QUANTIFICATION OF CRACKING BEHAVIOR OF COMPOSITE CLAY LINERS

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ABSTRACT

Cracking is a complex phenomenon which is active in materials like soils. As crack is a natural process it involves chemical, biological and weathering changes. The study of cracking behavior of liners used in landfill is very essential and need to quantify. The development of crack depends on moisture content, soil thickness, rate of drying and wetting, surface configuration, total drying period etc. In this study, to prepare composite clay liners (CCLs), disturbed soil samples were collected at a depth of 5 ft from the existing ground surface from a selected waste disposal site at Rajbandh, Khulna, Bangladesh. In the laboratory, the physical and index properties of soil sample were measured through the standard test methods. The values of initial moisture content, optimum moisture content (OMC), maximum dry density (MDD), specific gravity, liquid limit (LL), plastic limit (PL), plasticity index, shrinkage limit (SL), sand, silt and clay were found 37.65%, 20%, 1.53gm/cc, 2.61, 54%, 31%, 23% and 35.11%, 4.6%, 64.7%, 30.7%, respectively. In this study, to prepare CCLs, 30 cm diameter of steel circular mold with varying thickness like 10, 20 and 30 mm were used. In the laboratory, the CCLs were prepared with fly ash (FA) at varying mixing proportions like 20, 30, 40, 50 and 60% and brick dust (BD) with mixing proportion 10, 20, 30 and 40% by weight. The cycles of wetting and drying were subjected on the prepared CCLs to simulate the field behavior of liners in landfills. The formation of cracks were constant after 7 days in dry cycle and became zero after 4 days in wet cycle. For this consequence the duration of the wet cycle was 7 days and that of the dry cycle was also 4 days. In the test with multiple wet-dry cycles, the amount of cracking parameters did not change significantly after second cycle. In the laboratory, the engineering properties of FA and BD were measured. The cracking parameters like crack area, crack intensity factor (CIF), and crack density factor (CDF) were analyzed using ImageJ technique through MATLAB. From results it is clear that maximum values of CIF, CDF and crack area were found in control soil. In addition, the minimum values of CIF, CDF and crack area were found at mixing FA content of 60% and brick dust of 40% in soils. All the studied geometrical parameters decrease with increase of liner thickness except CDF. The value of CDF increases with increase of specimen thickness. Maximum and minimum CDF were found in 30mm and 10mm specimen thickness, respectively. The maximum and minimum values CIF, CDF and crack area were found at moisture content equals to LL and OMC, respectively. In addition, the values of geometrical parameter increases in relation to the increasing of moisture content i.e. the liners with LL showed comparatively the higher values of cracking parameters than that of other counter parts. The cracks were found comparatively wider and longer in fly ash than that of liners with brick dust.

Keywords: *Composite clay liners, Desiccation, Cracking behavior, ImageJ, MATLAB.*

1. INTRODUCTION

Before and after dumping of Municipal Solid Waste (MSW) in landfill, cap and base liner is needed to safe the environmental components and the underlying soil layer. It is important to design of cap and base liners properly in landfill to protect surrounding environment including underlying soils, groundwater and surface water bodies by contaminated leachate that generated from decomposed MSW in landfill (Carey et al., 2000). For better performance of liners, landfill liners should be low permeable throughout its lifetime (Omidi et al., 1996). The character 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 becomes constrained, desiccation cracks promote its geometrical characteristics (Corte and Higashi, 1960). Besides, moisture and density conditions, confining pressures, temperature, and cycles of wetting and drying are also responsible for crack formation (Morris et al., 1992). The formation of cracks at controlled weathering condition has a great impact on crack propagation rate and its geometric condition due to fluctuation of temperature. The design criteria of composite landfill liners such as hydraulic conductivity should be low i.e. $k<10^{-9}$ m/s, PI>7, at least 30% fines of which 15% clay and water content must be greater than plastic limit (Rafizul, 2014). The admixtures such as lime, cement, fly ash, bentonite, brick dust, sand, etc. have been commonly used to prepare composite liners with soil. Desiccation crack significantly affects the performance of clay liners. Cracks generate weak zone in a soil mass which reduce stability and overall strength of the liners. The formation crack also depends on moisture content, liners thickness, of drying and wetting, surface configuration, rate total drying period etc. Crack dimensions are generally measured using approximate method due to absence of established standard method. Now-a-days digital image analysis techniques are gaining more popularity in both crack quantification and characterization.

Yesiller et al. (2000) proposed that crack intensity factor (CIF) which is the ratio of the cracks area to the total area of surface of a drying soil specimen to quantify the extent of cracking of composite landfill liners. In their method, to calculate crack length, cracking images were skeletonized following Gonzalez and Woods (2002) method. A study conducted by Kleppe et al. (1985) and proposed a geometric parameter of crack density factor (CDF) which depends on the thickness of specimen. The CDF is the ratio of the summation of shrinkage area and crack area to initial specimen area. Therefore, Al Wahab and El-Kedrah (1995) stated that length and width of cracks can be determined using digital clipers. If directly measure the cracks parameters, larger error will fabricate in actual result due to irregular shape, length, width and depth of cracks as well as shrinkage (Tang et al., 2008). In this study, the commonly available admixtures such as fly ash and brick dust will be used to prepare composite landfill liners at varying mixing proportions. An image-based algorithm through MATLAB will be developed to quantify the desiccation cracks of composite landfill liners. Moreover, ImageJ will also be used to determine other relevant parameters so that geometrical characteristics of cracks can be easily described. The geometric parameters interms of CIF and CDF will be determined from binary image of MATLAB coding. In addition, the other features such as cracking area will be measured based on ImageJ software from binary image which is one of the output of MATLAB image analysis. In addition, the variation of CDF, CIF and crack areas with in relation to the changes of mixing water content in terms of OMC, PL and LL as well as specimen thickness will be investigated. In this study, a new window will may open for designers to construct cap and base liners in waste landfill easily and economically specially in least developed Asian countries like Bangladesh.

2. MATERIAL AND METHOD

To fulfill the desire objectives of this study, the soil samples were collected and then composite liners were prepared in the laboratory. In addition, the geometric parameters like CIF, CDF and crack area were computed and hence discussed in the following articles.

2.1 Collection of Soil Sample

In this study, disturbed soil samples were collected from a selected waste disposal site at Rajbandh, Khulna, Bangladesh which is approximately 20 km away from Khulna City. The soil samples were collected at a depth of approximate 5 feet below existing ground surface. In this study, the samples were first air-dried 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 such as initial moisture content, OMC, MDD, specific gravity, LL PL, SL and constituents of soil particles in soil were measured through ASTM standard depicted in Table 1.

Table 1. Physical and index properties of soil used in this study

Properties	**Unit**	**Values**	**Analytical method**
Initial moisture content, w	%	37.65	ASTM D 2974
Optimum moisture content, OMC	%	20	ASTM D 558
Maximum dry density, MDD	gm/cc	1.53	
Specific gravity, Gs	--	2.61	ASTM D 854
Liquid Limit, LL	%	54	ASTM D 4318
Plastic Limit, PL	%	31	
Plasticity index, PI	%	23	
Shrinkage limit, SL	%	35.11	ASTM D 427
Sand: silt: clay	%	4.6: 64.7: 30.7	ASTM D222

2.2 Collection of Additives

To prepare composite landfill liners, different types of admixtures like fly ash (FA) and brick dust (BD) were collected from local market. In this study, the FA and BD passing through 4 no. sieve were used and the physical and index properties of FA and BD was also measured through ASTM standards methods.

2.3 Preparation of Composite Liners

In the laboratory, the saturated surface dry additives like FA and BD were mixed with soil at various percentages separately to make soil slurry. In this study, the mixing proportions of 10, 20, 30 and 40% of BD by weight with soil were used to prepare composite landfill liner. In addition, the mixing proportions of FA of 20, 30, 40, 50 and 60% by weight with soil was used to prepare composite landfill liner. Experimental work has been carried out at three different moisture content i.e. at OMC, PL and LL. A study conducted by Tiwari (2015) and prepared liners with bentonite and fly ash at varying mixing proportions with the mixing water content equal to OMC, PL and LL. In the present study, for preparing composite liners with water content, the statement postulated by Tiwari (2015) were followed. The mixing soil pastes were kept in air-tight polythene bags for 2 hours due to uniform water absorption in wooden chamber. In addition, the effect of the variation of different mixing amount of admixtures on OMC and MDD as well as CIF, CDF and crack area were formulated. In this study, the diameter of steel circular mold of 30cm was used. In addition, the thickness of mold of 10, 20 and 30mm were considered to prepare composite liners.

2.4 Drying and Image Taking Process

After the preparation of composite specimens, the desired amount of composite slurry was poured in mold at varying thickness of 10, 20 and 30mm in the wooden chamber, where six heat lamps of 100W light bulbs were connected. So that desiccation crack would be formed due to evaporation of moisture from liner specimens shown in Figure 1. In this stage, it was ensured that each specimen could get equal heat. In addition, a thermometer was connected to the chamber to measure the variation of temperature in a regular basis and the temperature was found approximately 44^o C (Figure 1, a). During drying process, a digital camera (Nikon COOLPIX S2900) which was mounted at top of sample soil through steel made camera stand, used to take image of dying sample. A 1.5 feet of constant height was always maintained for taking image of one-day interval.

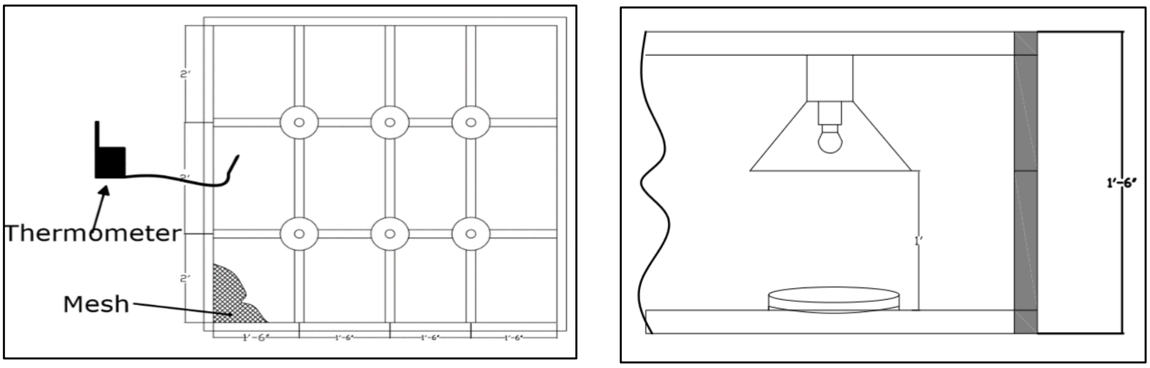

Figure 1: Chamber system for drying of soils (a) top view and (b) sectional view

Initially, all soils were subjected to two cycles: a dry cycle and a wet–dry cycle. The three cycles of wetting and drying were subjected on the prepared composite to simulate the field behavior of liners in landfills. In the wetting cycle, approximately 150ml/day of water for 4 days were used through spraying nozzle to simulate the percolation behavior of clay. At the beginning of drying and wetting cycle, the image of liners were taken at a short period of time <1hr, whereas, at the end of drying and wetting cycle, the image of liners were taken at a long period of time >24hrs.

2.6 Image Processing

Image analysis is a process where meaningful information are Extract from digital images clicked by digital camera. Image analysis is implemented in two basic steps.

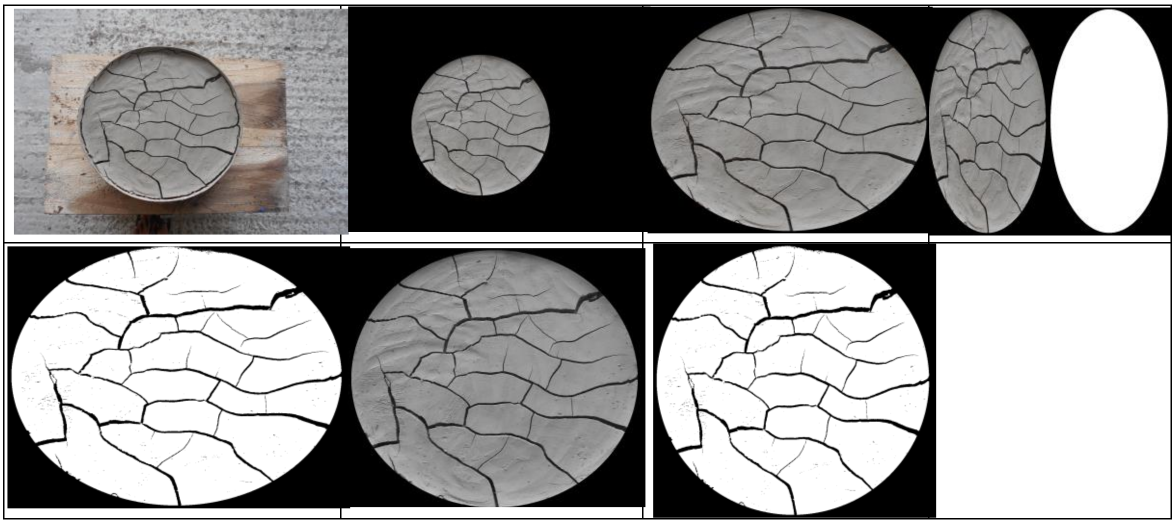

Figure 2. Image processing and analysis of a liners (20% fly ash with soil of 10mm thickness and at LL)

The first step implicates the image processing to prepare the image for analyses. This include cropping the unnecessary part of RGB image and then it convert to binary (black & white) image obtained by thresholding the RGB image shown in Figure 2. The second step comprises the investigation of image which is obtained and processed from step 1 to compute CIF, CDF and crack area.

2.7 Image Analysis

RGB Image obtained from camera were analyzed in MATLAB to calculate essential information. MATLAB program was set in such a way that it counts only the area of black pixels in the image. The black pixels were taken in MATLAB program as cracked area. In addition, summation of black pixels and white pixels were 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 Equation 1. For determine other parameter used ImageJ software and Microsoft excel. In addition for the determination of diameter of reduced specimen, a known distance in the image like the diameter of mold is marked by straight line and scale is set in ImageJ by the option Analyse-Set Scale-give value 30 cm. Then length of the reduced specimen was calculated at the same image by measure command (Analyze-measure). Other parameters like total area of cracks was calculated through MS excel. In addition, the value of CDF was computed using Equation 2.

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

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

3. RESULTS AND DISCUSSIONS

For the design of suitable liners in landfill with additives, the geometrical parameters like compaction characteristic, CIF, CDF are crack area are need to be analyzed. In this study, these parameters were analyzed and hence discussed in the following articles.

3.1 Compaction Characteristics

The variation of dry density to stabilized soil in relative to the changing of moisture content of stabilized soil with FA and BD content is revealed in Figure 3 and Figure 4, respectively. The following figures represents that the MDD decrease with the increase of of FA and BD content. The phenomenon behind this, the specific gravity of the FA and BD compared with soil and immediate formation of cemented products which is done by hydration which reduces the density of soil. As a results MDD decreases with the increase of admixture content in composite soils.

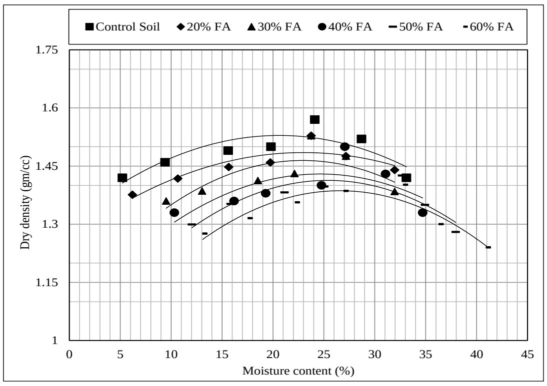

Figure 3: Variation of MDD with FA content

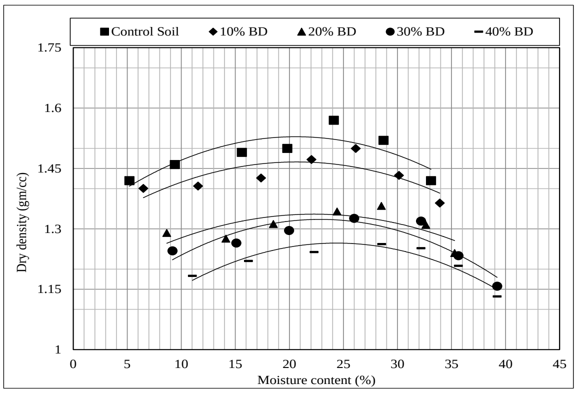

Figure 4: Variation of MDD with BD content

3.2 Crack Intensity Factor

The variation of crack intensity factor (CIF) with time, admixture content, moisture content and thickness of liners were analyzed and hence discussed in the following articles.

3.2.1. Variation of CIF with Time

The variation of CIF with time of liners having 10mm thickness at varying mixing proportions of FA and BD with mixing water content equals to OMC for different cycles is shown in Figure 5 and Figure 6, respectively. In the first dry cycle, CIF increases with time and become constant after four days (96hrs) for both liners. After end of first dry cycle with constant crack area at 168hrs for both liners, the amount of water was applied to start a wet cycle. In wet cycle, the developed cracks became zero and CIF was found to be zero for both liners. A study conducted by Yesiller et al. (2000) and stated that at the initial stage of dry cycle, the value of CIF increased upto certain level then became constant as well as at the wet cycle it goes to zero. The findings of the present study were well agreed with the postulation stated by Yesiller et al. (2000). Moreover, when the second dry cycle started, CIF increases rapidly in first two days then increases slowly and constant after four days (96hrs.) for both liners with FA and BD.

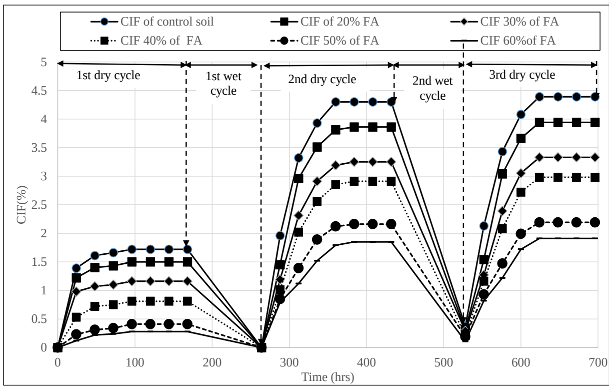

Figure 5: Variation of CIF with time of liners with FA having10mm thickness for multiple cycles at OMC.

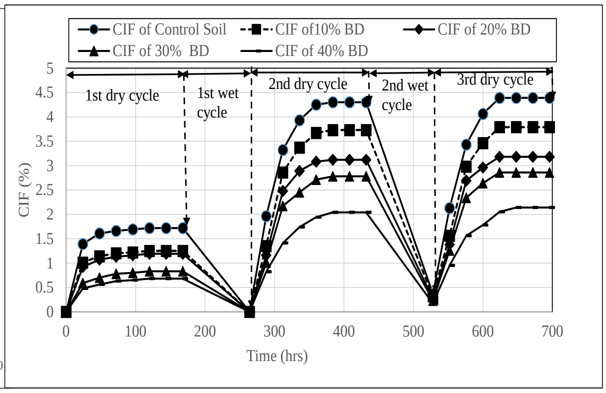

Figure 6: Variation of CIF with time of liners with BD having 10mm thickness for multiple cycles at OMC.

Figure 5 and Figure 6 reveal the values of CIF increased to 1.5 and 1.19 % in the first dry cycle for 20% of FA and BD respectively at 10mm thickness. On the other hand, it increases up to 3.84 and 3.12% in second wet-dry cycle for FA and BD respectively. In the test with multiple wet-dry cycles, the amount of CIF did not change significantly after second cycle. From figures it was observed that CIF was affected by fines content of the soils. In general high amount of CIF were observed in soil with high fine content (20% FA) and less CIF observed in soil with low fines content (20% BD) (Figures 5 and 6). The liners with BD for all mixing contents showed comparatively lower CIF for both first and second cycles than that of liners with FA. Figures depict lower CIF for both liners than that of control soil because the capacity of FA and BD are very low in terms of swell and shrink. For this reason it does not generate cracks. Crack area was reduced with the increase in FA content in the specimen and CIF was low. For this phenomena, liners with 60% FA and 40% BD shows comparatively lower CIF than that of other mixing content of FA and BD.

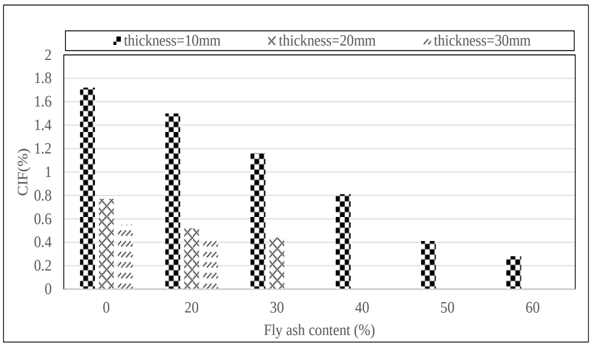

Figure 7: Variation of CIF with FA content at OMC for all the specimen thickness

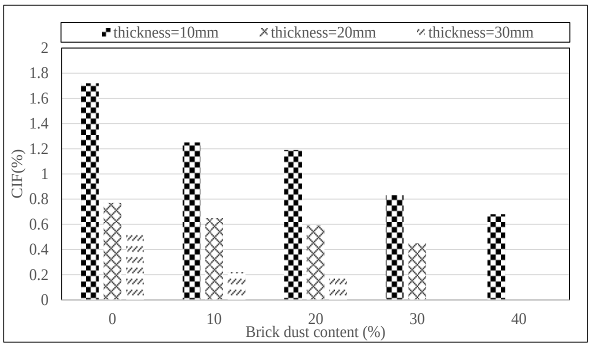

Figure 8: Variation of CIF with BD content at OMC for all the specimen thickness

3.2.2. Variation of CIF with Admixture Content

Figure 7 and Figure 8 illustrate the variation of CIF with the changing of FA and BD content at varying thickness with mixing water content equals to OMC for first dry cycle. CIF decreases with increase in FA and BD content. FA and BD have very low capacity to swell and shrink. For this consequence crack generally does not show. With the increase in FA in liners, crack area is reduced. As a result, low CIF was found. Figure 7 reveals CIF for control soil was 1.68% which decreases by increasing FA. CIF became zero for 30, 40, 50 and 60% of FA for 30mm thickness and 40, 50 and 60% of FA for 20mm thickness. On the other hand, CIF became zero with 30 and 40% for 30mm, while 40% for 20mm thickness of liner with BD.

3.2.3. Variation of CIF with Thickness

Figure 9 and Figure 10 clarifies the variation of CIF with moisture content and sample thickness at the end of dry cycle for FA and BD respectively. Intensity of cracks decrease with increase of specimen thickness. While for specimens of less thickness cracks were more. Figure 9 explains the values of CIF for 10, 20 and 30mm thickness at OMC are 1.5, .52 and 0.41 respectively. On the other hand, CIF increase with increase of moisture content. It were found 5.19, 4.69 and 4.13 for 10, 20 and 30mm thickness at LL respectively.

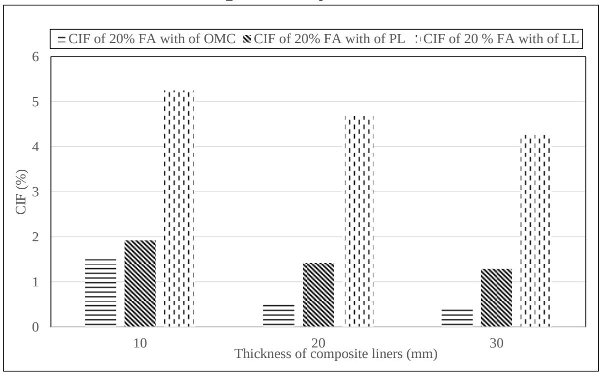

Figure 9: Variation of CIF with FA content at OMC, PL and LL for all the specimen thickness

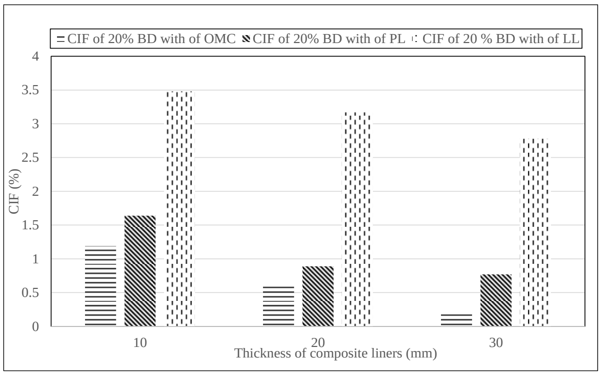

Figure 10: Variation of CIF with BD content at OMC, PL and LL for all the specimen thickness

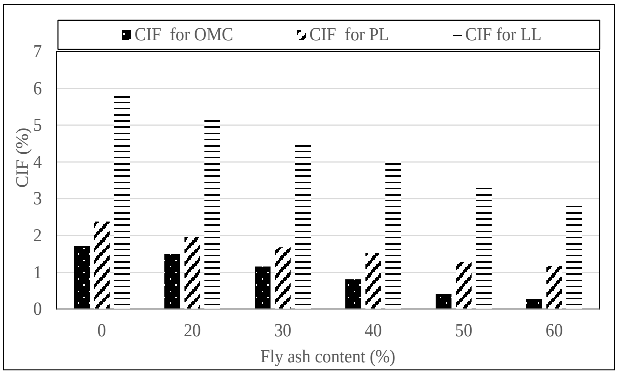

Figure 11: Variation of CIF with FA content at OMC, PL and LL for all fly ash content.

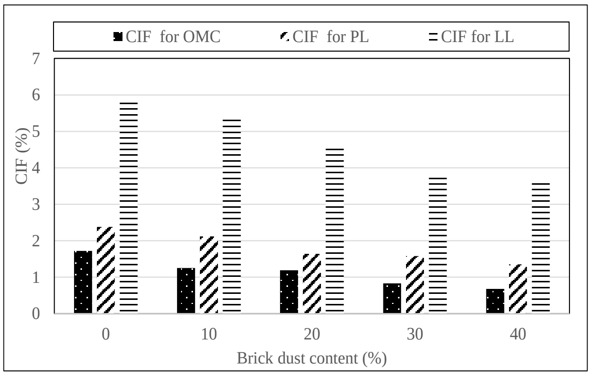

Figure 12: Variation of CIF with BD content at OMC, PL and LL for all fly ash content

3.2.4. Variation of CIF with Moisture Content

The variation of CIF with admixture content for FA and BD at varying moisture content equal to OMC, PL and LL shown in Figure 11 and Figure 12, respectively. Crack Intensity increases with increase of moisture content. For most of the specimens at OMC, cracks were almost zero with more reduced specimen area. While for specimens at PL and LL cracks were more with low reduced specimen area. As a result it accounts higher CIF for those specimen. CIF was .5, 1.96 and 5.25 for moisture content of OMC, PL and LL, respectively for (FA 20%). Figure 12 also proved that, CIF increases with increase of moisture content.

3.3. Crack Density Factor

The variation of crack density factor (CDF) with time, admixture content, moisture content and thickness of liners were analyzed and hence discussed in the following articles.

3.3.1. Variation of CDF with Time and Admixture Content

Figures 13 and 14 illuminate the variation of CIF of liners with FA and BD at OMC. The shrinkage potential of FA and BD are very low. Low shrinking materials means reduction in the percentage of high shrinking materials in the mix. For this reasons CDF values is reduced by means of more FA content. CDF generally increase with time and become constant after four days. After end of dry cycle wet cycle was started when CDF was Zero. When dry cycle started CDF increase rapidly in first three days than increase slowly and constant after five days (120hrs). In the test with multiple wet-dry cycles, the amount of CDF did not change significantly after second cycle. From figures it was observed that CDF was affected by fines content of the soils. In general high amount of CDF were observed in soil with high fine content (20% FA) and less CDF observed in soil with low fines content (20% BD) (Figures 13 and 14).

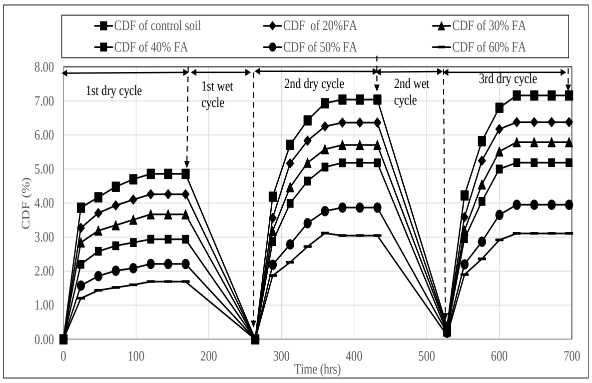

Figure 13: Variation of CDF of liners with FA having10mm thickness with time for multiple cycles

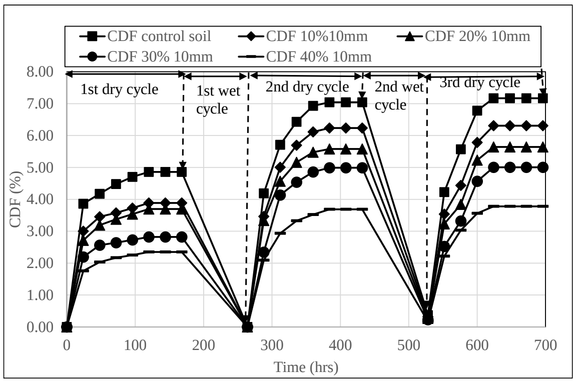

Figure 14: Variation of CDF of liners with BD having10mm thickness with time for multiple cycles

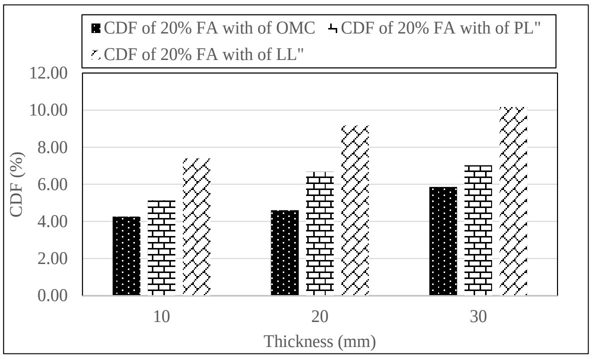

Figure 15: Variation of CDF with moisture content for all the specimen thickness for FA

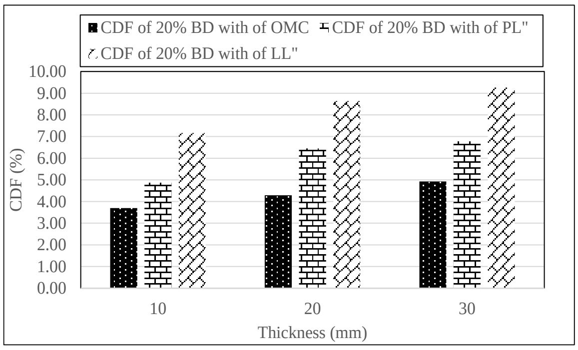

Figure 16: Variation of CDF with moisture content for all the specimen thickness for BD

3.3.2. Variation of CDF with Moisture Content and Specimen Thickness

In this study, composite liners with FA and BD at varying water content equals to OMC, PL and LL were prepared. The variation of CDF with moisture contents (OMC, PL and LL) as well as specimen thickness for 10mm thickness FA and BD is shown in Figure 15 and Figure 16, respectively. Soil can retain a large amount of water equals to LL and at constant FA or BD content. Greater values of moisture content in constant admixture content of liners specimen means low amount of solid soil particles. By the application of constant temperature, water will evaporate from the soil. As the small particles have very high cohesion they will move inwards. The movement of the particle will be more, if the amount of water is more or percentage of soil particles in the specimen is less. Increase in thickness leads to uneven drying of the layers of specimen, thus increases the surface cracks in a specimen which means increase of CDF. For this phenomenon, the values of CDF increase with the increase of Moisture content and thickness of the specimens. A study conducted by Tiwari (2015) and stated that CDF increase with increase of moisture content and specimen thickness which were agreed well with the findings with this present study.

3.4. Crack Area

The variation of crack area with time, admixture content, moisture content and thickness of liners were analyzed and hence discussed in the following articles.

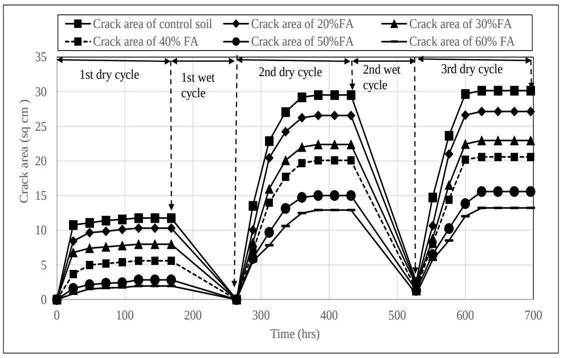

Figure 17: Variation of crack area of liners with FA having10mm thickness with time for multiple cycles

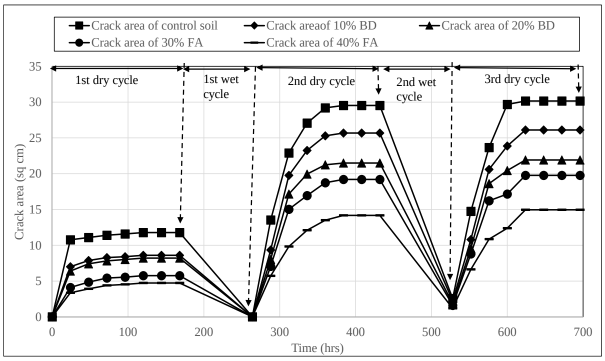

Figure 18: Variation of crack area of liners with BD having10mm thickness with time for multiple cycles

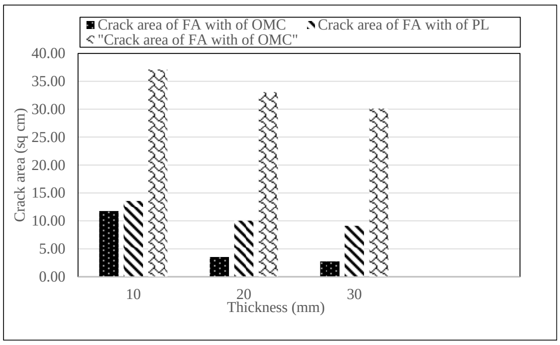

Figure 19: Variation of crack area with moisture content for thickness of liners with FA.

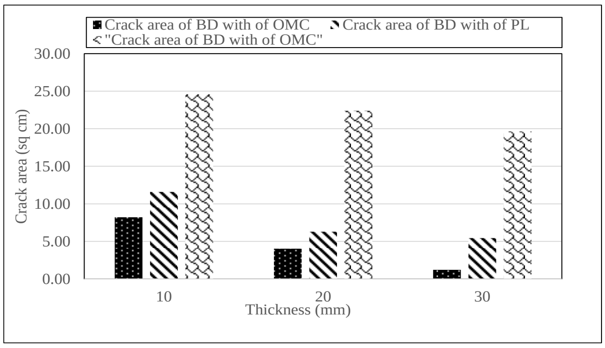

Figure 20: Variation of crack area with moisture content for thickness of liners with BD.

3.4.1 Variation of Crack area with Time and Admixture Content

Figure 17 and 18 clarify the variation of crack area of liners with FA and BD having10mm thickness with time for dry and wet cycles respectively. After end of first dry cycle with constant crack area at 168hrs for both liners with FA and BD, the amount of water was applied to start a wet cycle. In this wet cycle, the developed cracks became zero and for both liners with FA and BD. Moreover, when the second dry cycle started, crack area increases rapidly in first three days then increases slowly and constant after four days (96hrs.) for both liners with FA and BD. Cracks area reduces with increase in admixture content for a fixed moisture content and specimen thickness. Result reveals that crack area decreases with the increasing of FA and BD content. In addition, control soil showed comparatively higher crack area than that of composite liners prepared with FA and BD at varying mixing proportions. The reason behind this phenomenon, crack area depends on the cohesion/adhesion behavior of soil, as liners prepared with admixture FA and BD, therefore liners showed lower crack area.

3.4.2. Variation of Cracks Area with Moisture Content and Specimen Thickness

Figure 19 and Figure 20 clarify the variation of cracks area with FA and BD at varying water content equals to OMC, PL and LL for all specimen thicknesses for 20% FA and BD respectively. Crack is form in liners which is increase with moisture content but decrease with thickness. FA and BD have very low capacity to swell and shrink. However, after adding FA or BD, cracks were decrease with increase of FA or BD content. The values of crack area increase with the increase of moisture content. Large amount of water can retain which means low soil particle at liners. As a result, it forms more crack with increasing of moisture content.

4. CONCLUSIONS

This study mainly focus on some relevant factors that affect the behavior of composite liners subjected to drying and wetting. From results it is clear that maximum values of CIF, CDF and crack area were found in control soil. In addition, the minimum values of CIF, CDF and crack area were found at mixing FA content of 60% and brick dust of 40% in soils. All the studied geometrical parameters decrease with increase of liner thickness except CDF. The value of CDF increases with increase of specimen thickness. Maximum and minimum CDF were found in 30mm and 10mm specimen thickness respectively. The maximum and minimum values CIF, CDF and crack area were found at moisture content equals to LL and OMC, respectively. In addition, the values of geometrical parameter increases in relation to the increasing of moisture content i.e. the liners with LL showed comparatively the higher values of cracking parameters than that of other counter parts. The cracks were found comparatively wider and longer in fly ash than that of liners with brick dust. In the test with multiple wet-dry cycles, the amount of cracking parameters did not change significantly after second cycle. Result reveals cracking was affected by fines content of the soils. High amount of cracking parameters were observed in soil with high fine content (20% FA) and less was observed in soil with low fines content (20% BD).

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