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APPLICATION OF SOFTWARE FOR ASSESSING CRACKING BEHAVIOR OF COMPOSITE CLAY USED AS CAP LINER IN WASTE DISPOSAL SITES

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ABSTRACT

This study illustrates the cracking behavior of composite clay prepared in the laboratory by using different percentages of additives. For preparing of composite clay, soil sample was mixed with two additives of sandy and gravelly materials at varying percentages of mixing content. In the laboratory, seven number of cap liner specimens having the dimensions of 30cm×6cm×8cm were prepared. The cracking behavior was analyzed on the basis of cracking parameters. Moreover, in this study, the digital image analysis technique was used to determine the crack intensity factor (CIF). Furthermore, the CIF of each liner specimen were compared with the other specimens and the specimen prepared by using natural soil only (control specimen). From the study it was observed that the overall values of CIF were maximum for control specimen than that of other specimens. It was also observed that, with the increasing of sandy material in percentages, the values of CIF decreases gradually due to more fraction of sand having low shrinkage values. In contrary, with the increasing of gravelly material in percentages, the values of CIF decreases up to the certain percentage, then increases due to the weaken bond between the soil and gravelly material. Additionally, maximum and minimum CIF values were obtained as 13.394 % and 6.242 % in control specimen and specimen prepared with 40% gravelly materials, respectively. Furthermore, by comparing cracking behavior of two types of composite clay, it can be suggested that, 40% of gravelly material had shown comparatively the more suitable as a cap liner against of other counterparts.

Keywords: *Additives, CIF, Composite Clay, Cracking Properties, Digital Image.*

1. INTRODUCTION

When the landfill site has reached its ultimate capacity, a thick final layer of cover material is applied over the deposited waste in landfill/disposal sites which is called cap or cover liner. In developing countries like Bangladesh, a single layer made with only naturally available soil from the nearby locations of landfill site is commonly used as cover liner in almost all landfill sites (Rafizul *et al.,* 2012). Again most of the landfill sites in these countries are filled with sanitary wastes and other wastes. If cap liners are weak and forms cracks, rainwater can infiltrate through these cracks and can be mixed with wastes and produce leachate due to biochemical reaction which is very much hazardous liquid (Rafizul *et al.,* 2013). Landfill gases also produced from these sites and migrate through cracks. Different types of materials are used as cover liner to minimize these problems such as geotextile, geomembrane, and compacted clay etc (Visvanathan *et al.,* 2002). Again geotextile and geomembrane are efficient and of no crack as the top liner, but they are expensive. Compacted clay sometimes may be used as cap liner but it has less resistance against crack formation (Atique and Sanchez, 2011). Composite clay (Liner made by using mixture of clay and aggregates like brick khoa, sand, gravel etc.) may be considered because of its significant resistance against crack formation in top surface of cap liner. Brick khoa or gravels are the material of non shrinkage and posses sharp enough surfaces for suitable adhesion. Besides they have the sharp angle. Also clay is very effective to mix with aggregate to create a perfect bond. By this way shrinkage property of clay soil can be reduced.

Cracking is a complex phenomenon in materials like soils. It is a natural process involving weathering, chemical changes and biological (Atique and Sanchez, 2011). Desiccation cracking significantly affects soil performance. Cracks create a zone of weakness in a soil mass and reduce its overall strength and stability (Yesiller *et al*., 2000). Cracks can also create pathways for transport of fluids, which can significantly increase the hydraulic conductivity of the soils (Yesiller *et al*., 2000). These hydraulic changes affect the waste contaminant facilities. As cracks form as a result of drying of soil mass, drying causes shrinkage. Again type and amount of clay minerals present in a drying soil control desiccation cracking (Mitchell, 1993). Crack formation also depends on soil thickness, surface configuration, rate of drying, total drying time etc. (Colina and Rouxl, 2000). As soil structure is an important property which affects water storage and movement, it is necessary to measure crack size and pattern precisely (Atique and Sanchez, 2011). Images of cracking surface are processed to determine the dimensions of crack have been widely used in present time. Size distribution of crack was estimated by using electro-optical determination which was used by Guidi *et al.* (1978). Lima and Grismer (1992) also used photographic image analysis to determine soil surface cracking. Cracking index which is the ratio of the area of

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cracks to the total surface area of a soil was proposed by Wahab and Kedrah (1995) to quantify the extent of cracking. Where crack area is the product of its length and width. But Wahab and Kedrah (1995) did not give any methods to determine length and width of cracks and they believed that length and width of cracks was determined using ruler. Photographic image analysis techniques appeared to be a useful tool to distinguish differences in crack patterns which may be useful characterizing soil cracking (Atique and Sanchez, 2011). However Mi (1995) as well as Miller and Mishra (1989) proposed crack intensity factor (CIF) which is the ratio of the area of cracks to the total surface area of a drying soil mass to quantify the extent of cracking. Where crack area was determined by using a computer aided image analysis program, and it is the reliable method now a day.

This study was conducted to investigate the crack behavior of composite clay as cap liner. For these purpose local soil i.e soil which is used as top liner in Rajbandh waste dumping site and suitable additive as sandy and gravelly materials were used to prepare typical seven numbers of model cap liners (3 number of liners of sandy materials composite clay, and 3 of gravelly materials composite clay and also 1 of only clay soil) of size 30cm×6cm×8cm for different percentages of additives content. Cracks form on the surface of liners as a result of water loss to the atmosphere and convert the liners as drying soil mass. It is considered that in a drying soil, drying causes shrinkage and a crack initiates when the tensile stresses exceed the soil strength (Atique and Sanchez, 2011). In this paper crack intensity factor (CIF) is mainly considered as influencing factor behind cracking behavior of soil. Although exact measurement of geometrical properties of soil cracks is not possible due to irregular and complex shape of cracks, image analysis techniques have been widely used in recent years to characterize the crack network with improved accuracy (Tang *et al.,* 2008). In this way an image analysis algorithm has been developed (using MATLAB®) to determine cracking area on the surface of the liners. Finally, comprise crack intensity factor (CIF) of all cap liners with one another and select the suitable percentage and suitable additive for this study soil.

2. PROPERTIES OF SOIL AND ADDITIVE USED IN THIS STUDY

In this study, one soil sample and two types of additive of sandy and gravelly materials were used. In the laboratory, the basic properties of these used materials were analysis. The physical and index properties of soil sampled used in this study were characterized in the laboratory through ASTM (2004) standard methods. Results reveal that the used soil sample was inorganic clay with medium plasticity. There are no specific sizes of additive materials for composite clay, but the additive materials should be well graded (Rafizul *et al.,* 2007). However, gravel materials with passing of sieve 3/4″ and remaining on sieve No.16 as gravelly material and sand material with passing of sieve No.8 and remaining on sieve No.100 as sandy material were used as additives in this study. The basic geotechnical engineering properties of the soil and engineering properties of two types of additives is provided in Table 1. Moreover, the gradation curves for soil sample, sandy material and gravelly material are given in Figure 1.

Table 1: Basic properties of soil and additive materials used in this study

Properties	Value	Properties	Value
Initial moisture content (%)	38	*Atterberg limits*	
		Liquid limit (%)	45
		Plastic limit (%)	23
		Plasticity index (%)	22
		Shrinkage limit (%)	21
		Shrinkage ratio	1.7
Compaction properties		*Particle size analysis*	
Optimum water content (%)	23	% of Sand	1.4
Maximum dry unit weight (kN/m^3)	14.5	% of Silt	85.6
		% of Clay	13.0
Specific gravity	2.65		
		FM of sandy materials	2.78
USCS Classification	CL	Gravelly materials	¾″ downgrade

3. LABORATORY TEST PROCEDURE AND ANALYSIS

The overall tasks were completed in a sequential manner to reach the expected goals of this research. The total study works were done in such a manner that it can be adjusted with practical applications. However, the total study works were completed in four main steps; preparation of composite clay liner specimens; drying of liner specimens, taking of images; quantitative analysis of cracks by digital image analysis technique, and selection of optimum content of suitable additives and hence described in the following sub-articles.

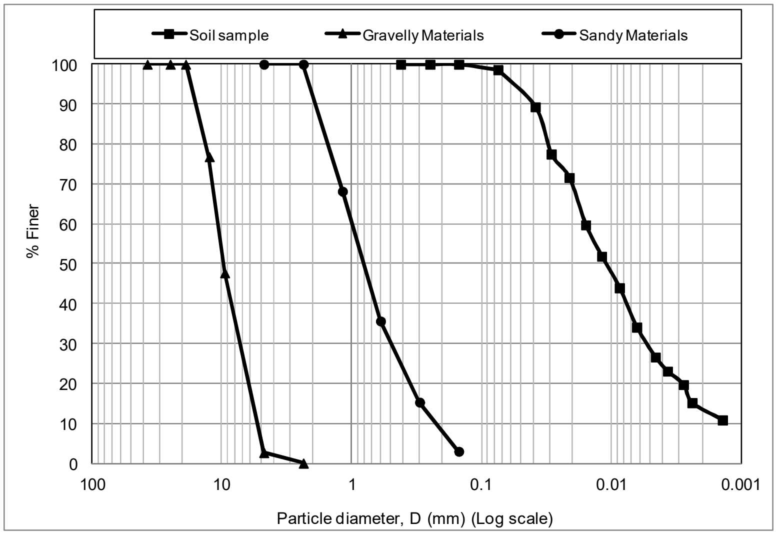

Figure 1: Gradation curves of used material in this study

3.1. Preparation of Composite Clay Liner Specimens

In the laboratory, for preparing of composite clay liner specimens, firstly all the soil samples were wetted by using approximate initial water content of 37.5 %. Afterward, the wetted soil sample was left for two hours due to the uniform water absorption. Then for preparing of composite clay, soil was mixed with two additives of sandy and gravelly materials at varying percentages of mixing content. In this case, soil was mixed with sandy and gravelly materials, independently at varying content of 20, 40 and 60 %. The used amount of additive materials was considered as the weighed condition of clay soil. For each percentage, one liner specimen was prepared in the laboratory. Moreover, one liner specimen was prepared using only natural soil sample which referred as "control specimen". Moreover, the composite clay prepared with sandy and gravel was referred as "sandy material composite clay" as well as "gravelly material composite clay". However, for preparation of liner specimens, wood made rectangular shape molds were used whose internal dimensions are 30cm×6cm×8cm.

3.2 Drying of Liner Specimens and Taking of Images

The prepared liner specimens were exposed to the atmosphere until they got dry completely. The liner specimens were placed outside in such a way that they got uniform sunlight. Due to evaporation of water from the liner specimens, they gradually became drying. Again drying causes shrinkage and subsequent cracking. Result reveals that the number and size of developed cracks increases in relation to the increasing of elapsed time. Furthermore, shrinkage was found in all sides of the prepared liner specimens. In practical field, the phenomena of shrinkage may also take place at the boundary lines of cap liner and in that case it may be considered as crack. So, in this study shrinkage of all four sides of the liner specimens was also considered as crack. Images of all liner specimens were taken at one day interval by fixing digital camera (14.1 mega pixel) at a height of 45 cm from top surface of the liner specimens. In addition, similar height and almost same environment were maintained for all images. Images of all cap liner specimens were taken at the time of six days from the preparation, because after six days all the liner specimens completely dried and it was confirmed from moisture content tests in the laboratory.

3.3 Quantitative Analysis of Cracks by Digital Image Technique

The accurate measurement of some geometrical parameters of soil like shrinkage cracks is not easy by direct measurement (Atique and Sanchez, 2011). Large measurement error is expectable due to irregular shape and complex cracking pattern. Generally, approximate methods were used to determine crack dimensions. The irregular shape and complex geometry of cracks prevent accurate measurements of length, width, and depth of the developed cracks. In addition, along the length of a crack, width and depth of cracks were not uniform. However, researchers Mi (1995) and Miller and Mishra (1989) postulated that the crack intensity factor (CIF) which is the ratio of the area of cracks to the total surface area of a drying soil mass to quantify the extent of cracking is the reliable method now a day. In this study, images of liner surface were analyzed using an image analysis algorithm. This algorithm was developed by MATLAB® code depending on the type of image to determine the area of cracks. If the type of image will be changed, the type of algorithm also changed. The steps of processing with algorithm are described in stepwise in following. Although in total forty two numbers of images were analyzed, however, the image processing of 40 % additives as gravelly materials contained specimen at sixth days to extract crack area is described briefly here.

Step 1: Read the image and convert the image to binary image

In this step the RGB image (DSC02089.JPG) was read and then converted to binary image. Here also the darkness of crack was adjusted up to level 0.30. Both these images were displayed which are shown in Figure 2 and Figure 3, respectively. Before the image was read it was adjusted to size 400 pixels × 300 pixels to reduce the time of analysis. Also the program code was given in following box.

```
I1 = imread('D:\ DSC01281.jpg');
figure, imshow(I1);
level=.30;
B = im2bw(I1, level);
figure, imshow(B);
```

Figure 2: RGB image **(**DSC02089.JPG)

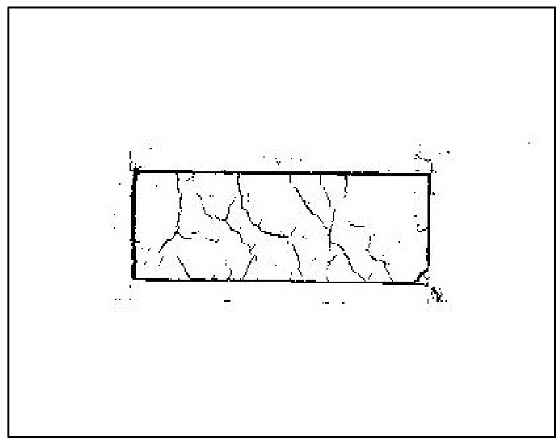

Figure 3: Binary image from RGB image

Step 2: Detect the liner specimen

In this step boundary of liner specimen was detected from binary image by drawing four straight lines on all four sides. Also the program code is given in following boxes.

```
j=200;
for i=1:1:300
    c=B(i,j);
    if c==0
        y1=i;
        break
    end
end
```

```
for i=300:-1:0
    c=B(i,j);
    if c==0
        y2=i;
        break
    end
end
```

```
i=150;
 for j=1:1:400
    c=B(i,j);
    if c==0
        x1=j;
        break
    end
end
```

```
for j=400:-1:0
    c=B(i,j);
    if c==0
        x2=j;
        break
    end
end
```

Step 3: Crop the liner surface from RGB image

After detection of the boundary, only portion of liner surface with cracks was cropped from the RGB image. Then the cropped image was displayed which is shown in Figure 4. Also the program code is given in following box.

```
topLine = x1;
bottomLine = x2;
leftColumn =y1;
rightColumn =y2;
width = bottomLine - topLine + 1;
height = rightColumn - leftColumn + 1;
PP = imcrop(I1,[topLine, leftColumn,
width,height]);
figure,imshow(PP);
```

Figure 4: Cropped image of liner surface from RGB image

Step 4: Convert the cropped RGB image of liner surface to grayscale image and then convert the grayscale image to binary image

In this step cropped RGB image was converted to grayscale image and then converted to binary image. At the same time the darkness of cracks was deepened at level 0.30. Also the binary image was filtered up to 250 levels. Both the grayscale and binary images were displayed which are shown in Figure 5 and Figure 6, respectively. Also the program code is given in following box.

```
K = rgb2gray(PP);
figure, imshow(K);
level = 0.30;
bw = im2bw(K,level);
bw = bwareaopen(bw, 250);
figure, imshow(bw);
```

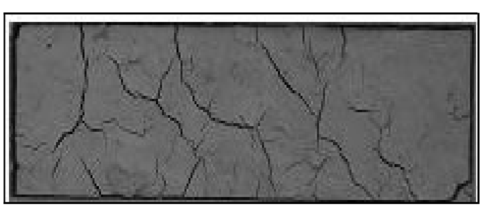

Figure 5: Grayscale image from cropped image

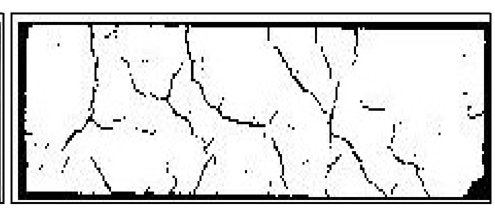

Figure 6: Binary image from grayscale image

Step 5: Calculation of crack area and CIF

In this step first the cracked and no cracked areas were determined in pixels. Then cracks area of specimen was determined in cm^2 by using total surface area of specimen (240 cm^2). Finally area of cracks was divided by total surface area of liner specimen and multiplied by hundreds (100) to determine CIF**.** Also the program code is given in following box.

3.4 Selection of Optimum Suitable Additives Content by Comparing CIF

After calculation of CIF, the values of CIF were compared for all cap liner specimens to select the optimum suitable additive content for which CIF was small.

4. RESULTS AND DISCUSSIONS

The results obtained after images of all composite clay cap liner specimens were analyzed by using program algorithm are described in the following sections. The cracking parameter of CIF of two types of composite clay is described independently.

4.1 Analysis of Cracking Behavior of Sandy Material Composite Clay

Cracking parameter like CIF of four numbers of sandy material composite clay specimens was described; those were prepared by using various percentages of sandy materials. The crack area and CIF for all the prepared sandy material composite clay specimens are shown in Table 2.

```
a1=0;   % number of black
a0=0;   % number of white
for i=1:1:height
    for j=1:1:width
        vvvv(i,j)=bw(i,j);
        if bw(i,j)==0
            a1=a1+1;
        else
            a0=a0+1;
        end
    end
end
black_pixel=a1 %no of black
white_pixel=a0 %no of white
totalarea=240;
crackarea=(totalarea/(a0+a1))*a1
CIF=(crackarea/240)*100
```

Table 2: Values of crack area and CIF with time for sandy material composite clay

Time (hours)	percentages of additives as sandy materials							
	0		20		40		60	
	Crack area (cm^2)	CIF (%)	Crack area (cm^2)	CIF (%)	Crack area (cm^2)	CIF (%)	Crack area (cm^2)	CIF (%)
0	00.00	00.00	00.00	00.00	00.00	00.00	00.00	00.00
24	14.4294	6.0123	12.6439	5.2683	13.6342	5.6809	8.7652	3.6522
48	20.5723	8.5718	18.9731	7.9055	20.9741	8.7392	13.7138	5.7141
72	28.7512	11.9797	26.4768	11.032	22.5642	9.4018	16.9327	7.0553
96	31.8354	13.2648	27.17624	11.3234	23.7583	9.8993	18.5276	7.7198
120	32.1325	13.3885	29.3219	12.2175	24.1570	10.0654	19.3275	8.0531
144	32.1455	13.394	29.4652	12.2772	24.9833	10.4097	19.5467	8.1445

From the crack area of all liner specimens, it can be supposed that the crack area of the control liner specimen was found higher than that of the crack area of other liner specimens. Moreover its value was found 32.1455 cm^2 after 144 hours of elapsed time, then, as a result the CIF value was also higher than the sandy material composite clay. This occurred due to the control specimen was prepared by using only clay soil. Again with the increasing of percentage of sand, clay was replaced by sand and sand is less shrinkage material than the clay due to their different particle sizes. From the values of crack area and CIF for all liner specimens, it can be also concluded that the values of crack area and CIF for all liner specimens increase with the increasing of elapsed time. Additional, it was noticed that the values of CIF at 120 hours and at 144 hours were almost same.

4.1.1 Variation of CIF with Time for Sandy Materials Composite Clay

Crack intensity factors (CIF) were determined using crack area of top liners which are plotted against elapsed time for various percentages of sandy materials is depicted in Figure 7. From the variations between CIF and elapsed time for all percentages it is observed that, CIF increased gradually in relation to the elapsed time and after three or four days it was found almost same. This occurred due to loss of water from specimens after elapsed time to the atmosphere and converts the liners as drying soil mass. It was observed that, the rate of increase of CIF was found comparatively higher for specimen prepared with only clay soil (for 0 % additive content) than others and it was maximum of 13.394 %. In contrast, the rate of increase of CIF was comparatively less than the specimen prepared with 60 % of additives content and it was found 8.1445 % at the end of 144 hours indicating that 8.1445 % of surface area was covered with cracks. Also with the increasing of parentages of sandy materials, the values of CIF with time decreases (Figure 7).

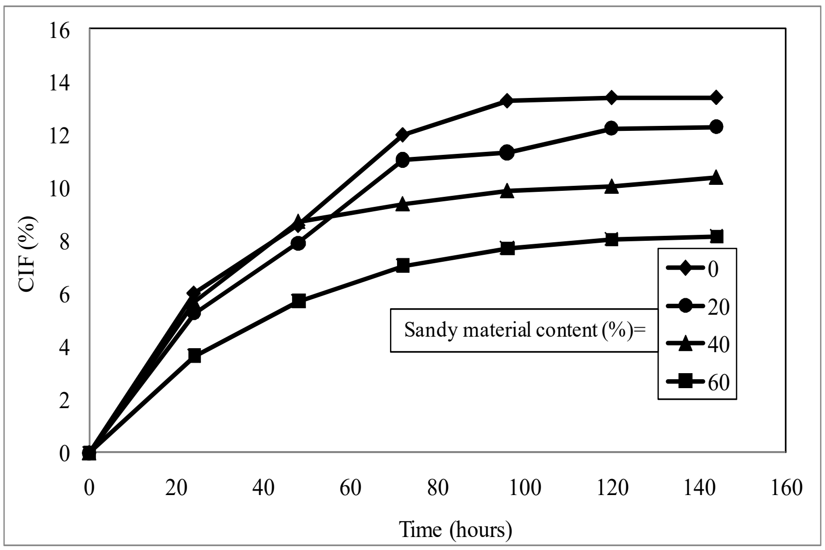

Figure 7: Variation of CIF with time for sandy materials composite clay

4.2 Analysis of Cracking Behavior for Gravelly Material Composite Clay

The CIF values of the prepared four numbers of gravelly material composite clay specimens were described; those were prepared by using various percentages of gravelly materials. The crack area and CIF for all the prepared gravelly material composite clay specimens are shown in Table 3.

Table 3: Values of crack area and CIF with time of gravelly material composite clay

Time (hours)	percentages of additives of gravelly materials							
	0		20		40		60	
	Crack area (cm^2)	CIF (%)	Crack area (cm^2)	CIF (%)	Crack area (cm^2)	CIF (%)	Crack area (cm^2)	CIF (%)
0	00.00	00.00	00.00	00.00	00.00	00.00	00.00	00.00
24	14.4294	6.0123	12.7391	5.308	6.1973	2.5822	8.2359	3.4316
48	20.5723	8.5718	17.1843	7.1601	11.4813	4.7839	14.9762	6.2401
72	28.7512	11.9797	20.8286	8.6786	13.6419	5.6841	15.8429	6.6012
96	31.8354	13.2648	21.1740	8.8225	14.1733	5.9055	17.7530	7.3971
120	32.1325	13.3885	22.3761	9.3234	14.5571	6.0655	18.2142	7.5893
144	32.1455	13.394	22.9412	9.5588	14.9807	6.242	18.3745	7.6560

From the crack area of all liner specimens, it can be said that crack area of liner specimen for 0 % additives is higher than the crack area of other liner specimens. And it was found as 32.1455 cm^2 after 144 hours. As a result

CIF value was found also higher than the gravelly material composite clay. This occurred due to control specimen prepared by using only clay soil. Again with the increasing of percentage of gravel, clay was replaced by gravel and gravel is non shrinkage material than clay due to their different particle sizes. From the values of crack area and CIF for all liner specimens, it can be also said that the values of crack area and CIF for all liner specimens increases with the increasing of elapsed time and values at 120 hours and at 144 hours are shown the almost same values of CIF.

4.2.1 Variation of CIF with Time for Gravelly Materials Composite Clay

Figure 8 illustrates the values of CIF with in relation to the elapsed time. The CIF were determined using crack area of top liners against elapsed time for various percentages of gravelly materials. From the variations between CIF and elapsed time for all percentages it is observed that, CIF gradually increased with time and after three or four days it was found almost same values of CIF. This occurred due to with the loss of water for elapsed time to the atmosphere and converts the liners as drying soil mass. It is observed that, rate of increasing of CIF was comparatively higher for specimen prepared with only clay soil (for 0 % additive content) than others and it was maximum value as 13.394 %. Moreover, the rate of increase of CIF was comparatively less than for specimen prepared with 40 % additives content and it was found as 6.242 % at the end of 144 hours indicating that 6.242 % of surface area was covered with cracks.

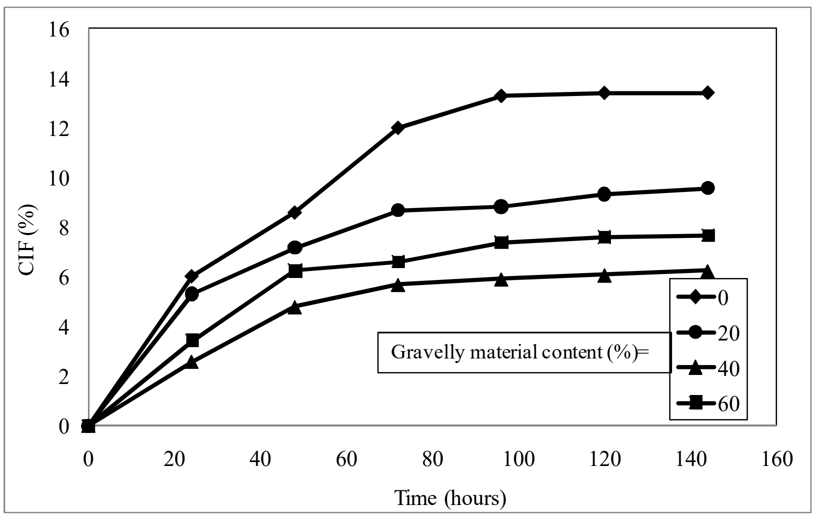

Figure 8: Variation of CIF with time for gravelly materials composite clay

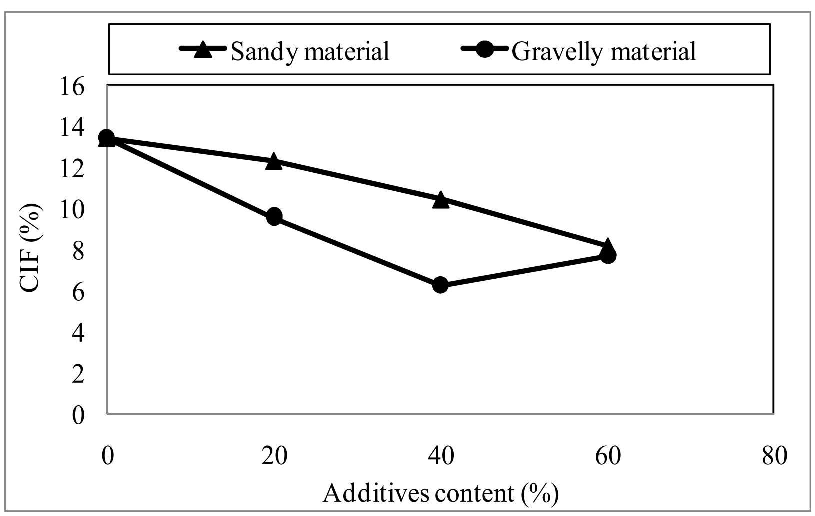

Figure 9: Variation of additives content at sixth days with CIF

4.3 Comparison of Cracking Behavior of Two Types Composite Clay Liner Specimens

The CIF was plotted after crack formation and propagation in all top liner specimens made with various percentages of two types composite clay as shown in Figure 9. From the variation of additives content and CIF, it can be concluded that the values of CIF were lowest for 40 % gravelly materials than other percentages of sandy and gravelly materials. It was also observed that, with the increasing of percentage of sandy material, CIF decreases gradually, this occurred due to sand having low shrinkage material. On the other hand, with the increasing of percentage of gravelly material, CIF decreases up to the certain percentage, then increases due to the higher percentages of gravelly materials and lack of proper bond between soil and gravelly material.

5. CONCLUSIONS

This research mainly focuses on some relevant factors that affected the behavior of cap liner specimens submitted to drying. The following concluding remarks were derived:

1. The volumetric shrinkage of soil was found low as 20.5 % which indicated the high potential for shrinkage and swelling of soil.
2. Cap liner specimens prepared with only natural soil sample (control specimens) showed the total distributed crack area of 32.146 cm^2 and hence CIF of 13.394 %.
3. The maximum and minimum CIF obtained as 13.394 % and 6.242 % in control specimen and specimen prepared with 40% gravelly materials, respectively.
4. The value of CIF decreases gradually in relation to the increasing of percentage of sandy material.
5. If the percentage of sandy material will be 100%, then CIF would significantly low because clay will be replaced completely by sand and in that case it will not be composite clay. So, in this study, sandy material content was stopped up to a certain percentage.
6. Based on the above findings, it can be concluded that the use of additives content such as gravelly materials of 40%, considerably reduced the cracking formation of cap liner specimens.

So it can be recommended that, composite clay can be used as top liner materials in practical waste disposal sites with its greater advantages than the use of only clay soils. Before use of composite clay as top liner in real field, it must be analyzed by preparing model specimens for various percentages of additives for that soil to find out the suitable percentage for which cracking properties are less significant.

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