



Quantification of Geometrical and Morphological Characteristics of Desiccation Crack and Shrinkage Behavior of Composite Clay Liner

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PAPER INFO

Paper history:

Received 23 October 2018

Accepted in revised form 31 December 2018

Keywords:

Landfill liner

Desiccation cracks

Composite clay

Image based algorithm

ABSTRACT

Clay soil and their related irregular behavior such as shrinkage, swelling, desiccation cracks etc. are the main concern for the construction of composite clay liner (CCL) in waste landfill site. In this study, an investigation was conducted on a scaled model of prototype landfill liner to quantify both the geometrical and morphological characteristics of desiccation crack of CCL. For evaluating its cracking behavior cement, Khoa Brick and fiber were used as additives for two phases of investigation. In this study, for the quantification of geometrical and morphological characteristics of desiccation crack of CCL, both the image-based algorithms on MATLAB and Image J software was performed. To evaluate additives significance on soil, surface crack ratio, average length and width of cracks, number of crack segments, crack density and others related parameters were determined. Results showed significant impact on clayed soil due to presence of various types and percentages of additives. Experiential results depicted that surface crack ratio increases with reducing water content on prototype sample and finally stabilized its propagation. For preparing CCL with clay from selected landfill site of Khulna the optimum content of additives were found 5, 5 and 1.5% for Khoa Brick, cement and polymer fiber, respectively.

doi: 10.5829/ijee.2018.09.04.09

INTRODUCTION

Before and after deposit of municipal solid waste (MSW) in landfill, cap and base liner is needed to be provided. Properly design of landfill liner, protects surrounding environment including soil, ground water and surface water by containing leachate that are generated in landfill by controlling injection to the ground water, and assisting in control of migration of landfill gas [1]. The most common material used for liner system is compacted clay as it is well-known that clay soil has low hydraulic conductivity which is the premier characteristic of liner. For better performance of liner, clay liner should be low permeable throughout its lifetime [2]. But this character of clay soil can be highly compromised when desiccation cracks start to propagate through soil [3]. If surficial tensile stress exits soil tensile strength and volumetric shrinkage becomes constrained, desiccation cracks promote its geometrical characteristics [4]. Capillary force related to soil moisture, start to evaporate at atmosphere and soil begin to shrink. Due to drying of soil, suction develops inside soil mass which increases soil effective stress. Besides, moisture and density conditions, confining pressures, temperature, and cycles of wetting and drying are also responsible for crack formation [5].

Fine grained soil which has more pore spaces than coarse grained soil, is sensitive for crack formation due to its high suction value [6]. A high plasticity index (PI) and low shrinkage limit indicate high potential for shrinkage swelling. For example $PI > 35$, excessive shrink is expected [7].

Lime, cement, fly ash, sand etc. have been added to high volumetric shrinked soil to minimize their shrinkage [2]. Addition of lime content in clay soil helps to reduce soil shrinkage and crack intensity [8]. But due to presence of lime in clay, soil hydraulic conductivity increases to by a factor of 10 to 1000. Shrinkage of Cement Soil Liner (CSL) decreases with adding of cement content to its optimum content and after that it has little effect in crack reduction. According to U.S. Environmental Protection Agency, CSL is sensitive in electroplating sludge and acidic steel pickling waste but highly effective in toxic pesticide formation, oil refinery sludge, pharmaceutical and plastic waste. But, recently, concept of randomly intrusion of fiber in clay soil has been introduced by many researchers. Randomly inclusion of fiber on sandy soil not only increases its shear strength but also increases its compressive strength [9]. But fiber reinforced soil strength is greatly depended

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on its fiber distribution and orientation on soil matrix [10]. Soil ductile behavior is significantly increased due to inclusion of fiber [11]. Besides, Fiber length (From 64 to 254 mm) has no significant effect on changing magnitude of dry density and optimum moisture content [12]. Al-Wahab and El-Kedrah [13] also found the same output about dry density and moisture content which did not significantly fluctuate by addition of fiber but decreased its shrinkage/swell and crack index. It is a natural process involving weathering, chemical and biological changes of soil. Crack dimensions are generally measured by using approximate method due to absence of established standard method. A scale range from 0 to 4 indicates the severity of cracking. Severity number 0 indicates absence of crack where 4 indicates presence of severe crack of widths >20 mm [14]. Based on research purposes various researchers developed various methods and computer-based code to quantify and characterize cracks. Al Wahab and El-Kedrah [13] proposed crack index which is ratio of the cracks area (Product of crack length and width) to total surface area of the soil. It is believed that dimension measured by Al Wahab and El-Kedrah was based on ruler. Guidi et al. [15] used electro-optical method to determine the crack quantity which is simplified block diagram of apparatus and followed procedure was described by Petruzzelli et al. [16]. If directly measure the cracks parameters, larger error will fabricate in actual result due to irregular shape, length, width and depth of cracks and shrinkage [17]. Now-a-days digital image analysis techniques are gaining popularity in both crack quantification and characterization. Therefore, photographic image analysis appears to be useful tool of crack characterizing process. Various researchers described their own methods for cracks analysis based on image techniques. Lima and Grismer [18] and Logsdon et al. [19] used photographic method to measure surficial cracks. Liu et al. [20] and Tang et al. [17] used their own developed software known as CIAS to find out geometric parameters such as number of intersections per unit area, N_{int} ; number of crack segments per unit area, N_{seg} ; mean crack length, L_{av} ; mean crack width, W_{av} and mean clod area, A_{av} which were determined from final crack patterns. In their method, to calculate crack length, cracking images were skeletonized following Gonzalez and Woods [21] method. Finally, the calculated crack length based on the mid-axis length of the crack segments. On the other hand, Miller et al. [22] introduced image-based parameter, crack intensity factor (CIF) which was defined as ratio of area of surficial cracks to total surface area of the drying soil. In this study an image-based algorithm was used to quantify cracks area in MATLAB. Then Image J software was used to determine other relevant parameters so that both geometrical and morphological characteristics of cracks can be easily described.

MATERIAL AND METHOD

Collection of soil sample

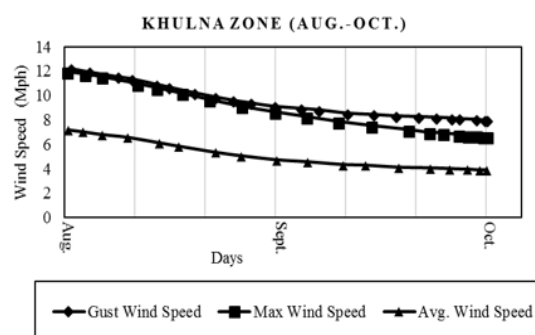
In this study, disturbed soil sample was collected from a selected waste disposal site at Rajbandh, Khulna, Bangladesh which is approximately 20 km away from Khulna City. Soil sample was collected from a depth of 1.5 m below existing ground level and carried out to laboratory. The collected soil sample was tested in two different environmental conditions, once at earlier September 2016 and another was late December 2016. In the laboratory, the physical and index properties of soil were measured through ASTM standards and depicted in TABLE 1.

Additives

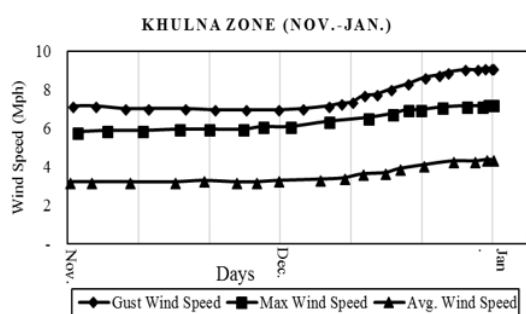
In this study, to prepare CCL, different types of commonly used additives like Khoa Brick, ordinary Portland cement and polymer fiber was collected from local market. Khoa Brick and Ordinary Portland Cement were used to reduce crack in clay soil as well as fiber was used to increase soil strength. Size of Khoa Brick used in the investigation was 1” downgraded. In this study, 12mm length fiber was used to prepare composite clay with soil.

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

Properties	Unit	Values	Analytical method
Initial moisture content	%	31.50	ASTM D 2974
Optimum water content	%	18	ASTM D 558
Maximum dry density	kN/m ³	16.75	
Specific gravity	--	2.64	ASTM D 854
Liquid limit, LL	%	52	ASTM D 4318
Plastic limit, PL	%	26.80	
Plasticity index, PI	%	25.20	
Shrinkage limit, SL	%	38.43	ASTM D 427
Shrinkage ratio, SR	%	1.35	
Sand: silt: clay	%	2.4:67.6:30	ASTM D222

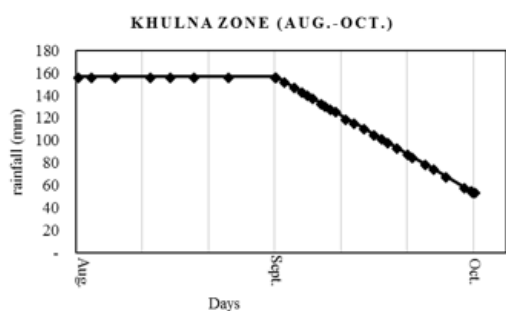


(a)

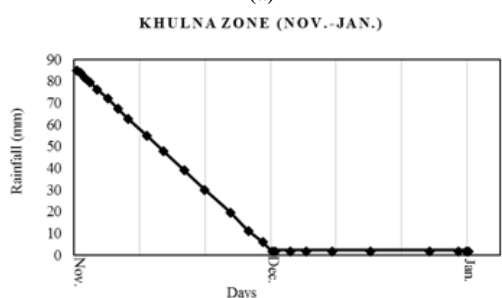


(b)

Figure 1. Daily wind flow during testing time



(a)



(b)

Figure 2. Daily rainfalls during testing time

Climate

Study of cracks at uncontrolled weathering condition has a great impact on crack propagation rate and its geometric condition due to fluctuation of temperature, evaporation, wind speed etc. The average rainfall and wind speed of testing zone at Khulna were collected from WorldWeatherOnline.com and illustrates in Figures 1 and 2 during the period of this research. From these figures it was observed that there were distinct wind speed and rainfall difference in two different testing times. Then the collected climatic data was analyzed using GetData Graph Digitizer and reproduced those graphs. Investigations were conducted in two different phases. The first phase was conducted during 1 September to 12 September, 2016 using Khoa Brick and cement as additives in soil. Furthermore, the second phase of test by using polymer fiber in soil was conducted at 27 December, 2016 to 8 January, 2017.

Program set-up and investigations

Sample preparation

In the laboratory, the saturated surface dry additives like Khoa Brick, cement and polymer fiber were mixed with wetted soil at various percentages separately to make soil slurry provided in Table 2. Finally, a desired amount of composite slurry was poured in rectangular wooden mold of internal dimension of 30cm x 6cm x 8cm shown in Figure 3. It was make sure that no air bubble was present on prepared desired composite clay liner. Khoa Brick and cement were used as additive in sample specimen which were tested at earlier September. On the other hand, polymer fiber additive was used in sample specimens for testing in late December.

Drying and image taking process

After the preparation of soil sample specimens, it was placed in open air under sunlight so that desiccation crack could be formed due to evaporation of moisture from liner specimens. In this stage, it was ensured that each specimen could get equal sunlight. During drying process, a digital camera (14 Mega Pixel) which was mounted at top of sample soil through wooden made camera stand, used to take image of dying sample. A 40 cm of constant height was always maintained for taking image of one-day interval shown in Figure 4. The sequentially taking images were used for analysis of both geometric and morphological characteristics of propagating cracks through image processing technique.

TABLE 2. Additive contents for preparing composite clay liner

Additive Content for First Phase			Additive Content for Second Phase		
Additive	Percentage (%)	Water Content	Additive	Percentage (%)	Water Content
Cement	5	46.10	Polymer Fiber	0.5	48.23
	10	44.20		1.0	50.41
	20	45		1.5	47.84
Khoa Brick	10	50.55	2.0	47.24	
	15	50	2.5	43.3	
	20	52.69			

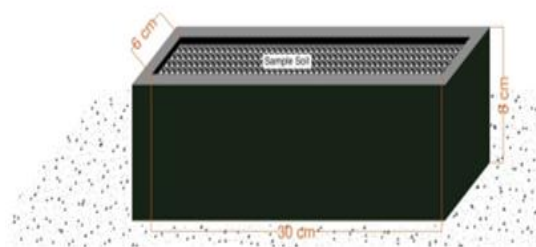


Figure 3. Sample mold for preparing CCL

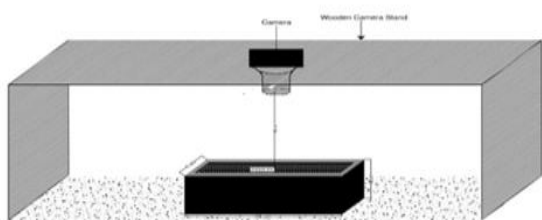


Figure 4. Camera Setup for taking image

Image processing

Digital image processing technique is gaining popularity due to its flexibility of quantification and less errors’ process. In this study, an image-based algorithm was used to analyze liner surface that was developed in MATLAB to determine cracking area and cracking density factor (CDF) along with Image J software to determine other related cracking parameters. The whole sequential manner of image processing is illustrated in Figure 5 described in the following flow diagram.

Quantitative analysis of image

In this study, the following features were determined to analyze cracking pattern of composite clay.

- a) Number of segments per unit area (N_{seg}). It is the ratio of total number of segments to modified soil area after shrinkage.

Total length of cracks (L_{total}), average width of cracks (W_{avg}), and crack density (Dc). The crack

- b) density can be defined as crack length per unit area. Total crack length was measured by calculating middle axis length of each segment. The area of cracks is equal to the product of crack length and width. The average crack width was calculated by dividing crack area with total crack length
- c) The crack intensity factor (CIF). It is the ratio of cracks area (A_c) to total surface area of drying soil. This surficial cracking parameter is time related parameter. In addition, the calculated crack density factor (CDF) is the ratio of total shrink and crack area to initial area of soil sample.
- d) The crack reduction factor (CR), is calculated by using Equation (1).

$$CR = \frac{(CDF_n - CDF_c) \cdot 100}{CDF_n} \quad (1)$$

Where,

CDF_n = Crack Density Factor for natural soil (control) sample (%)

CDF_c = Crack Density Factor for composite soil sample (%)

In this study, all the above parameters were determined based on two software analysis. Total cracking area including shrinkage area and CDF were determined from binary image of MATLAB Coding. In addition, the other features such as crack length, cracking area, number of segments were measured based on Image J software from binary image which was one of the output of MATLAB image analysis.

RESULTS AND DISCUSSION

Geometrical analysis of cracks

In this study, the geometry of cracks like crack length, width, no. of segments and their orientation on soil profile were investigated. The final crack pattern of composite soil of different percent of additives with cement, Khoa Brick and polymer fiber for two phases were investigated as shown in Figure 6. The soil sample was split into several numbers of clods and segments. Some of crack segments were interrelated and others were dead end cracks. But their formation pattern and number were distinctive than each other’s (Figure 6).

In this study, the control specimen is representing the sample having no additive (Figure 6). Control specimen surface has split into clods due to crack formation. From Figure 6 in case of control sample, it was found that cracks are relatively straight, smooth and continuous through short direction of specimen. Number of cracks were relatively low than other corresponding composite sample. But their wideness was significantly larger than composite one. Furthermore, it was found that during irregular weather condition (1st phase) comparatively less numbers but wider cracks were formed than 2nd phase of control specimens.

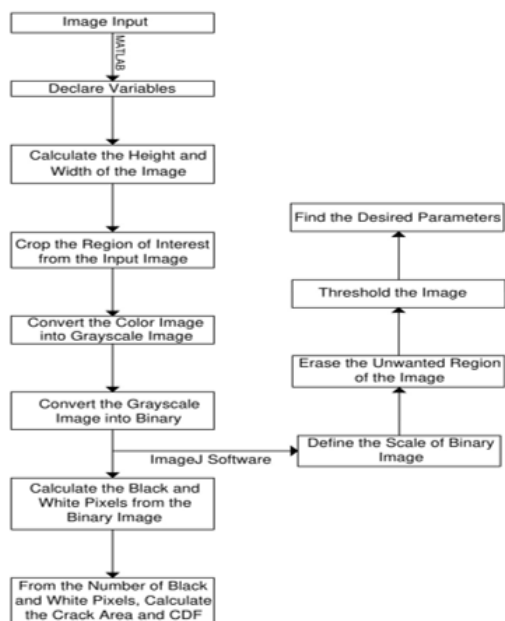


Figure 5. Sequential manner of image processing of this study

In addition, the morphology of cracks was significantly influenced by intrusion of additives in soil. Relatively irregular, discontinuous and jagged cracks were observed for composite clay sample with Khoa Brick, cement and fiber with the increasing of additives content (Figure 6). As a result, the number of cracks also increased. Therefore, this result was found quietly different for cement additive samples. The average width of cracks was dramatically reduced in cement soil liner (CSL) than that of Khoa Brick additives. Lot of micro cracks were formed in CSL and some of them were rarely visible to naked eye. There was significant crack formation difference in between Khoa Brick additive and cement additive sample. Small, narrow and dead end cracks were found in CSL. On the other hand, cracks interlocked in among themselves by forming networking of micro cracks in Khoa Brick additives samples. Comparatively, longer, wider and Y shape cracks were produced in Khoa Brick additive samples (Figure 6).

In addition, in Figure 6, 2nd phase of testing, the morphology of cracks was influenced by inclusion of fiber content in soil. It was observed that there was significantly increment of number of cracks which followed its continuation from control specimens to highest percentage of fiber additives. But their wideness was reducing by following increasing order additive percentages and small and micro cracks were formed. Besides, relatively smooth, regular cracks at lower fiber content has become irregular, tortuous and jagged at higher fiber content. This irregularity has become more jagged and complex at 2.0% fiber content specimen. In comparison with natural soil specimens, composite specimens are representing comparatively much finer, shorter and more interlocking cracks.

Quantitative analysis of cracks

In this study, the quantitative analysis of cracks for composite liner for each phase was done using image processing techniques. Cracking behavior of three distinct additives sample showed different patterns and quantitative variations provided in Table 3.

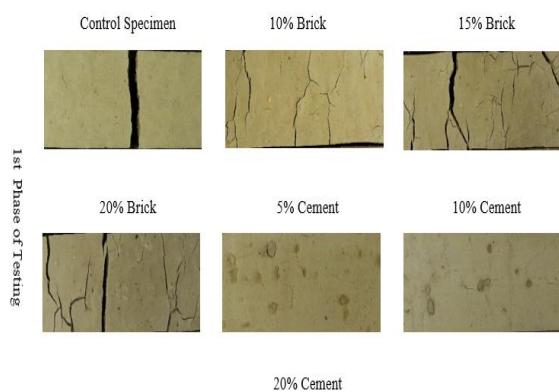


Figure 6. Typical image of final cracks pattern of different soil specimen with various percentage of additives of two phases.

Based on result, it was found that the crack intensity factor (CIF) initially decreases with the increasing of additives percentage in soil for cement, Khoa Brick and fiber additives in 2nd phase (Table 3). But after particular content of every additive, it was again started to increase with adding of its additive percentages (Figure 7). For cement, Khoa Brick and fiber content, the critical percentages were found to be 5, 10 and 1.5%, for cement, Khoa Brick and fiber content, respectively. In addition, it was also found that the CIF and additive content graph was steep for cement and fiber additive where it was quite irregular for Khoa Brick content.

The relationship between no. of crack segments and additive content is shown in Figure 8. From Figure 8, it was found that number of crack segments increases with the adding of materials in soil for cement and Khoa Brick content. However, exactly the opposite scenario was found for fiber additive (Figure 8). The no. of crack segment was quite constant up to certain percentage of fiber content and after that, it has sharply risen (Figure 8). On the other hand, no. of crack segments was rising for cement and Khoa Brick content for certain percentage with 10% for both cement and Khoa Brick content. Moreover, after that, it has again started to flow downward.

The relationship between crack density (Dc) and additives contents is shown in Figure 9. In addition, Dc is conditionally interrelated with no of cracks segments and total cracks length. Nevertheless, the result indicates the variation of crack density with additive content was mostly related with no. of crack segments as both the no. of crack segments and Dc were shown similarity in shape (Figure 9). A study conducted by Tang et al. [23] also found the similar outcome, therefore, the findings of this study agreed with the result postulated by Tang et al. [23].

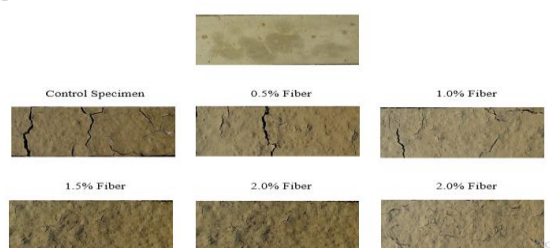


Figure 7. Variation of final CIF with additive contents

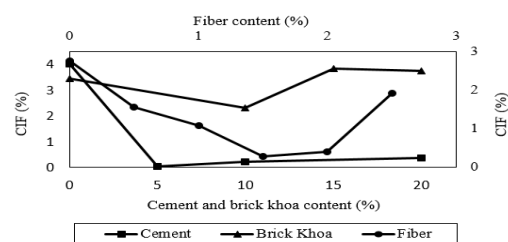


Figure 8. Variation of No. of crack Segments with additive content

TABLE 3. Cracking behavior of composite liner at varying percentages of additive contentPhase-01

Additives	(%)	Total Crack Area (Crack+ Shrinkage), cm ²	Crack Area (cm ²)	Shrinkage Area (cm ²)	Reduced Soil Area after Shrink (cm ²)	Total Crack Length (cm)	Average Crack Width (mm)	No. of Crack Seg.	Nseg.	Dc.	CIF	CDF	CR
Control Specimen	0	35.29	7.272	28.018	211.982	8.753	8.308009	2	0.009435	0.041291	3.43	14.704	0
	10	31.8028	4.903	26.8998	213.1002	72.574	0.675586	42	0.19709	0.340563	2.301	13.251	9.882
Brick Additive	15	30.6584	8.09532	23.132	216.868	60.076	1.347513	30	0.138333	0.277016	3.733	12.774	13.124
	20	29.9209	8.36495	20.983	219.017	65.209	1.282791	31	0.141542	0.297735	3.819	12.467	15.214
	5	4.065	0.05	4.015	235.985	1.973	0.253421	3	0.012713	0.008361	0.021	1.694	88.481
Cement Additive	10	7.0991	0.49	7.075	232.925	19.948	0.245639	11	0.047226	0.085641	0.21	2.958	79.884
	20	11.8563	0.8436	9.534	230.466	7.303	1.155142	9	0.039051	0.031688	0.366	4.94	66.403

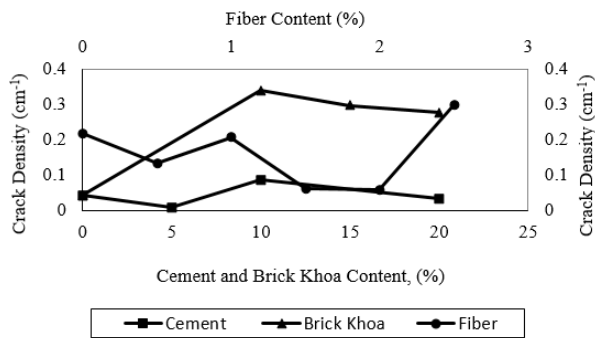


Figure 9. Variation of crack density with additive content

The variation of average crack width with additive content in composite liner is shown in Figure 10. The relationship between average crack width and additive content indicates that the crack width decreased significantly with the increasing of additive content in soil. The change of crack width was more noteworthy at low additive like cement content with 5% cement; average crack width increases while others additives contents showed few reluctant in this regard. In fiber additive, the drastically change was found at 1% fiber content inclusion in soil. After that, for next percent, crack width was more or less constant as well as further addition of fiber; crack width also increases again in composite liner.

The crack density factor (CDF) is quite similar parameter of CIF. In CDF, both crack and shrink area were considered. The variation of CDF in relation to the changes of additive content in soil is shown in Figure 11. From analysis it was found that CDF initially decreases

with progressively adding of additives in soil. But after certain content of additive, this downward trend started to go upward for cement and Khoa Brick content though quite opposite scenario was found in polymer additive. This abrupt behavior of sample specimens can be explained through combined effect of cracks and shrink area. As in CDF parameter both crack and shrink area were considered and clay soil is very prone to large shrink. In this study, CDF parameter is mostly driven by shrinkage area and after 1% fiber content, cracking area increased. However, the trend of CDF and fiber content was still downward because of the intrusion of excessive fiber in soil allowed huge reduction shrinkage area but in the meanwhile; it increases more tortuous and jagged cracks in soil.

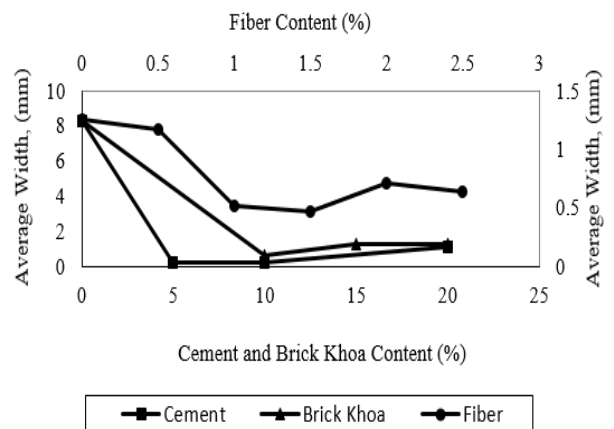


Figure 10. Variation of average crack width with additive content

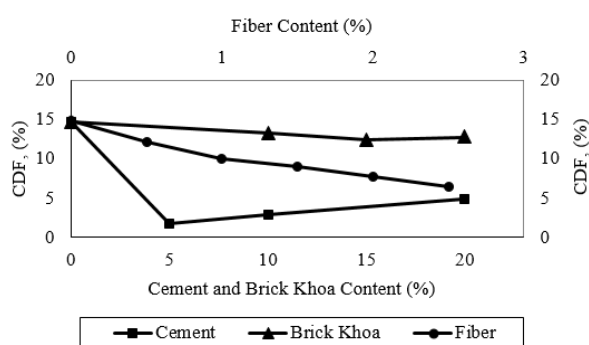


Figure 11. variation of CDF with additive content

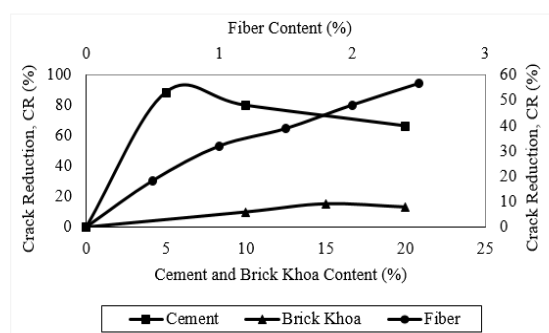


Figure 12. Crack reductions for various additives content

Crack resistance of composite soil

Figure 12 demonstrates that intrusion of additives in soil were effective in the reduction of desiccation cracks of composite clay. These types of similar findings have already been found by various researchers [3, 8, 13, 24, 25]. For quantification of additives influence in soil Millar and Rifai [3] had introduced crack reduction (CR) equation (Equation 1) which was used to find out suitable percentage of additive for particular type of soil. The relationship between CR and additives content (Figure 12) it was found that increasing of additive content in soil significantly increased its CR. Such as for change of Khoa Brick content 10 to 20%, CR was 9.882 to 15.214% in where for fibrous soil changing of fiber content from 0.5 to 2.5% were causing a CR of 18.27 to 56.56%. But quite different result was found for cement content. Although at initial the trend was upward but after crossing of 5% cement content in soil, it again started to fall towards downward. Additionally, capillary suction is the prime reason for crack formation. This capillary suction is sensitive for fine grained soil like clay as there is a lot of pore space in clayed soil. This pore space can be reduced by using coarse grained materials. That's why addition of Khoa Brick on clayed soil is effective for CR. On the other hand, addition of binder materials like lime, cement etc. is effective for CR as they act as a binder in between soil particles. But this binder material has optimum quantity for particular type of soil. And after crossing of optimum dose of cement content in soil (i.e. 5% for Rajbandh Soil) CR was also decreasing.

When Soil tensile stress exits its own tensile strength, soil starts to crack. But this tensile strength can be increased by using fibrous materials in soil. After addition of small quantity of polypropylene fiber in soil, the bonding strength friction in between soil matrix and fiber hinder the relative movement of fiber in soil [26]. As a result, fibrous soil tensile strength has increased due to reinforced of soil by fiber which is able to bear some tensile stress by bridging of formed cracks due to desiccation [25-27]. The changing of evaporation rate is depending on the amount of water reaches to the soil surface. According to Tang et al. [23] investigation an assumption was assumed about redistribution of water in

the soil matrix by fiber which reduces the magnitude and concentration of capillary suction developed during desiccation process. For this reason, with increasing of fiber content in sample soil, relatively smaller crack started to produce in comparison with previous former sample soil. As a result, CR trend for fibrous soil was always upward. But above optimum value of fiber, crack reduction was quite low because of additional intrusion of fiber reduced soil shrink but increased number of cracks.

Analysis of crack formation rate

The variation of CDF with time for various percent of cement content comparing with control specimen shown in Figure 13. Figure 13 reveals that crack formation in all specimens was more or less uniform and in low rate during first 120 hours. But after that cracks formed in specimens were more rapidly than that of initial rate. The rate of formation of cracks in control specimen was more rapid and non-uniform than cement additive specimens (Figure 13). Possible cause for formation of cracks in low rate for first 120 hours was due to rain, all specimens were get cured by rain water and evaporation rate was also low as potential moisture different in between sample and surrounding environment was low. For this reason, cracks developed very slowly at the surface of specimen and only few of cracks were seen appeared at the soil surface. Besides, cement also got curing in this time and after that, sunlight was uniform and due to sunny day evaporation rate was also high. As a result, rate of formation of cracks was also high. The maximum CDF was found 14.7% for control specimen, while, minimum was found 1.69% for 5% cement additive.

In addition, the variation of CDF with time for various percent of Khoa Brick content is shown in Figure 14. From Figure 14, it was found that maximum CDF was 14.7% for control specimen, while, minimum was 12.47% for 15% Khoa Brick additive after 240 h. of preparation of specimens. Same causes were also working behind the initial low cracking rate in sample that was elucidated in composite liner with cement. Besides, non-uniform sunlight due to cloud and moisture of atmosphere influenced the rate of formation of cracks

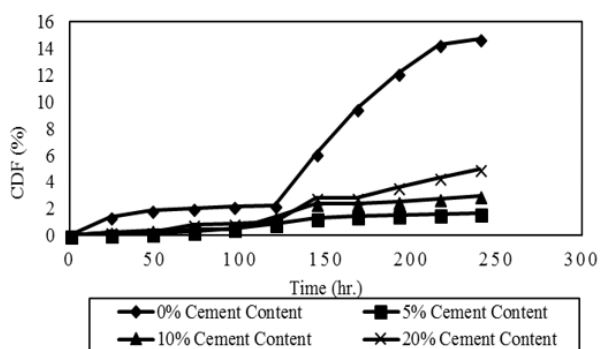


Figure13. Variation of CDF with time for composite liner with cement

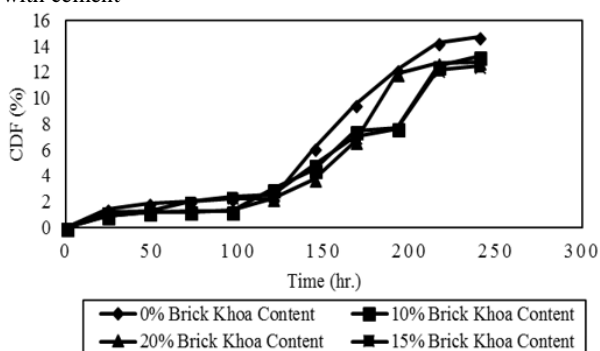


Figure14. Variation of CDF with time for composite liner with brick khoa

in liner. But after 120 h. rate of formation of cracks were almost double of initial as sunlight was uniform.

Furthermore, the CDF in composite liner with various percent of polymer fiber against time is shown in Figure 15. It was observed that initially CDF of all specimen increases at a high rate. Initial high rate of crack propagation of cracks on fibrous soil can be described by Figures 1b and 2b. From those figures it was found that during testing time wind velocity was high in comparison with 1st phase of investigation. On the other hand, average rainfall was very low. As a result, evaporation rate during this time was very high. For this reason, initial cracks propagation rate was so high and wider crack were appeared at very early of time. But after 24 hours, slight retardation of cracks formation was observed. This retardation was occurred due to inconsistent sunlight during this time. The CDF were found 12.07, 10.0, 9.0, 7.7 and 6.42% for 0.5, 1.0, 1.5, 2.0 and 2.5%, respectively after 312 h. Again, rate of increase of CDF was found much less than for 2.5% polymer fiber additive contents. The increasing rate of CDF was found almost higher for control specimen. It was observed that CDF for 0.5% fiber additive having maximum CDF of 12.07%, while 6.417% of CDF for 2.5% fiber additive in composite liner. From Figure 14 it was observed that CDF for 2 and 2.5% polymer additives were adjacent. Besides, excessive fiber intrusion will increase the hydraulic conductivity in soil. On the contrary, long and wider

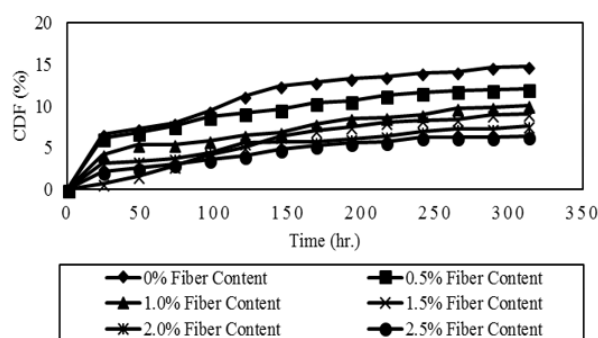


Figure 15. Variation of CDF with time for composite liner with fiber additive

cracks were produced at 1st phase of testing, very early of cracks propagating stages.

Cracking behavior and pattern with additives

The mean maximum crack width of composite liner with various additives at varying mixing proportions with their respective control specimens. From analysis, it was found that mean maximum crack width decreases with the intrusion of additives in soil for both the phases of experiment. It was also observed that the mean maximum crack width was differed from control specimens for both the phases of experiment. The maximum crack width of 1st phase of experiment was wider than 2nd phase. In addition, number of cracks for control specimen of 2nd phase was more intensive than 1st phase of control specimen (Table 4). The smallest width of crack was found for composite liner with cement, while, wider cracks were found for Khoa Brick additive. Besides, quite gentle width of cracks was found for fiber additive.

In this study, Khoa Brick and cement are acting as reducing capillary suction where fiber acts as reinforcement of soil. So, determination of optimum fiber length is also important for getting maximum effective bridging effect of fiber. In two phases of experiment, fiber was used in 2nd phase in where control specimen's maximum crack width is 3.28 mm. So, for this optimum fiber length should be at least more than 3.5 mm. But it was also observed that for 1st phase of same soil's control specimen, maximum average cracks width was found 9.2 mm. For this reason, in this study, 12 mm of fiber length was selected as. As from some previous studies it was observed that fiber length has great impact on mechanical behavior of soil and some other researcher found the optimum length of fiber is important due to obtain best reinforcement effect [28, 29]. Fiber benefits the clay soil by bearing tensile stress. So, fiber length should be selected at least more than maximum crack width that is produced in control specimen. If fiber length exits its optimum length then proper reinforcement benefit may not be found. On the other hand, Fuller Curve should be used for finding the effective gradation of coarse aggregates as additive.

TABLE 4. Mean maximum width of cracks at different sample specimens

Additive Types	Content %	Crack Width (mm)	Additive Types	Content %	Crack Width (mm)
Control Specimen	0	9.2	Control Specimen	0	3.28
Cement	5	0.28	Fiber	0.5	2.85
	10	0.568		1.0	1.77
	20	0.49		1.5	0.8
Brick	10	2.08	2.0	0.703	1.64
	15	4.8			
	20	5.86			

Optimum additive content

Selection of optimum contents of additives on clayed soil for desiccation cracks is quite wearisome because cracks on particular soil depend on various parameters. Researchers defined their own method to determine the optimum content of additives such as Millar and Rifai [3] proposed a parameter known as reduction factor which calculation procedure is depicted at Equation (1). As CR cannot be only the parameter to describe the desiccation cracks, in this study, new way of optimum content determination is described in where percentage contribution of various parameters against their total amount that described the desiccation cracks in soil was considered. Graphical presentations were drawn at Figures 16, 17 and 18 in where percent contributions of various parameters of cracks for each sample were shown. In Figure 16, percent contributions of crack describing parameters for 0, 10, 15 and 20% of Khoa Brick contents samples are shown. From graphical presentation it was found that minimum contribution of these parameters was for 15% Khoa Brick content. On the other hand, from Figure 17 which is representing Millar and Rifai [3] relationship in between crack reduction and additive content, it was found that maximum crack reduction was occurred for 15% Khoa Brick content. According to Millar and Rifai [3] equation, optimum additives content was selected with respect to maximum crack reduction value. On the contrary, in this process, optimum percentage of additives was selected by following minimum percent of contribution which considered all relevant parameters that contributed to describe desiccation cracks in soil. Maximum crack reduction and minimum cracking parameters contribution was found for 15% Brick Khoa content. Therefore, optimum content of Brick Khoa for Rajbandh soil was found 15% which can also be verified by following crack reduction percentage.

In addition, from similar analysis of cement and fiber content, it was found that maximum CR and minimum crack parameters contribution was 5 and 1.5% for cement

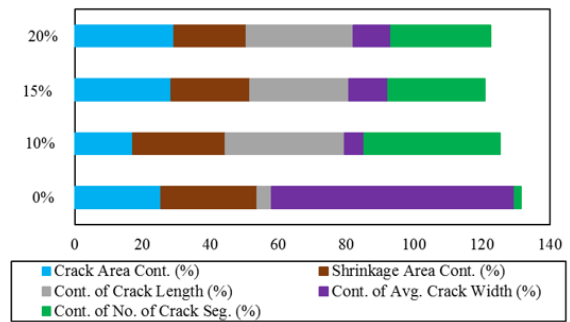


Figure 16. Selection of optimum percentage of Brick Khoa Content

and fiber content, respectively. Optimum content of cement was 5% for composite clay liner. On the other hand, optimum content for fiber additive was 1.5% though the maximum crack reduction was occurred for higher percent of fiber content. As at higher percentage of fiber content, fiber mixing on soil will be become difficult and number of cracks also will also be increased which may allow to increase hydraulic conductivity of fibrous soil. For this reason, optimum content for fiber additive was selected 1.5%.

CONCLUSIONS

The cracks were found comparatively wider, longer and Y shape in Khoa Brick than that of CCL with cement. In contrast, quite small, narrow and jagged cracks produced in 2nd phase than that of 1st phase. Fibrous soil cracks were comparatively irregular, tortuous and jagged at

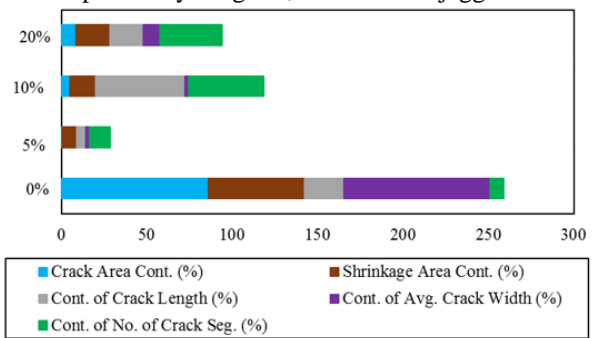


Figure 17. Selection of optimum percentage of cement content

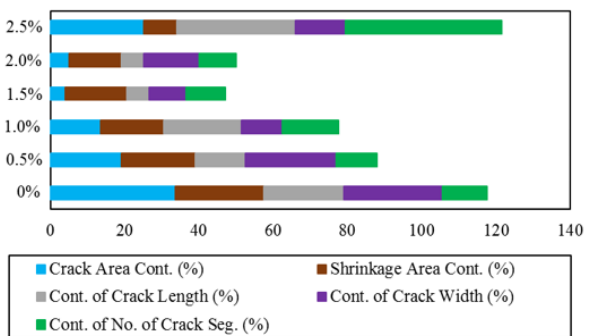


Figure 18. Selection of optimum percentage of fiber content

higher percent of fibers. The CIF, average crack width and CDF decreases initially in relation to the increasing of additive contents in soil, however, after 5% cement, 10% Khoa Brick and 1.5% fiber content, it starts to go upward. Number of crack segment increases upto 10% of cement and Khoa Brick and after that it goes downward, while it constant up to 2% of fiber and then it suddenly increases. The optimum content of additives were found 5, 5 and 1.5% for Khoa Brick, cement and polymer fiber respectively for preparing with clay from selected landfill site of Khulna.

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Persian Abstract

DOI: 10.5829/ijee.2018.09.04.09

چکیده

خاک رس و رفتار نامنظم مرتبط با آن، مانند انقباض، تورم، ترک خوردگی و غیره، نگرانی اصلی در ساخت خطوط ریخته گری ترکیبی (CCL) در محل دفن زباله است. در این مطالعه، یک مطالعه بر روی یک مدل مقیاس پذیر از پلی اتیلن نمونه سازی شده برای اندازه گیری هر دو ویژگی هندسی و مورفولوژیکی ترک خوردگی ترک CCL انجام شد. برای ارزیابی رفتار ترک خوردگی سیمان، آجر خاچ و فیبر به عنوان افزودنی برای دو مرحله تحقیق مورد استفاده قرار گرفت. در این تحقیق برای اندازه گیری ویژگی های هندسی و مورفولوژیکی ترکیب خشکی CCL، هر دو الگوریتم مبتنی بر تصویر بر روی نرم افزار MATLAB و Image J انجام شد. برای بررسی اهمیت افزودنی در خاک، نسبت کرک سطح، طول و عرض عرض ترک، تعداد قطعات کرک، تراکم تراکم و پارامترهای دیگر تعیین شده است. نتایج نشان داد که اثر خاک بر روی خاک رسی به دلیل وجود انواع مختلف و درصد افزودنی ها، اثرگذار است. نتایج تجربی نشان داد که نسبت ترک خوردگی سطح با کاهش میزان آب نمونه بر روی نمونه اولیه افزایش می یابد و در نهایت باعث تثبیت انتشار آن می شود. برای تهیه CCL با خاک رس از محل دفن زباله KhuIna، مقدار مطلوب افزودنی ها به ترتیب ۵، ۵ و ۱،۵ درصد به ترتیب برای سیمان و سیمان Khoa یافت شد.
