EXPERIMENTAL ANALYSIS OF DESICCATION CRACKS IN COMPOSITE LANDFILL LINERS WITH FLY ASH AND BRICK DUST

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Abstract - This study illustrates the desiccation cracks of composite landfill liners using image analysis technique. To these attempts, composite liners were prepared with fly ash and brick dust at varying mixing proportions and different moisture content. The drying and wetting cycles were subjected on liner specimens. The desiccation cracks in terms of intensity factor (CIF), crack density factor (CDF) and cracks area were quantified. Result reveals CIF, CDF and crack area reduces with the increasing of fly ash and brick dust content. Additionally, CIF, CDF and cracks area increases with the increasing of water content. Result reveal liners with moisture content equals to liquid limit showed comparatively higher desiccation cracks than that of liners with optimum moisture content and plastic limit. The image processing technique through this study provided a better and easiest way to analyze desiccation cracks of liners.

Keywords - Composite landfill liners, desiccation cracks, cycles, Image J, MATLAB, Khulna.

I.INTRODUCTION

In landfills, cap and base liners are required to protect surrounding environment like surface water, ground water and underlying soils [1, 2]. Researcher [3] stated that, for any admixtures that are used as liners, it should be low permeability i.e. k<10-9 ms-1, at least 30% fines, plastic limit less than moisture content, plasticity index (PI) greater than 7%. The commonly available admixture such as sand, cement, lime, bentonite, brick dust and fly ash are used to prepared composite liners. A researcher [4] used fly ash with bentonite to investigate the effect of fly ash content on the plasticity, compaction properties, cracking behaviour, etc. of composite soils. Another researcher [5] used brick dust with lime to study their combined effect on engineering properties of soil. It is very essential to measure cracking behaviour of liners for better performance. Now-a-days an image-based analysis techniques are gaining popularity to quantify crack development and characterization. Researchers [2,6,7] used image analysis technique to konow the cracking behaviour of composite landfill liners. If directly measure the cracks parameters, larger error will fabricate in actual results due to irregular length, width and shape of cracks [8]. In this study, admixture like fly ash and brick dust were used to prepare composite liners. To quantify and analyze of desiccation cracks/cracking behaviour of composite liners a MATLAB code was developed. In addition, ImageJ and MS excel were also used. CIF was measured from MATLAB coding. Besides, CDF and crack area were determined using ImageJ and MS excel. Moreover, the variation of CIF, CDF and crack areas with in relation to the changing of mixing water content as well as specimen thickness were investigated. A new window will may open through this study for designers to prepare cap and base liners in waste landfill easily and economically specially in least developed Asian countries like Bangladesh.

II. MATERIAL AND METHOD

To fulfill the desire goal of this study, the following procedures were performed and hence discussed herewith.

2.1 Collection Of Soil Sample

In this study, disturbed soil samples at a depth of approximately 5 feet below existing ground surface were collected from a waste disposal site at Rajbandh, Khulna, Bangladesh. Soil samples were first air-dried and then powdered. The powdered samples were then sieved through #4 and used to prepare composite liners. In the laboratory, physical and index properties of soil 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 found as 37.65%, 20%, 1.59gm/cc, 2.61, 54%, 31%, 23% and 35.11%, 4.6%, 64.7%, 30.7%, respectively.

2.2 Collection Of Additives

To prepare composite liners, fly ash and brick dust were collected from local market. In this study, fly ash and brick dust were passing through #4 sieve. In the laboratory, physical and index properties of admixtures were measured. The values of optimum moisture content, maximum dry density, specific gravity and liquid limit of fly ash were 34%, 1.52gm/cc, 2.23 and 42.6% respectively. In addition, the values of optimum moisture content and maximum dry density of brick dust were 31%, and 1.46gm/cc, respectively.

2.3 Preparation Of Composite

Experimental work was carried out by mixing of fly ash and brick dust separately with air dried soil in different percentages. The mixing proportions of 20, 30, 40, 50, 60 and 70% of fly ash with soil were used to prepare composite landfill liners. Moreover, mixing proportions of 10, 20, 30, 40, 50 and 60% brick dust by dry weight with soil was used. In this study, three different moisture contents equals to optimum moisture content, plastic limit and liquid limit were considered to prepare liners. The mixing soil slurry were kept in air-tight polythene bags for 2 hours due to uniform water absorption in wooden chamber. In this study, diameter of steel circular mold of 30cm was used. Thickness of mold like 10, 20 and 30mm were used to prepare composite liners.

2.4 DRYING AND IMAGE TAKING PROCESS

After preparing specimens, desired amount of soil slurry was poured in mold and kept the mold 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 water. In this stage, it was ensured that each specimen could get equal heat. A thermometer was connected to the chamber to measure the variation of temperature in a regular basis and the temperature was found approximately 38º C. During drying process, a digital camera was mounted at top of sample through a 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 as shown in Figure 1.

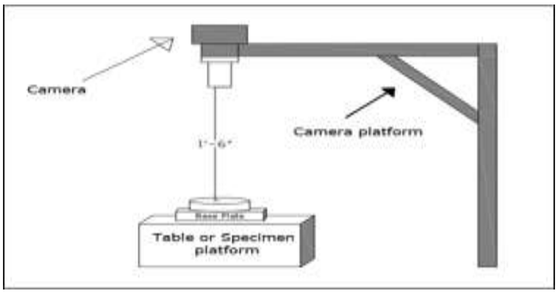

Figure 1. Camera setup for taking image

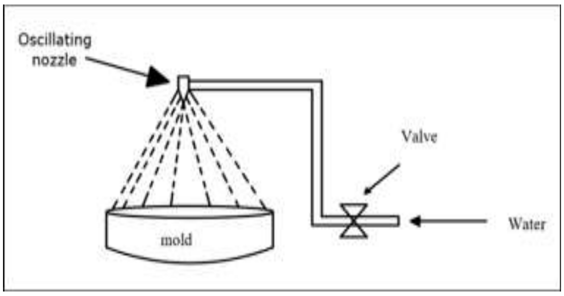

Figure 2: Spraying nozzle setup for spraying water

2.5 Wetting And Drying Cycles

Initially, all liner specimens were subjected to two cycles: a dry cycle and a wet–dry cycle. Three cycles of wetting and drying were subjected to simulate the field behavior of liners. In drying cycle, formation of cracks were constant for both liners after seven days (168hrs). After the end of first drying cycle with constant crack area at 168hrs for both liners, desired amount of water was applied to start a wetting cycle. In wetting cycle, about 250ml/day of water for 4 days were used through spraying nozzle to simulate the percolation behavior of clay shown in Figure 2. In wetting cycle, developed cracks became zero for both liners after 4 days. For this reasons, duration of drying and wetting cycles was considered as 7 and 4 days, respectively.

2.6 Image Processing

Extraction of meaningful information from digital images clicked by camera by means of image processing is performed in two basic steps. The first step involves image processing in which image was prepared in various stages for further analysis. This included cropping unnecessary part of RGB and then to a binary image obtained by thresholding RGB image shown in Figure 3. The second step consists of the analysis of processed image to calculate the parameters that characterize CIF, total area of cracks and CDF.

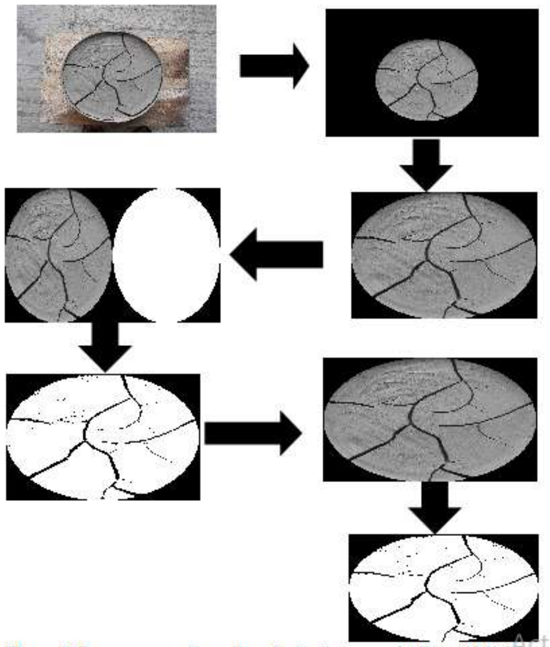

Figure 3. Image processing and analysis of a composite liner (30% fly ash with soil of 30mm thickness at water content equal liquid limit)

2.7 IMAGE ANALYSIS

RGB Image obtained from camera were analyzed in MATLAB to gain useful information. MATLAB program was developed in such a way that it counts only the area of black pixels in image. These black pixels shows cracked area. 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 following Equation 1. For determination of other parameter, ImageJ and MS excel were used. For determination of diameter of reduced specimen, a known distance in image like diameter of mold was marked by straight line and scale is set in ImageJ by going to the option Analyse-Set Scale-give value 30cm. In the same image length of reduced specimen was calculated by measure command (Analyze-measure). Other parameters like total area of cracks were calculated through MS excel. The values of CDF were computed using the following Equation 2.

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

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

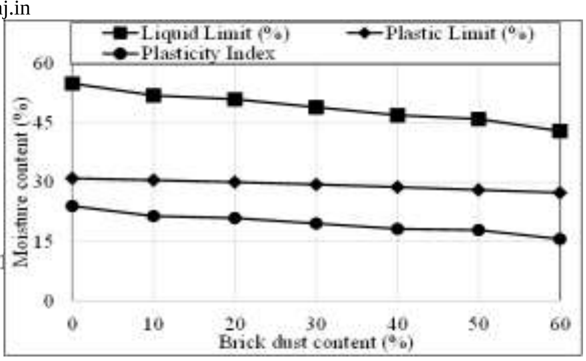

Figure 5: Atterberg's Limit of composite soil replacement with BD

III. RESULTS AND DISCUSSION

The variation of engineering properties of soil slurry at varying mixing proportions of admixtures as well as the effects of cycles, thickness, moisture and admixture content on desiccation cracks of liners with fly ash and brick dust were analyzed and hence presented in the following articles.

3.1 Atterberg's Limit

Figure 4 and Figure 5 illustrates the comparison of Atterberg's limit in terms of liquid limit (LL), plastic limit (PL) and plasticity index (Pl) of soil slurry with fly ash and brick dust, respectively. Atterberg's Limit depends on the proportions of fly ash and brick dust content in liners. The values of LL, PL and PI of soil slurry reduces due to increasing of fly ash and brick dust content.

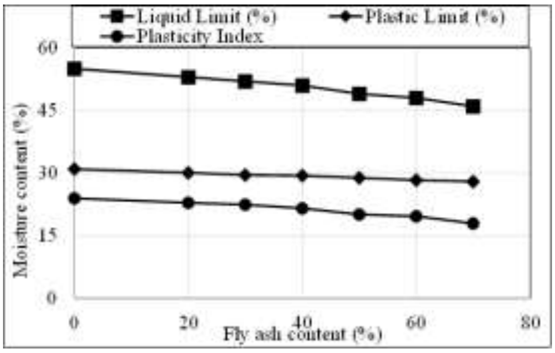

Figure 4: Atterberg's Limit of composite soil replacement with FA

The LLs were measured 53, 52, 51, 49, 48 and 48% for slurry with 20, 30, 40, 50, 60 and 70% fly ash, respectively (Figure 4). In addition, it was observed 52, 51, 49, 47, 46 and 43% for the mixing percentages of 10, 20, 30, 40, 50 and 60% brick dust in liners, respectively (Figure 5). The LL of slurry with 20% fly ash content were counted 30.11%.

The values of LL reduces with the increasing of fly ash content in liners and it was found 29.55, 29.43, 28.86, 28.32 and 28.02% for the mixing percentages of 30, 40, 50, 60 and 70% fly ash content, respectively. In addition, PL with 10, 20, 30, 40, 50 and 60% brick dust content in liners were observed 30.53, 30.04, 29.42, 28.77, 28.09 and 27.37%, respectively. The values of PI for slurry with 10, 20, 30, 40, 50 and 60% brick dust were 21.47, 20.96, 19.58, 18.23, 17.91 and 15.62%, respectively. Moreover, the PI values with 20, 30, 40, 50, 60 and 70% fly ash were 22.89, 22.45, 21.57, 20.14, 19.68 and 17.98%, respectively.

3.2 Compaction Characteristics

The variation of dry density in relation to the changing of water content of soil slurry with fly ash and brick dust content depicted in Figure 6 and Figure 7, respectively. Due to presence of fly ash and brick dust content in soil, weight of the soil specimen increases with the increase compacting efforts. Therefore, dry density increases with the increasing of admixture content in soils. Dry density for control soil was 1.59gm/cc and it increases with the increasing of percentage of admixture content. It increases with the increasing of fly ash content and it was found 1.64, 1.67, 1.69, 1.71, 1.72 and 1.74 gm/cc for 20, 30, 40, 50, 60 and 70% fly ash content, respectively.

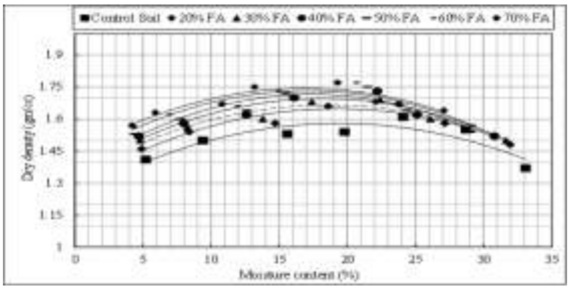
Figure 6: Variation of MDD with FA content

Optimum moisture content (OMC) for the same mixing percentages of fly ash were measured 19, 18, 17.5, 17, 16.5 and 16%, respectively. Besides, it was measured 1.65, 1.67, 1.69 1.71, 1.76 and 1.81 for 10, 20, 30, 40, 50 and 60% brick dust content, respectively. OMC were found 19, 18, 17.5, 17, 17 and 16.5% for the same percentages of brick dust content, respectively.

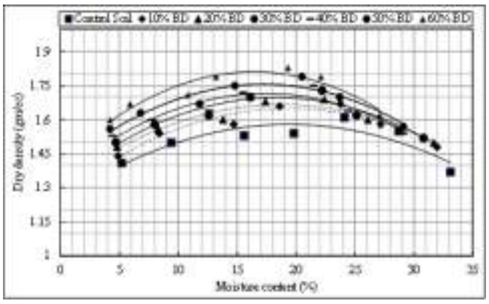

Figure 7: Variation of MDD with FA content

3.3 Desiccation Cracks

The desiccations cracks/creaking parameters interms of CIF, CDF and crack area of composite liners were analyzed and hence discussed in the following articles.

3.3.1 Crack Intensity Factor

The effect of cycles, admixture and moisture content of CIF of liners were analyzed and presented hereby.

3.3.1.1 Effect Of Cycles And Admixture Content

The variation of CIF with in relation to the changes of drying and wetting times as well as mixing proportions of fly ash (FA) and brick dust (BD) content with mixing water content equals to optimum moisture content (OMC) having specimen thickness 30mm, is shown in Figure 8 and Figure 9, respectively. The intensity of cracks was subjected very low during 1st drying cycles. It was observed that, in the 1st drying cycles, CIF less than 1% for both liners. After 1st drying cycle, it was applied approximately 250mm to circulate wetting cycle for both liners. The cracks were gradually closed due to the application of water and no cracks were observed on liners after 4 days. In 2nd drying cycle, intensity of cracks increases rapidly in 1st two days and then slowly moved upward and became constant after 5 days.

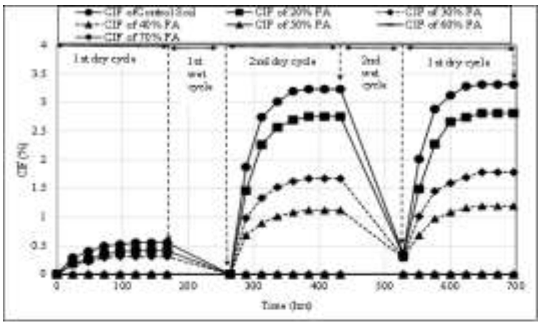

Figure 8: Variation of CIF with time of liners with fly ash having 30mm thickness for dry and wet cycles at OMC.

The values of CIF for fly ash did not decrease to 0% subsequent to 2nd wet cycle. Because the application of water on the soil surface did not result in closing all of the crack. It is believed that rearrangement of soil fabric diminishes and eventually ceases subsequent to one or two wetting and drying cycle. Therefore, with multiple wet and dry cycles experiment, amount of cracking did not significantly change after 2nd wet and dry cycles. From Figure 8 and Figure 9 it was clearly observed the effect of proportions of admixture content in liners like fly ash and brick dust on CIF. With the increasing of admixture content in liners, the values of CIF were reduced. The fly ash and brick dust have low capacity of swell and shrink. Due to low capacity of swell and shrink, it lost it tendency of cracks with the increasing of fly ash and brick dust content in liners. Therefore it was counted lower CIF with the increasing of mixing percentages of admixture contents in liners. In the 2nd drying cycle, CIF were counted 2.75, 1.67 and 1.12% for the changing percentages of 20, 30 and 40% fly ash content, respectively (Figure 8). It was measured 2.62, 1.56 and 0.99% intensity of cracks at same drying cycles having with 10, 20 and 30% brick dust, respectively (Figure 9). In addition, no CIF for liners with 50, 60 and 70% fly ash as well as liners with 40, 50 and 60% brick dust were observed.

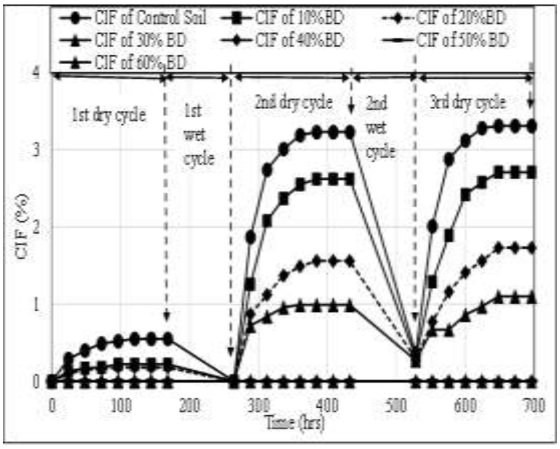

Figure 9: Variation of CIF with time of liners with brick dust having 30mm thickness for dry and wet cycles at OMC.

3.3.1.2 Variation Of Cif With Thickness And Moisture Content

The variation of CIF of composite liners at varying thickness as well as moisture content equals to OMC, PL and LL for 50% fly ash and 50% brick dust as shown in Figure 10 and Figure 11, respectively. From figures, it can be easily observed that, values of CIF increases with the increasing of water content, while it reduces with the increasing of liner thickness. Water are evaporated from soil due to the application of temperature on the liner specimen. Due to high cohesion behaviour, small particle of soil are moved inwards rapidly. This inwards movement of soil particles will be more, if the proportions of moisture content is more or proportions of solid particle are less. The inwards movement of solid particle leads more cracks on the liners. As a result, intensity of crack in specimen was found higher at mixing water content equal LL than that of OMC and PL.

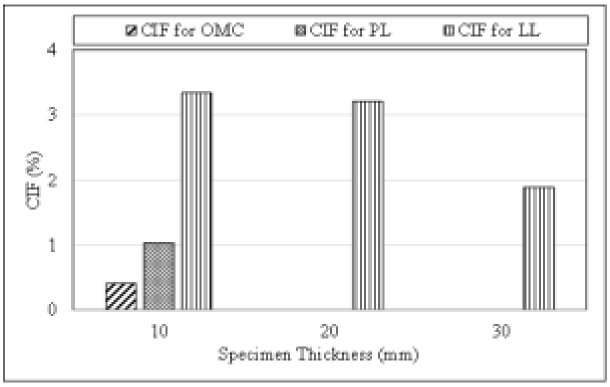

Figure 10: Variation of CIF with 50% FA Content at OMC, PL and LL for all the Specimen Thickness

CIF were measured 0.41, 1.04 and 3.34% for 50% fly ash content having liner thickness of 10mm at varying water content equals to OMC, PL and LL, respectively (Figure 10). In addition, it was found 0, 1.06 and 1.89% having with 50% brick dust content at different water content equals OMC, PL and LL, respectively (Figure 11).

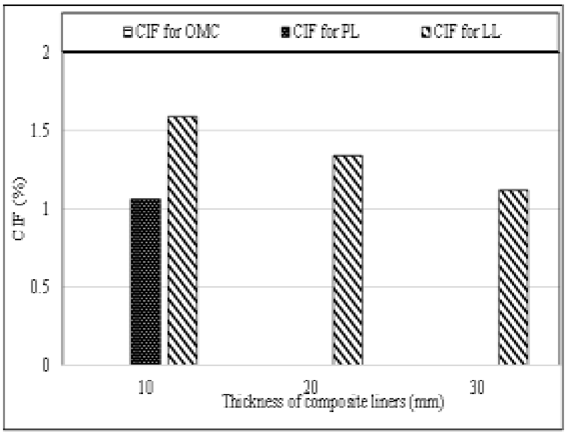

Figure 11: Variation of CIF with 50% BD Content at OMC, PL and LL for all the Specimen Thickness

The tendency of cracking are seen higher in thinner sample due to high rate of desiccation. Consequently, CIF decrease with increase of specimen thickness. Therefore, intensity of cracks for liners of 10mm thickness for both admixture content were comparatively higher than that of liners with 20 and 30mm thickness. It was observed 3.34, 3.21 and 1.89% for 50% fly ash content at water content equals to LL having with liner thickness of 10, 20 and 30mm, respectively (Figure 10). Moreover, 1.59, 1.34 and 1.12% were measured for liners having 50% brick dust content at same water content and thickness, respectively (Figure 11).

3.3.2 Cracks Area

The variation of cracks area of composite liners with the changes of liner thickness, moisture and admixture content were analyzed and hence discussed in followings.

3.3.2.1 Variation With Liner Thickness And Moisture Content

Figure 12 and Figure 13 illuminates the effect of cracks area with liners thickness at varying mixing moisture content equals to OMC, PL and LL for 50% fly ash and brick dust content, respectively. Cracks area depends on some geometrical parameters like moisture content and liners thickness. With the increasing of water content more cracks were detected for liners, while, with the increasing of liners thickness it was reduced. Due to inwards movement of solid particle, cracks area of liners were found higher at water content equals to LL than that of liners with OMC and PL.

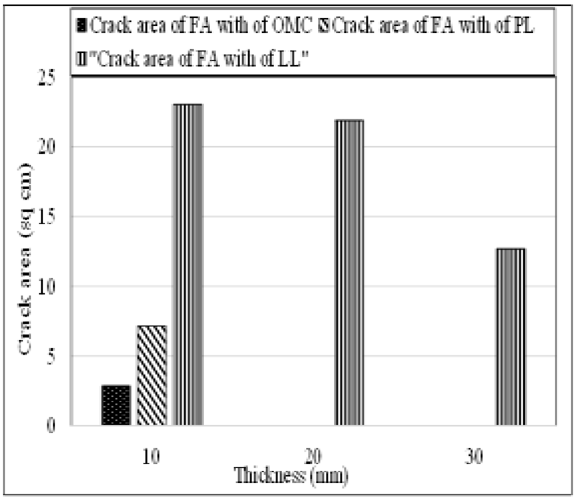

Figure 12: Variation of crack area with FA Content at OMC, PL and LL for all the specimen thickness

Cracks area reduces due to increase of liners thickness and it was counted higher cracks area of liners having with 10mm than that of 20 and 30mm thickness. The cracks area were found 23.03, 21.88 and 12.69 cm^2 for liners with 50% fly ash at moisture content equals to LL having 10, 20 and 30mm liners thickness, respectively (Figure 12). In addition, 10.47, 9.26 and 7.52 cm^2 were measured for liners with 50% brick dust at same moisture content and liners thickness, respectively (Figure 13). The tendency of cracks reduces due to decrease of water content in liners. It was counted 2.85 and 7.17cm2; 0 and 4.31cm^2 crack area for 50% fly ash and brick dust having with water content equals OMC and PL, respectively. In addition, No cracks were observed for liners with moisture content equals to OMC and PL having 20 and 30mm with fly ash content and 10, 20 and 30mm liners thickness with brick dust content, respectively.

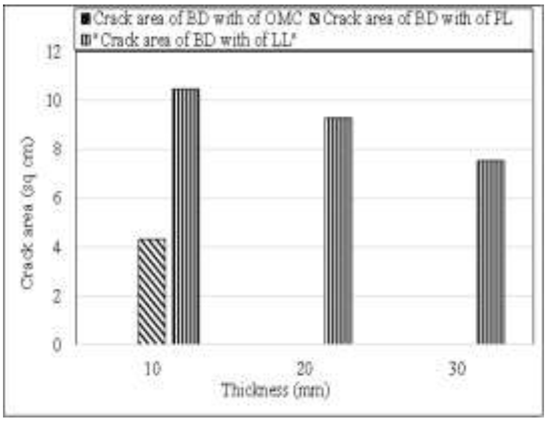

Figure 13: Variation of crack area with BD Content at OMC, PL and LL for all the specimen thickness

3.3.2.2 Variation With Admixture Content And Moisture Content

Figure 14 and Figure 15 depicts the effect of cracks area of liners with water content equals to OMC, PL and LL for 10mm thickness with fly ash and brick dust, respectively.

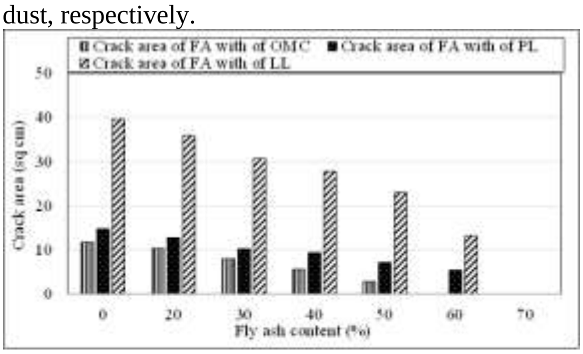

Figure 14: Variation of crack area of stabilized soils with FA content at varying mixing water content

The behaviour of crack area depends on swell, shrink and cohesions of soil. The swell and shrink capacity of fly ash and brick dust are very low. Since, composite liners were prepared with fly ash and brick dust, it reduced the tendency of cracks with the increasing of fly ash and brick dust in liners. From Figures, it was observed, area of cracks were going downwards with the increasing of fly ash and brick dust and it was going upwards with the increasing of water content in the liners. The area of cracks for control soil having with water content equals OMC, PL and were measured 11.77, 14.78 and 39.58 cm^2, respectively.

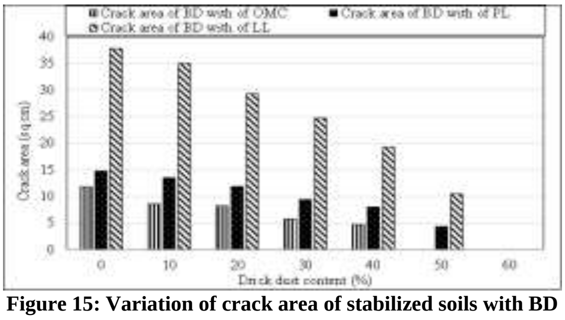

Figure 15: Variation of crack area of stabilized soils with BD content at varying mixing water content

Cracks are were reduced due to increase of fly ash and brick dust. It was found 10.31, 12.77 and 35.86; 7.99, 10.20 and 30.86; 5.60, 9.34 and 27.74; 2.85, 7.17 and 23.03; 0, 5.40 and 13.19cm^2 for liners with 20, 30, 40, 50 and 60% with fly ash having water content equals to OMC, PL and LL, respectively. Additionally, liners with 10, 20, 30, 40 and 50% brick dust, it was observed 8.60, 13.52 and 34.97; 8.20, 11.85 and 29.28; 5.75, 9.41 and 24.71; 4.73,8.00 and 19.25; 0, 4.31 and 10.47cm^2 at water content equals OMC, PL and LL, respectively. No cracks were detected for all liners having 70 and 60% fly ash and brick dust, respectively.

3.3.3 Crack Density Factor

The variation of CDF of composite liners with the changes of liner thickness, moisture and admixture content were analyzed and hence discussed in followings.

3.3.3.1 Variation With Liner Thickness And Moisture Content

The variation of CDF with varying liners thickness equals 10, 20 and 30mm as well as different mixing water content in terms of OMC, PL and LL for 50% fly ash and brick dust content are shown in Figure 16 and Figure 17, respectively.

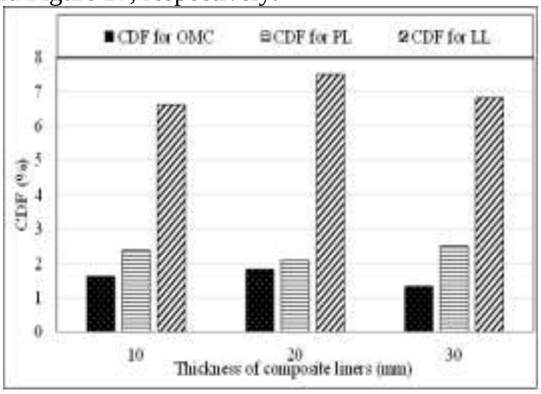

Figure 16: Variation of CDF of stabilized soils with FA content at varying mixing water content and specimen thickness

Result depicts CDF increases with the increasing of water content and liner thickness. The density of crack in liners was found higher at mixing water content equals to LL than that of liners with OMC and PL. The values of CDF were found 6.62, 7.50 and 6.82% for liners with water content equals to LL for 50% fly ash content having 10, 20 and 30mm liners thickness, respectively. In addition, it was to 2.37, 2.09 and 2.50%; 1.62, 1.82 and 1.33% for same thickness with water content equals to PL and OMC, respectively. On the other hand, same increment were observed with the liners of brick dust. The density of cracks were counted 2.71, 4.74 and 4.95%; 1.81, 1.86 and 1.96%; 1.03, 1.59 and 1.73% for liners of 50% brick dust with mixing water content equals to LL, PL and OMC having with 10, 20 and 30mm liners thickness, respectively.

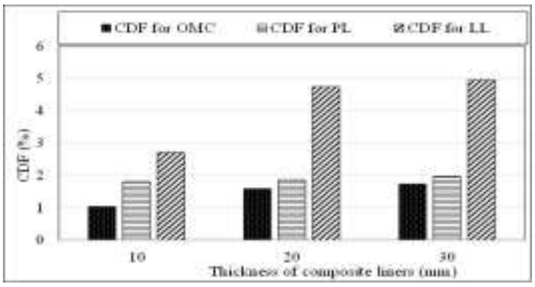

Figure 17: Variation of CDF of stabilized soils with BD content at varying mixing water content and specimen thickness

3.3.3.2 Variation With Admixture Content And Moisture Content

The effect of CDF with mixing proportions of fly ash and brick dust at varying water content equals to OMC, PL and LL for 10mm liners thickness depicted in Figure 18 and Figure 19, respectively. The density of crack is the defined as the percentage of surface shrinkage area in a liner specimen. Surface shrinkage area means summation of crack area and shrinkage area. The percentages of overall surface shrinkage in liners were reduced with the increasing of fly ash and brick dust content. Results reveal, the density of cracks were reduced due to increase of fly ash and brick dust content while it was increased with the increasing of water content in the liners. CDF were counted 11.97, 10.20, 8.42, 6.62, 4.85 and 1.28% for liners with fly ash for 20, 30, 40, 50, 60 and 70% as well as 11.51, 8.48, 6.66, 4.70, 2.71 and 1.22% for brick dust with 10, 20, 30, 40, 50 and 60% having water content equals to LL, respectively. In addition, this values were reduced due to decreasing water content.

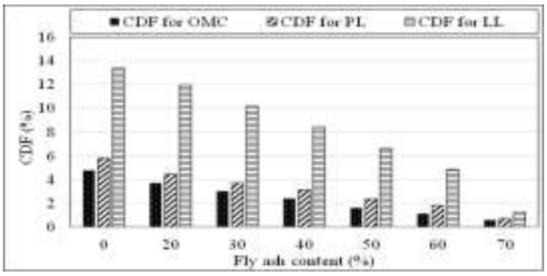

Figure 18: Variation of CDF of stabilized soils with FA content at varying mixing water content

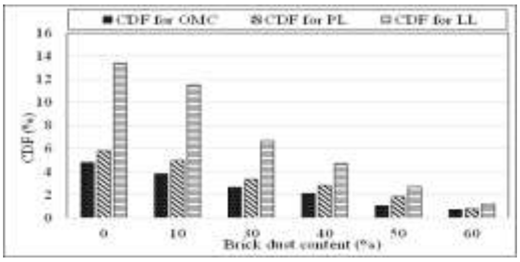

Figure 19: Variation of CDF of stabilized soils with BD content at varying mixing water content

IV. CONCLUSION

Results reveal CIF, CDF and cracks area reduces with the increasing of mixing proportions of fly ash and brick dust content in liners. CIF, CDF and cracks area increases due to increase of water content in liners. CIF and cracks area reduces, while CDF increases with the increasing of liners thickness. The amount of cracks increases significantly after 1st drying and wetting cycles. However, with multiple wetting-drying cycles, amount of cracking did not change significantly after 2nd cycle. A new window will may open through this study for designers to prepare cap and base liners in waste landfill easily and economically specially in least developed Asian countries like Bangladesh.

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