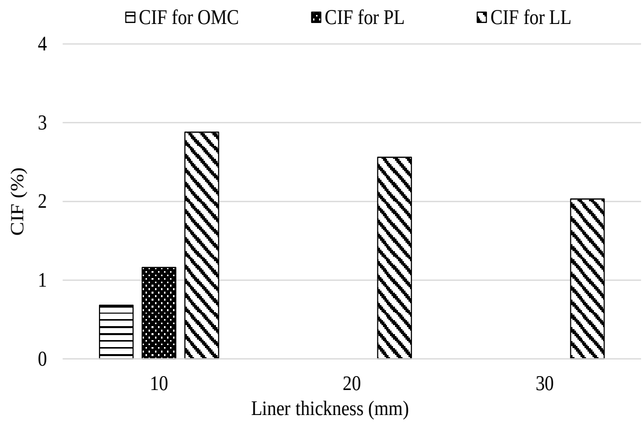

Figure 12 Variation of CIF with BD Content at OMC, PL and LL for all the specimen thickness

On the other hand, with an increase of moisture content, stress due to shrinkage increase in the specimen during drying. Because of this increased stress, CIF increases with the increase of moisture content. For this consequence, the intensity of crack in the specimen was found higher for liner with mixing water content equal LL than that of liners with OMC and PL.

From Figure 11 and Figure 12, the values of CIF were 0.81, 1.36 and 4.04% for FA in 10 mm specimen thickness at different water content equal OMC, PL and LL, respectively. In addition, CIF of liners with BD for different water content equals OMC, PL and LL were found 0.68, 1.16 and 2.88%, respectively. For the liners of 30 mm thickness for both FA and BD at OMC and PL the values of CIF were zero (Figure 11 and Figure 12). According to Singh et al. (2017), the crack intensity factor increases with the increase of moisture content. The finding results are agreed well with Singh et al. (2017).

4.3.3 Variation of CIF with Admixture Content and Moisture Content

The effect of CIF with changing FA and BD content at varying moisture content equals OMC, PL and LL for 30 mm specimen thickness are provided in Table 3 and Table 4, respectively. CIF is the percentage of crack in reduced liners specimen area. With the increasing of admixture content, CIF generally decreases. FA and BD have very low capacity of swelling and shrinkage behaviour. Due to low capacity of shrink, with the increase of FA and BD in specimen, shrinkage area was reduced, while reduction area increased. Crack area also reduced. As a result, lower CIF was obtained. Therefore, CIF decreases with the increase of admixture content like FA and BD in liners.

The values of crack intensity were found 4.15, 2.79, 2.28, 1.89 and 1.81% for 20, 30, 40, 50 and 60% FA at water content equals LL of 30 mm liner specimen (Table 3). In addition, CIF for 10, 20, 30, 40 and 50% BD were 4.24, 3.94, 2.62, 2.03 and 1.12%, respectively, at moisture content equal LL of 30 mm liner thickness (Table 4). The CIF became zero in liners with 30, 40, 50, 60 and 70% FA and 30, 40, 50 and 60% BD at water content equal OMC. In addition. CIF was also zero in 40, 50, 60 and 70% FA and 30, 40, 50 and 60% BD at water content equal PL (Table 3 and Table 4).

4.4 Crack Area

4.4.1 Variation of Cracks Area with Moisture Content and Specimen Thickness

The variation of cracks area with liner thickness at varying water content equal OMC, PL and LL for 40% FA and BD are presented in Figure 13 and Figure 14, respectively. At constant FA or BD content, higher moisture content in a specimen means low amount of solid soil particles. On the application of temperature, water will evaporate from the soil and the very small particles of soils will move radially inwards as they have high cohesion. This inward movement will be more if the percentage of water is more or the percentage of solid particles is less. For this consequence, crack area are increased with the increase of moisture content. As a result, the values of crack area for LL are higher than that of other counterparts in terms OMC and PL. The tendency of cracking are seen higher in thinner sample due to the high rate of desiccation. For this phenomenon, the crack area decreased with increased specimen thickness. As a result, the value of the crack area for 10 mm is higher than that of 20 and 30 mm.

Table 3 Results of CIF of composite liners at varying water content and liner thickness

Composite liners prepared with fly ash	CIF (%) of liners at different fly ash and moisture content (%)		
	OMC	**PL**	**LL**
S100, FA0	0.55	1.01	4.63
S80, FA20	0.41	0.83	4.15
S70, FA30	0	0.69	2.79
S60, FA40	0	0	2.28
S50, FA50	0	0	1.89
S40, FA60	0	0	1.81
S30, FA70	0	0	0

Table 4 Results of CIF of composite liners at varying water content and liner thickness

Composite liners prepared with brick dust	CIF (%) of liners at different brick dust and moisture content (%)		
	OMC	**PL**	**LL**
S100, BD0	0.55	1.01	4.63
S90, BD 10	0.22	0.84	4.24
S80, BD 20	0.18	0.77	3.94
S70, BD 30	0	0	2.62
S60, BD40	0	0	2.03
S50, BD50	0	0	1.12
S40, BD40	0	0	0

Figure 13 and Figure 14 reveal, crack area became zero in 30 mm specimen for both OMC and PL for 40% FA content. In addition, area of crack became zero in 20 mm and 30 mm specimen for both OMC and PL for 40% BD. The values of crack area were found 27.74, 25.27 and 15.24 cm^2 for 40% FA at moisture content equals LL for 10, 20 and 30 mm, respectively (Figure 13). In addition, crack areas were found 19.48, 17.45 and 13.63 cm^2 for 40% BD at moisture content equals LL for 10, 20 and 30 mm, respectively (Figure 14).

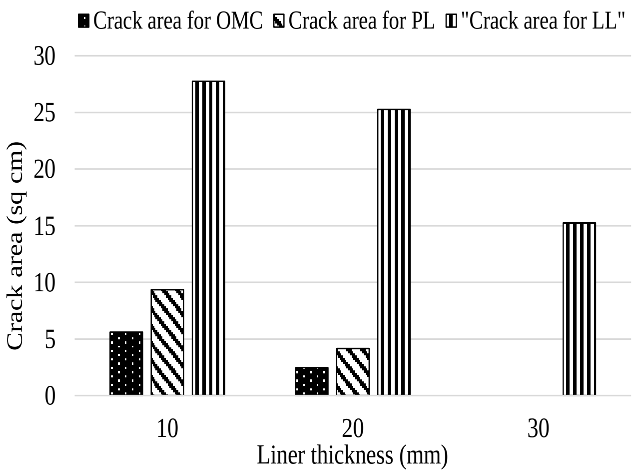

Figure 13: Variation of crack area with FA Content at OMC, PL and LL for all the specimen thickness

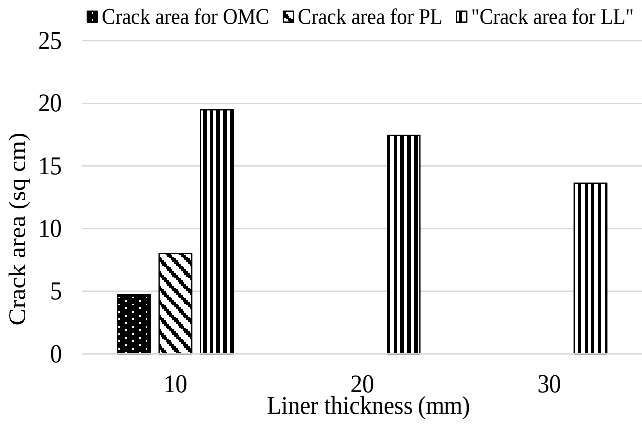

Figure 14 Variation of crack area with BD Content at OMC, PL and LL for all the specimen thickness

4.4.2 Variation of Crack Area with Admixture Content and Moisture Content

The variation of cracks area at varying moisture content in terms of OMC, PL and LL for 30 mm thickness with FA and BD are presented in Table 5 and Table 6, respectively. Cracks area depends on the swell, shrink and cohesion behavior of soil. FA and BD have low capacity of swell and shrink. As the specimen of liners were prepared with admixture FA and BD, therefore liners showed lower crack area with the increasing of admixture content with FA and BD. In addition, the area of crack increase with the increase of water content because of the reasons mention earlier. Table 5 and Table 6 clarify, crack area became zero 30, 40, 50, 60 and 70% FA and 30, 40, 50 and 60% of BD at moisture content equals OMC for 30 mm specimen. In addition, area of crack became zero for 40, 50, 60 and 70% of FA and 30, 40, 50 and 60% of BD at PL for 30 mm thickness (Table 5 and Table 6).

Therefore, the crack area was observed 30.60 cm^2 for control soil at moisture content equal LL for 30 mm thickness and crack area were reduced 27.53, 18.57, 15.24, 12.69, 9.76 and 0 cm^2 for 20, 30, 40, 50, 60 and 70% of FA (Table 5). In addition, the value of cracks area was found 28.12, 26.22, 17.51, 13.63, 7.52 and 0 cm^2 for 10, 20, 30, 40, 50 and 60 % of BD at moisture content equal LL for 30 mm thickness (Table 6).

Table 5 Results of cracks area of composite liners at varying mixing proportions of fly ash and water content

Composite liners prepared with fly ash	Cracks area (cm^2) of liners at different fly ash and moisture content (%)		
	OMC	**PL**	**LL**
S100, FA0	5.66	6.68	30.60
S80, FA20	4.74	5.51	27.53
S70, FA30	0.00	4.59	18.57
S60, FA40	0.00	0.00	15.24
S50, FA50	0.00	0.00	12.69
S40, FA60	0.00	0.00	9.76
S30, FA70	0.00	0.00	0.00

Table 6 Results of cracks area of composite liners at varying mixing proportions of brick dust and water content

Composite liners prepared with brick dust	Cracks area (cm^2) of liners at different fly ash and moisture content (%)		
	OMC	**PL**	**LL**
S100, BD0	5.66	6.68	30.60
S90, BD10	4.47	5.57	28.12
S80, BD20	4.21	5.12	26.22
S70, BD30	0.00	0.00	17.51
S60, BD40	0.00	0.00	13.63
S50, BD50	0.00	0.00	7.52
S40, BD60	0.00	0.00	0.00

4.5 Crack Density Factor (CDF)

4.5.1 Variation of CDF with Admixture Content and Moisture Content

Table 7 and Table 8 elucidate the variation of crack density factor (CDF) with admixture of FA and BD at different water content for 30 mm, respectively. CDF is the percentage of surface shrinkage area in a specimen. Surface shrinkage area means the summation of crack and shrinkage area. FA and BD have very low capacity of shrinkage potential. The addition of low shrink materials means reduction of percentage of high shrinkage materials in the mixtures. As a result, percentage of overall surface shrinkage in composite landfill liners was reduced with the increase of FA and BD content. From Table 7 and Table 8, it was observed that CDF reduced with the increase of FA and BD content in liners. At constant FA or BD content, higher water content specimen observed higher CDF due to low amount of solid particles. Therefore, CDF of liners with water content equals LL was greater than other liners with water content equal to OMC and PL.

Table 7 Results of CDF of composite liners at varying mixing proportions of brick dust and water content

Composite liners prepared with fly ash	CDF (%) of liners at different fly ash and moisture content (%)		
	OMC	PL	LL
S100, FA0	5.16	6.02	14.31
S80, FA20	4.55	5.09	13.27
S70, FA30	3.23	4.32	10.68
S60, FA40	2.57	2.92	8.64
S50, FA50	2.14	2.50	6.82
S40, FA60	1.84	2.06	4.62
S30, FA70	1.33	1.53	1.94

Table 8 Results of CDF of composite liners at varying mixing proportions of brick dust and water content

Composite liners prepared with brick dust	CDF (%) of liners at different brick dust and moisture content (%)		
	OMC	PL	LL
S100, BD0	5.16	6.02	14.48
S90, BD10	4.50	5.25	13.22
S80, BD20	3.52	4.14	12.02
S70, BD30	2.57	2.78	9.88
S60, BD40	2.01	2.34	7.82
S50, BD50	1.73	1.96	4.95
S40, BD60	1.03	1.20	1.97

From the following Figures, CDF was observed 14.31% for control soil specimen at LL for 30 mm thickness and it was reduced to 13.27, 10.68, 8.64, 6.82, 4.62 and 1.94% for 20, 30, 40, 50, 60 and 70% of FA content, respectively (Table 7). In addition, CDF was found 13.22, 12.02, 9.88, 7.82, 4.95 and 1.97% for 10, 20, 30, 40, 50 and 60% BD content respectively (Table 8). As the same reduction of CDF was observed at water content equals OMC and PL. The reduction value of CDF at OMC were 4.55, 3.23, 2.57, 2.14, 1.84 and 1.33% for 20, 30, 40, 50, 60 and 70% FA content, respectively (Table 7). In addition, at water content equal OMC, the CDF for 10, 20, 30, 40, 50 and 60% BD were 4.50, 3.52, 2.57, 2.01, 1.73 and 1.03%, respectively (Table 8).

4.5.2 Variation of CDF with Specimen Thickness and Moisture Content

Figure 15 and Figure 16 elucidate the variation of CDF with liners thickness and varying moisture content in terms of OMC, PL and LL for 40% FA and BD, respectively. At constant FA or BD content, a higher water content specimen means low amount of solid particle. Due to the application of temperature, water will be evaporated from soil. The small particle of soil will be moved inward rapidly because of their high cohesion behaviour. The movement of soil particles will be more if the proportion of solid particles is less or the proportion of water content is more. On the other hand, an increase of specimen thickness leads to uneven drying of the layers of the specimen. Thus increasing the surface shrinkage and crack in the soil specimen. Therefore, in most of the specimens, CDF increases with the increase of water content and specimen thickness. The values of CDF were found 5.29, 8.59 and 8.64% for 40% FA at moisture content equals LL for 10, 20 and 30 mm, respectively (Figure 15). In addition, CDF were found 4.70, 7.79 and 7.82% for 40% BD at moisture content equals LL for 10, 20 and 30 mm, respectively (Figure 16). From the following figures, CDF for liners with 30 mm specimen at varying water content equals OMC, PL and LL were found 2.57, 2.92 and 8.64% for FA and 2.01, 2.34 and 7.82% for BD, respectively.

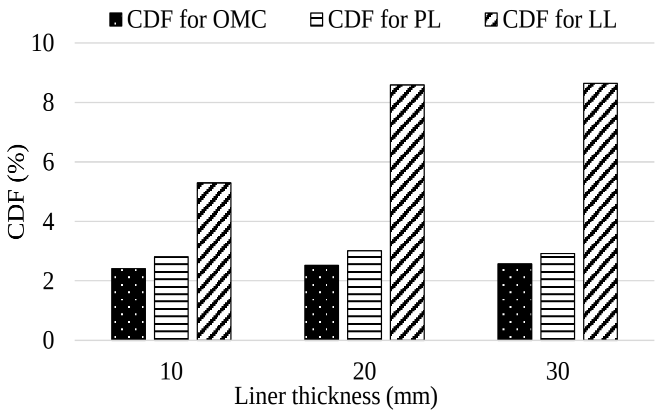

Figure 15 Variation of CDF of stabilized soils with FA content at varying mixing water content and specimen thickness

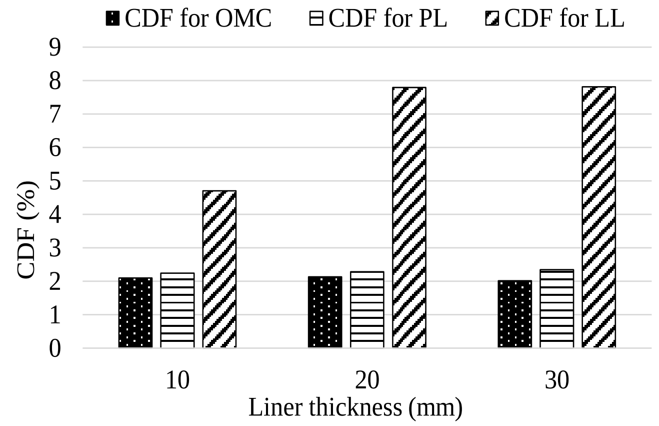

Figure 16 Variation of CDF of stabilized soils with BD content at varying mixing water content and specimen thickness

5. CONCLUSIONS

This study represents an automated system to analyze cracking and shrinkage behaviour of composite landfill liners. The device and associated image processing software create a possible way to analyze various cracking parameters easily, quickly and in a better mode. Result reveals CIF, CDF and crack area decreases with the increase of fly ash and brick dust content in composite landfill liners. In addition, CIF, CDF and crack area increase with the increase of water content in liners. The liners prepared with admixtures at water content equal to liquid limit showed maximum CIF, CDF and crack area. The CIF and crack area decrease with the increase of liner thickness except for CDF. The values of CDF increase with the increase of liner thickness. With the multiple wetting-drying cycles experiment, amount of cracking did not significantly change after 2nd wetting-drying cycle. The admixture which was used and its percentages in the composite soil can be changed depending on the soil conditions, landfill types, cost of materials, availability of materials, location of landfill sites, climate and weather conditions, etc.

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