ISSN 2229-5518

Selection of Suitable Composite Clay as Cap Liner in Landfill: Extensive Software

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Abstract— Composite clay that is the mixture of clay, as the main body and aggregates which are floating within the clayey matrix is more economical and effective material in cap liner than other traditional materials such as, geotextile, geomembrane, and compacted clay etc. Composite clay is also effective in reducing crack formation, which is the main problem when only compacted clay is used in cap liner. Investigation of cracking behavior of composite clay as cap liner of local clay soils (soils near Rajbandh dumping site) is the main aim of this study. To reach these attempts, mixtures of clay soils at varying percentages of three suitable additives such as brick khoa, sandy and gravelly materials used as composite clay. Moreover, nineteen (19) numbers of cap liner specimens of size 30cm×6cm×8cm were prepared using this composite clay. Cracking parameters of each liner specimen were compared with other specimens and specimens made by using clay soil only (control specimens) which is another aim of this study. Here crack intensity factor (CIF), which is the ratio of the surface area of cracks to the total surface area of a soil and shrinkage on all four sides of specimen were considered as controlling cracking parameters. CIF was determined by digital image analysis technique in this study. From the study it was observed that overall values of CIF and shrinkage almost maximum for control specimens than other specimens. In contrary, maximum and minimum CIF obtained in the tests were 14.94% and 6.24% occurred in specimen 1 of 5% brick khoa and 40% gravelly materials as additives content. In addition, maximum and minimum shrinkage obtained in the tests were 2.4cm and 0.35cm in length direction and 0.82cm and 0.2cm in width direction occurred in control specimens 1 and 2 and 60% gravelly materials and specimens 2 of 15% brick khoa and 60% gravelly materials as additives contents respectively. Again by comparing cracking behavior of three type's composite clay as top liner specimens made with various percentages of brick khoa, sandy and gravelly materials, it can be suggested that, 40 to 60% of gravelly materials is more suitable as a cap liner against of other counterparts.

Index Terms— Composite Clay, Cracking Parameters, CIF, Digital Image Analysis Technique, Shrinkage, Additives, Clayey Matrix

1 Introduction

When the landfill site has reached its ultimate capacity, a thick final layer of cover material is applied 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. 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. 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. Again geotextile and geomembrane are efficient and of no crack as the top liner, but they are expensive. Compacted clay liners also effective, but they are less susceptible to crack formation. Composite clay liner (Liner made by using mixture of clay and aggregates like brick khoa, sand, gravel etc.) is one of the better solutions from the economic point of view.

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Bricks 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 [1]. Desiccation cracking significantly affects soil performance. Cracks create a zone of weakness in a soil mass and reduce its overall strength and stability [2]. Cracks can also create path-ways for transport of fluids, which can significantly increase the hydraulic conductivity of the soils [2]. 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 [3]. Crack formation also depends on soil thickness, surface configuration, rate of drying, total drying time etc. [4]. As soil structure is an important property which affects water storage and movement, it is necessary to measure crack size and pattern precisely [1]. 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 in 1978 [5]. Lima (1992) also used photographic image analysis to determine soil surface cracking [6]. Cracking index which is the ratio of the area of cracks to the total surface area of a soil was proposed by Al Wahab and El-Kedrah in 1995 to quantify the extent of cracking [7]. Where crack area is the product of

ISSN 2229-5518

its length and width. But Al Wahab and El-Kedrah 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 [1]. However Mi (1995) and Miller et al. (1998) 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 [8,9]. 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 soils (soils which are used as top liner in Rajbandh dumping site) and suitable additive as brick khoa were used to prepare typical 19 numbers of model cap liners (10 number of liners were prepared using brick khoa composite clay, 3 number of liners were prepared using sandy materials composite clay, and 3 number of liners were prepared using gravelly materials composite clay) 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 [1]. In this paper crack intensity factor (CIF) is mainly considered as influencing factors 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 [10]. In this way an image analysis algorithm has been developed (using MATLAB®) to determine cracking area on the surface of the liners. Finally comprise different crack properties 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 MATERIALS USED IN THIS STUDY

The soil samples and three type's additives used in this study were characterized by their own engineering properties. However the soil is classified as inorganic clays of medium plasticity. Whereas brick khoa with 1 in. downgrade, stone materials with passing of sieve 3/4″ and remaining on sieve No.16 as gravelly materials and sand with passing of sieve No.8 and remaining on sieve No.100 as sandy materials were used as additive materials. Some of the basic Geotechnical Engineering properties of the soil and engineering properties of three type's additives are given in Table 1.

3 LABORATORY TEST PROCEDURE AND ANALYSIS

The study works were completed in a sequential manner to reach the expected goals of the study. The total study works were done in such a manner so that it can be adjusted with practical applications. However the total study works were completed in four main steps; preparation of composite clay cap liner specimens; drying of liner specimens, taking of images and measurement of shrinkage; quantitative analysis of cracks by digital image analysis technique, and selection of optimum content of suitable additives are described below.

3.1 Preparation of Composite Clay Liner Specimens

For preparation of composite clay cap liner specimens, firstly all soil samples were wetted by using approximately the initial water content (37.5%). The wetted soil was then left for two hours due to uniform water absorption. Saturated surface dry additives (brick khoa, sandy and gravelly materials) were mixed with wetted soil at various percentages separately. In these study five percentages (5, 10, 15, 20, and 25%) of brick khoa content and three percentages (20, 40 and 60%) of sandy and gravelly materials content were used where percent weight of additives is percentage of weight of wetted soil. For brick khoa composite clay for each percentage two liner specimens were prepared and for sandy and gravelly materials for each percentage one liner specimen was prepared. Also three liner specimens were prepared using only soil sample (control specimens). However for preparation of liner specimens, wood made rectangular shape molds were used whose internal dimensions are 30cm×6cm×8cm.

TABLE 1 PROPERTIES OF SOIL SAMPLE AND ADDITIVE MATERIALS

Properties	Value	Properties	Value
Initial Moisture Content (%)	37.50	Liquid Limit (%)	44.80
		Plastic Limit (%)	23.43
		Plasticity Index (%)	21.37
		Shrinkage Limit (%)	20.56
		Shrinkage Ratio	1.68
Optimum Water Content (%)	22.80	% of Sand	1.4
Maximum Dry Unit Weight (KN/m³)	14.52	% of Silt	85.6
		% of Clay	13.0
Specific Gravity	2.65	Brick Khoa	1.5″downgrade
USCS Classification	Cl	Fm of Sandy Materials	2.78
		Gravelly Materials	3/4″downgrade

ISSN 2229-5518

3.2 Drying of Liner Specimens, Taking of Images, and Measurement of Shrinkage

After preparation of liner specimens, they were brought to outside so that they got dry. The liner specimens were placed in outside in such a way, so 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. With the increase of time, number and size of cracks increase. Also shrinkage of all four sides of the liner specimens took place. Images of all liner specimens were taken at one day interval. Also average shrinkages in both length and width directions were measured by using liner scale. Images were taken by fixing digital camera (14.1 mega pixel) at a height of 45cm from top surface of the liner specimens. And this height was maintained for all images. All the measurements and images were taken at the time of six days from the preparation of specimens, because after six days the liner specimens were completely dried.

3.3 Quantitative Analysis of Cracks by Digital Image Analysis Technique

According to Atique and Sanchez, 2011, accurate measurement of geometrical parameters of soil shrinkage cracks is not easy by direct measurement. Large measurement error is expectable due to irregular shape and complex cracks pattern. Generally approximate methods are used to determine crack dimensions. The irregular shape and complex geometry of cracks prevent accurate measurements of length, width, and depth. Also along the length of a crack, width and depth of cracks are not uniform. However Mi (1995) and Miller et al. (1998) 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 is the reliable method now a day.

In this study images of liner surface were analyzed using an image analysis algorithm developed by MATLAB® code to determine the area of cracks. For this purpose an algorithm has been developed. The steps of processing with algorithm are described below. Here image processing of a 25% additives (brick khoa) contained specimen at fourth days to extract crack area is described.

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

In this step the RGB image (DSC01281.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 1 and Figure 2 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 is given in following box.

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

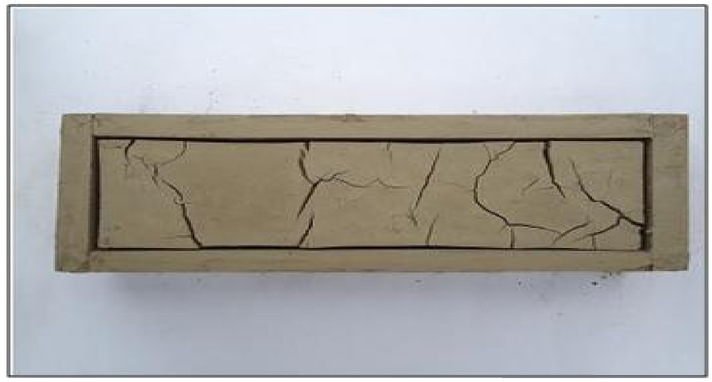


Figure 1 RGB image (DSC01281.jpg)

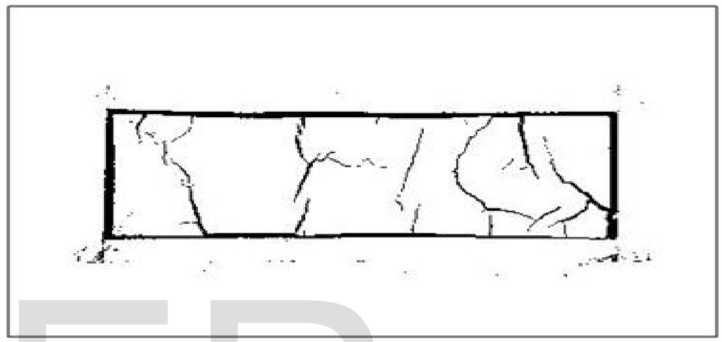


Figure 2 Binary image from RGB image

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 3. 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 3 Cropped image 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 4 and Figure 5 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 4 Grayscale image from cropped image

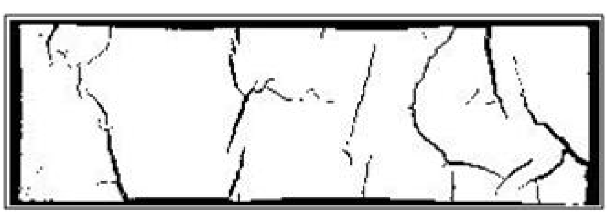


Figure 5 Binary image from grayscale image

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 ($240cm^2$). 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.

```
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
```

3.4 Selection of Optimum Suitable Additives Content by Comparing CIF and Shrinkage

After calculation of CIF, the values of CIF and measured average shrinkages of all four sides of specimens from the inside edges of molds were compared for all cap liner specimens to select the optimum suitable additives content for which both CIF and shrinkage are less.

4 Results and Discussions

The results obtained after images of all composite clay cap liner specimens were analyzed by using program algorithm and average shrinkages for both length and width directions of all specimens were measured are described in this section. Crack parameters of three type's composite clay are described separately.

4.1 Analysis of Cracking Behavior for Brick Khoa and Clay Soil Mixture

Crack parameters of twelve numbers composite clay cap liner specimens are described; those were made by using various percentages of brick khoa as additives. Mainly two controlling parameters (CIF, shrinkage) were used to characterize crack of all specimens.

Crack areas and CIF of all composite clay cap liner specimens were extracted accurately with program algorithm. Crack area and CIF for all liner specimens made by using various percentages of brick khoa as additives are shown in Table 2 and Table3. From the crack area of all liner specimens, it can be said that crack area of liner specimen 1 for 5% additives (brick khoa) is higher than the crack area of other liner specimens. And its value was found $35.8462cm^2$ after 144 hours. As a result CIF value was also higher than others. 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 increase with the increase of time

TABLE 2 VALUES OF CRACK AREA AND CIF WITH TIME

Time (Hours)	Percentages of Additives (Brick Khoa)											
	0%				5%				10%			
	Specimen 1		Specimen 2		Specimen 1		Specimen 2		Specimen 1		Specimen 2	
	Crack Area (cm²)	CIF (%)	Crack Area (cm²)	CIF (%)	Crack Area (cm²)	CIF (%)	Crack Area (cm²)	CIF (%)	Crack Area (cm²)	CIF (%)	Crack Area (cm²)	CIF (%)
0	00.00	00.00	00.00	00.00	00.00	00.00	00.00	00.00	00.00	00.00	00.00	00.00
24	15.2703	6.36263	15.6764	6.53183	15.4715	6.44646	15.3361	6.39004	15.1716	6.3215	14.5727	6.07196
48	20.0368	8.34867	24.5220	10.2175	27.3149	11.3812	22.5114	9.37975	25.2820	10.5342	25.1539	10.4808
72	29.1121	12.13	29.9149	12.4645	33.3259	13.8858	29.8673	12.4447	27.1447	11.3103	26.7614	11.1506
96	31.1121	12.9634	32.5047	13.5436	33.7247	14.052	30.4460	12.6858	30.4196	12.6748	26.4551	11.2023
120	32.2183	13.4243	34.7891	14.4955	35.1505	14.646	30.5308	12.7212	31.5290	13.1371	27.5615	11.484
144	32.9871	13.7446	34.8634	14.5264	35.8462	14.9359	30.8976	12.874	31.7179	13.2158	27.6231	11.5096

TABLE 3 VALUES OF CRACK AREA AND CIF WITH TIME

Time (Hours)	Percentages of Additives (Brick Khoa)											
	15%				20%				25%			
	Specimen 1		Specimen 2		Specimen 1		Specimen 2		Specimen 1		Specimen 2	
	Crack Area (cm²)	CIF (%)	Crack Area (cm²)	CIF (%)	Crack Area (cm²)	CIF (%)	Crack Area (cm²)	CIF (%)	Crack Area (cm²)	CIF (%)	Crack Area (cm²)	CIF (%)
0	00.00	00.00	00.00	00.00	00.00	00.00	00.00	00.00	00.00	00.00	00.00	00.00
24	10.5280	4.38667	17.2670	7.19458	16.3262	6.80258	18.0244	7.51017	12.7341	5.30588	15.0554	6.27308
48	18.4932	7.7055	27.2948	11.3728	25.8945	10.7894	26.6544	11.106	20.6935	8.62229	24.2794	10.1164
72	19.8860	8.28583	32.4007	13.5003	28.3793	11.8247	30.0586	12.5244	21.6698	9.02908	24.4603	10.1918
96	22.8376	9.51567	33.0356	13.7648	30.3346	12.6394	30.3761	12.6567	23.3593	9.73304	25.9164	10.7985
120	23.2423	9.68429	34.1453	14.2272	31.6464	13.186	32.8481	13.6867	23.4796	9.78317	27.6821	11.5342
144	23.5243	9.80179	35.0815	14.6173	32.0427	13.3511	32.9249	13.7187	24.3531	10.1471	27.7257	11.5524

and values at 120 hours and at 144 hours were almost same.

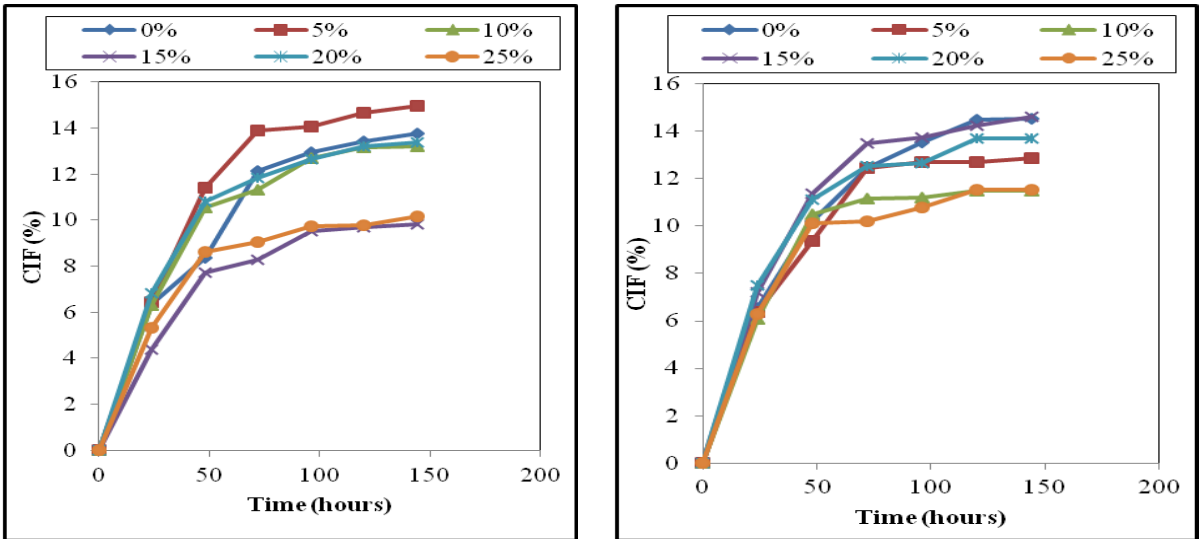
Again the cap liner specimens shrink to inside of molds from the inside walls because the size of liner specimens was small. But in real field this shrinkage is very negligible and in that case it is considered as crack. However in this study shrinkage was taken into consider because in this case its value was not negligible. Shrinkage occurred in both length and width directions. Again liner specimens shrink almost parallel to the inside walls of mold and its average values are used here. However first variation of CIF with time is analyzed. Then variation shrinkage with time is analyzed.

4.1.1 Variation of CIF with Time for Brick Khoa Composite Clay

Crack intensity factor (CIF) was determined using cracks area of cap liners which was plotted against elapsed time for various percentages of brick khoa are shown in Figure 6. Again each percentage has two specimens. From the variations between CIF and elapsed time for all percentages it was observed that CIF increased rapidly up to 72 hours. Also the rate of increase of CIF were found much higher for specimen 2 of 0%, specimen 1 of 5%, and specimen 2 of 15% additives content than others and their maximum values were 14.5264%,14.9359% and 14.6173% respectively. Again rate of of CIF was much less than for specimen 1 of 15% additives content and its value was found 9.8018% at the end of 144 hours indicating that 9.8018% of surface area was covered with cracks. Over all CIF increase rate was found almost higher for specimens made with only clay soils than the other specimens.

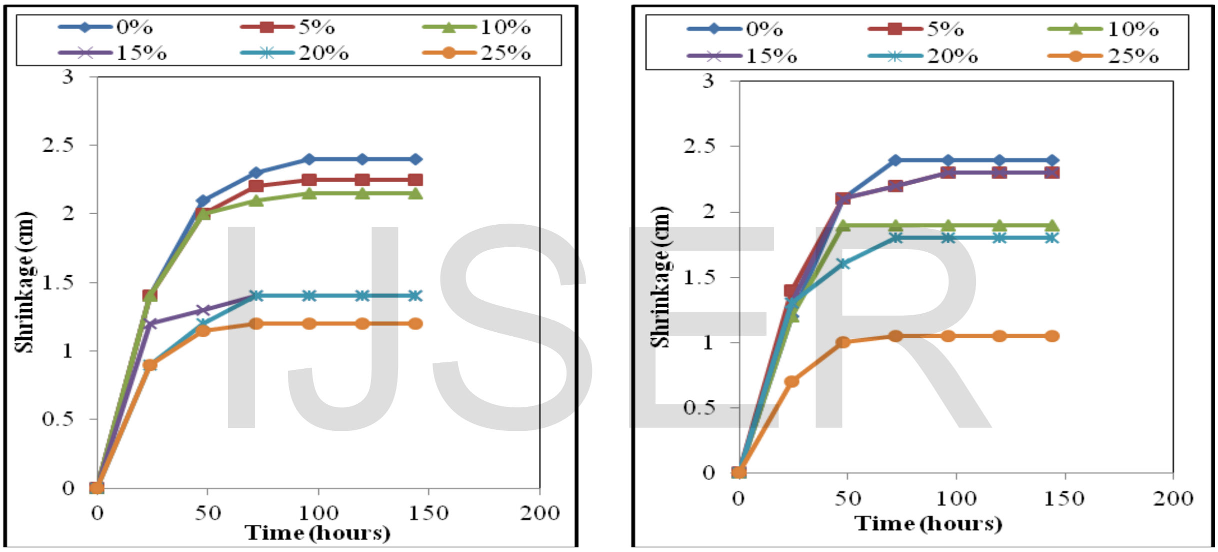
4.1.2 Variation of Shrinkage with Time for Brick Khoa Composite Clay

Shrinkages of cap liner specimens in both length and width directions were plotted against elapsed time for various percentages of brick khoa are shown in Figure 7 and Figure 8 respectively for specimen 1 and specimen 2 separately. Both the shrinkage in length and width directions increased with time and after a time left it became constant. In this study after four days it became almost constant. In length direction variation of shrinkage with time is high when brick khoa content is 0% and low when brick khoa content is 25% for both specimen 1 and 2. On the other hand this variation almost same for all specimens in width direction. However maximum value of shrinkage in length direction was 2.4 cm occurred in specimens which were made with only clay soil. Whereas maximum shrinkage in width direction occurred in specimen 2 for 15% additives content and its value was 0.82 cm.



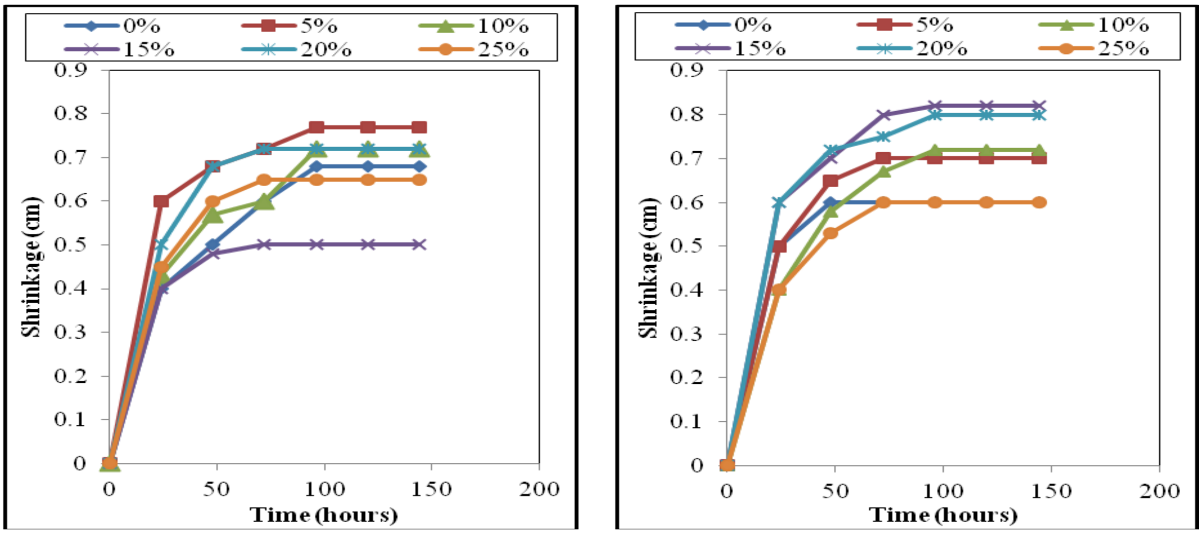
(a) (b)

Figure 6 Variation of CIF with time for brick khoa composite clay for (a) specimen 1 (b) specimen 2



(a) (b)

Figure 7 Variation of shrinkage with time in length direction for brick khoa composite clay for (a) specimen 1 (b) specimen 2



(a) (b)

Figure 8 Variation of shrinkage with time in width direction for brick khoa composite clay for (a) specimen 1 (b) specimen 2

4.2 Analysis of Cracking Behavior for Sandy Materials and Clay Soil Mixture

Crack parameters of four numbers composite clay cap liner specimens are described; those were made by using various percentages of sandy materials (sands with passing of sieve No.8 and remaining on sieve No.100) as additives.
Crack area and CIF for all liner specimens made by using various percentages of sandy materials as additives are shown in Table 4.
From the crack area of all liner specimens, it can be said that crack area of control liner specimen is higher than the crack area of other liner specimens. And its value was found 32.1455 cm^2 after 144 hours. As a result CIF value was also higher than others. 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 increase with the increase of time and values at 120 hours and at 144 hours are almost same.
Again similar to brick khoa composite clay liner specimens also shrink almost parallel to the inside walls of mold and its average values are used here. However first variation of CIF with time is analyzed. Then variation shrinkage with time is analyzed.

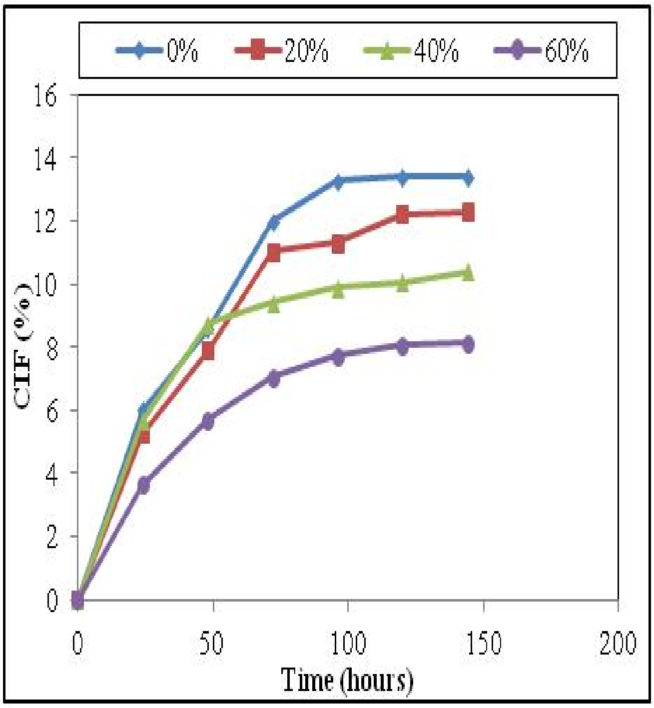


Figure 9 Variation of CIF with time for sandy materials composite clay

TABLE 4 VALUES OF CRACK AREA AND CIF WITH TIME

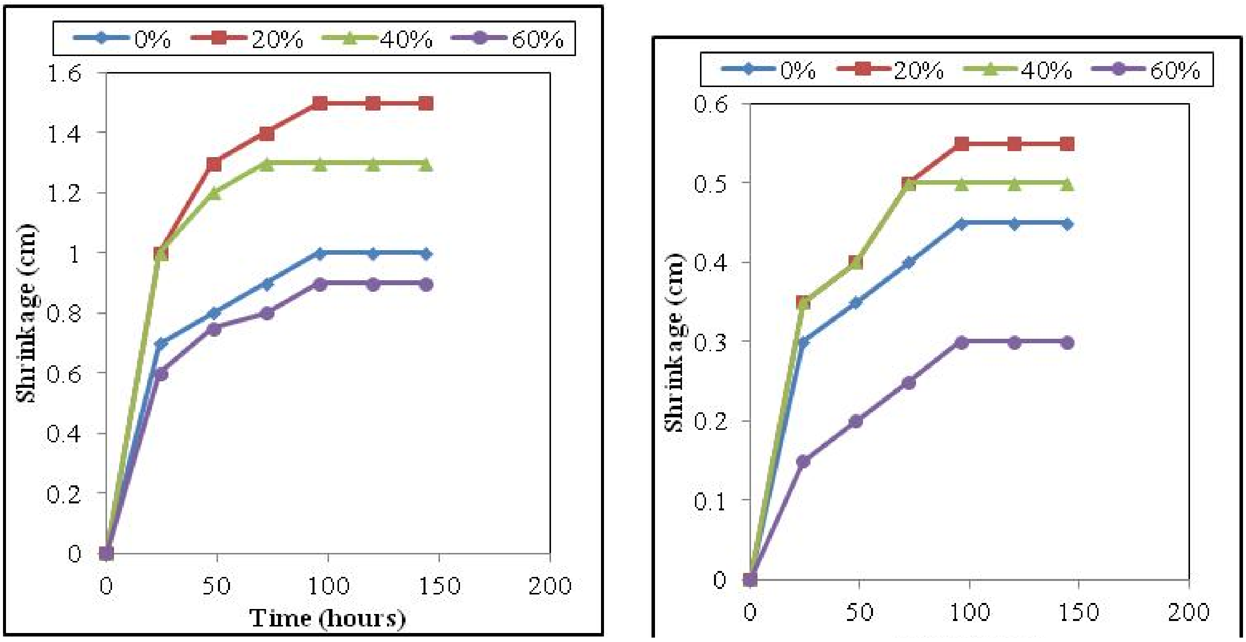
Time (hours)	percentages of additives (sandy materials)							
	0%		20%		40%		60%	
	Crack area (cm^2)	CIF (%)	Crack area (cm^2)	CIF (%)	Crack area (cm^2)	CIF (%)	Crack area (cm^2)	CIF (%)
0	00.00	00.00	00.00	00.00	00.00	00.00	00.00	00.00
24	14.4294	6.0123	12.6439	5.2683	13.6342	5.6809	8.7652	3.6522
48	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

4.2.1 Variation of CIF with Time for Sandy Materials Composite Clay

Crack intensity factor (CIF) was determined using cracks area of top liners which was plotted against elapsed time for various percentages of sandy materials is shown in Figure 9. Again each percentage has one specimen. From the variations between CIF and elapsed time for all percentages it was observed that rate of increase of CIF is much higher for specimen made with only clay soil (for 0% additive content) than others and its maximum value was found 13.394%. Again rate of increase of CIF was much less than for specimen made with 60% additives content and its value was found 8.1445% at the end of 144 hours indicating that 8.1445% of surface area was covered with cracks. Also with the increase of parentages of sandy materials, the values of CIF with time decreased.

4.2.2 Variation of Shrinkage with Time for Sandy Materials Composite Clay

Shrinkages of top liner specimens in both length and width directions were measured are plotted against elapsed time for various percentages of sandy materials are shown in Figure 10. Both the shrinkage in length and width directions increased with time and after a time left it became constant. In this study after four days it became almost constant. Again from the values of shrinkage it can be said that values of shrinkage in length direction in all cases are greater than the values in width direction. In both length and width directions, variations of shrinkage with time are high when sandy materials is 20% and low when sandy materials content is 60%. However maximum value of shrinkage in length direction was 1.5 cm occurred in specimen which was made with 20% sandy materials. Whereas maximum shrinkage in width direction also occurred in specimen for 20% additives content and its value was 0.55 cm.



(a) (b)

Figure 10 Variations of shrinkage with time for sandy materials composite clay in (a) length direction (b) width direction

4.3 Analysis of Cracking Behavior for Gravelly Materials and Clay Soil Mixture

Crack parameters of four numbers composite clay top liner specimens are described; those were made by using various percentages of gravelly materials (stone materials with passing of sieve 3/4″and remaining on sieve No.16) as additives. Crack area and CIF for all liner specimens made by using various percentages of gravelly materials as additives are shown in Table 5. From the crack area of all liner specimens, it can be said that crack area of liner specimen for 0% additives (sandy materials) is higher than the crack area of other liner specimens. And its value was found 32.1455 cm^2 after 144 hours. As a result CIF value was also higher than others. 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 increase with the increase of time and values at 120 hours and at 144 hours are almost same.

Again similar to brick khoa composite clay liner specimens also shrink almost parallel to the inside walls of mold and its average values are used here.

TABLE 5 VALUES OF CRACK AREA AND CIF WITH TIME

Time (hours)	percentages of additives (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

However, first variation of CIF with time is analyzed. Then variation shrinkage with time is analyzed.

4.3.1 Variation of CIF with Time for Gravelly Materials Composite Clay

Crack intensity factor (CIF) was determined using crack area of top liners which was plotted against elapsed time for various percentages of gravelly materials are shown in Figure 11. Again each percentage has one specimen. From the variations between CIF and elapsed time for all percentages it is observed that rate of increase of CIF is much higher for specimen made with only clay soil (for 0% additive content) than others and its maximum value was found 13.394%. From the variation it can be also said that with the increase of additives content CIF decreases, but after a certain percentage this value increases. This is due to at higher additives content proper bond between soil and gravel materials is not possible. Again rate of increase of CIF was much less than for specimen made with 40% additives content and its value was found 6.242% at the end of 144 hours indicating that 6.242% of surface area was covered with cracks.

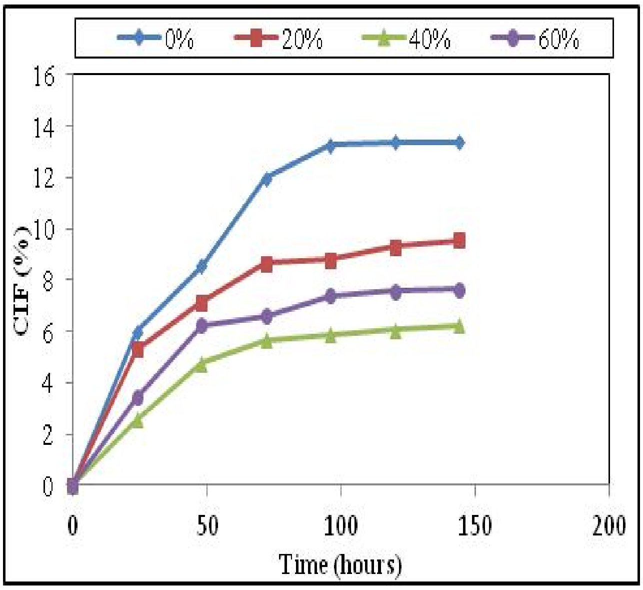


Figure 11 Variation of CIF with time for gravelly materials composite clay

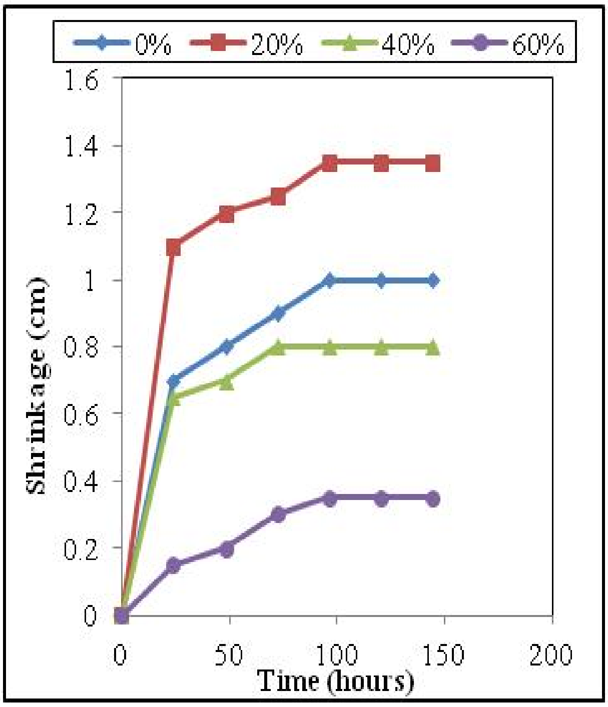
4.3.2 Variation of Shrinkage with Time for Gravelly Materials Composite Clay

Shrinkages of top liner specimens in both length and width directions were measured are plotted against elapsed time for various percentages of gravelly materials are shown in Figure 12. Both the shrinkage in length and width directions increased with time and after a time left it became constant. In this study after four days it became almost constant. Again from the values of shrinkage it can be said that values of shrinkage in length direction in all cases are greater than the values in width direction.

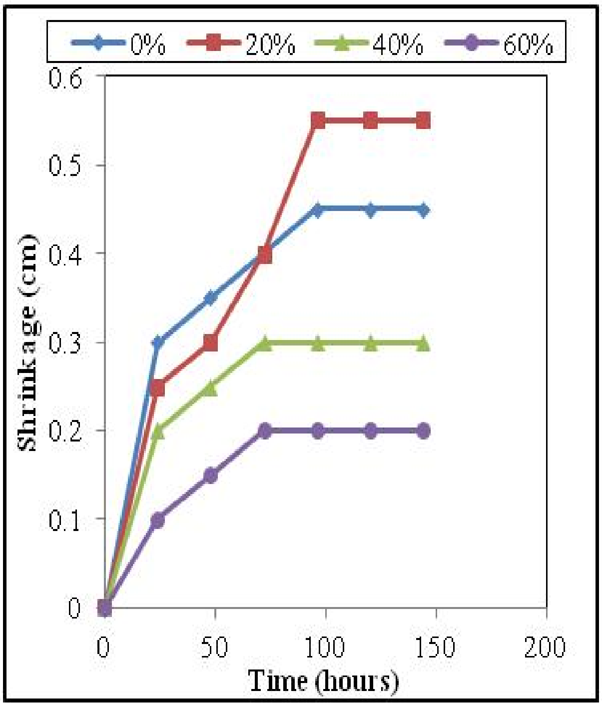
In both length and width directions, variations of shrinkage with time are high when gravelly materials is 20% and low when sandy materials content is 60. However maximum value of shrinkage in length direction was 1.35 cm occurred in specimen which was made with 20% sandy materials. Whereas maximum shrinkage in width direction also occurred in specimen for 20% additives content and its value was 0.55 cm.

4.4 Comparison of Cracking Behavior of Three Types Composite Clay Top Liner Specimens

Crack intensity factor (CIF) and shrinkage were plotted after crack formation and propagation in all top liner specimens made with various percentages of three types composite clay as shown in Figure 13. From the variation of additives content and CIF, it can be said that the value of CIF is lowest for 40% gravelly materials than other percentages of brick khoa, sandy and gravelly materials. Again from the variations of shrinkage and percentages of additives content, shows that the values of shrinkage in both length and width directions are lowest for 60% gravelly materials than other percentages of brick khoa, sandy and gravelly materials. Also all the cracking properties decrease up to a certain percentage, then again increase this is due to at higher percentages proper bond between soil and additive materials is not possible. Finally comparing cracking behavior of three type's composite clay made with various percentages of brick khoa, sandy and gravelly materials, it can be suggested that, 40 to 60% of gravelly materials is more suitable for this study soil between these three additives. By using 40 to 60% gravelly materials, CIF can be reduced up to 6 to 7% than control specimens. Other percentages also show almost less CIF than control specimens.

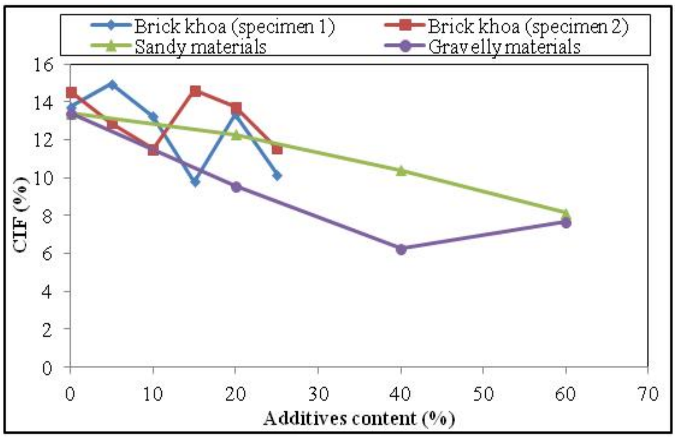


(a)

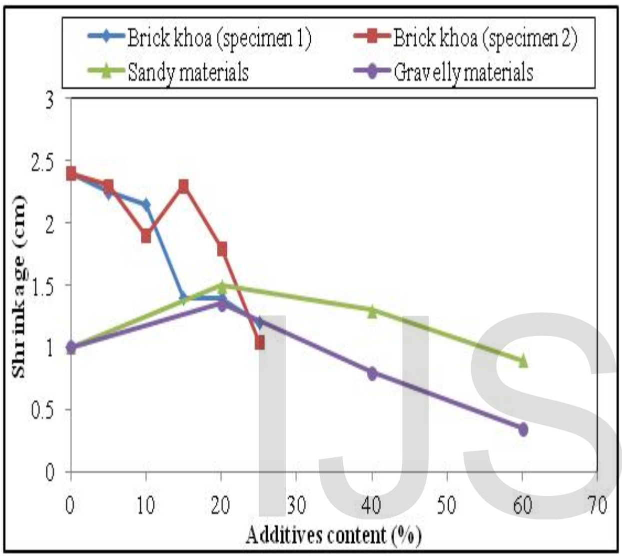


(b)

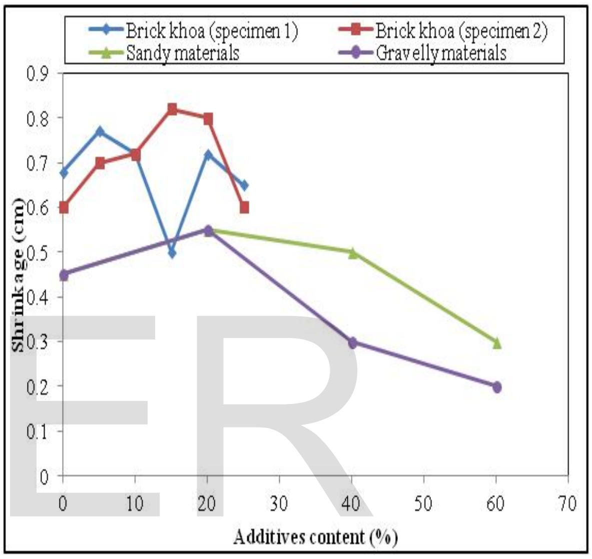
Figure 12 Variations of shrinkage with time for gravelly materials composite clay in (a) length direction (b) width direction with 60% gravelly materials as additives content



(a)



(b)



(c)

Figure 13 Variation of additives content at sixth days with (a) CIF, (b) shrinkage in length direction, (c) shrinkage in width direc-

5 Conclusion

This work focuses on the study of some relevant factors that affect the behavior of top liner specimens subjected to drying. The experimental research has been performed on soil samples from near Rajbandh dumping site. The following conclusions were derived:

1. The volumetric shrinkage of soil used in this study was found low which is 20.56%. Low shrinkage limit indicates high potential for shrinkage and swelling.
2. Top liner specimens made with only clay soil sample (control specimens) gave the total average distributed crack area of 33.33 cm2 and hence average crack intensity factor 13.89%. Also total shrinkage in length and width directions was found 1.93 cm and 0.58 cm respectively.
3. Variations of maximum and minimum values of CIF obtained for specimen 1 of 5% brick khoa and 40% gravelly materials respectively.
4. On the other hand, variations of maximum and minimum values of shrinkage in length direction obtained for control specimen 1 and specimen made and in width direction variations of maximum and minimum values of shrinkage obtained for specimen 2 of 15% brick khoa materials as additives content and 60% gravelly materials as additives content respectively.

Based on the above findings, it can be said that the use of additives content as gravelly materials of 40% to 60% considerably reduced cracking formation and shrinkage of top liner specimens for this study soil sample. Other percentages also show almost less cracking formation and shrinkage than control specimens. So it can be recommended that, composite clay can be used as top liner materials in practical landfill sites and also in sanitary landfill sites with its greater advantages than the use of only clay soils. Additive materials and its percentages in composite clay can be changed depending on the landfill types, availability of materials, soil conditions, cost of materials, location of landfill sites, climate and weather conditions etc. 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 smaller.

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