STUDY ON DESICCATION CRACKING BEHAVIOUR OF NATURAL FIBER - REINFORCED CLAY

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Abstract - *Clay-rich soils having low hydraulic conductivity are used in waste containment systems like landfill covers and liners. Expansive clays can potentially be used as an impervious barrier material in landfill lining systems due to their high clay content and low hydraulic conductivity. However, because of their shrink-swell nature, they are prone to severe desiccation cracking, which causes distress in landfill lining systems' impervious barriers, affecting mechanical and hydraulic performance. The enhancement in the crack resistance of locally available expansive clay by natural fiber reinforcement was investigated with the help of an experimental setup in this study. The set-up consists of three 200 W Tungsten Halogen lamps enclosed within a thermocol incubator. The propagation and evolution of cracks in the soil specimen were analyzed using a digital image analyzing system. The results exhibit that the cracking behavior of expansive clay on desiccation is significantly influenced by fiber reinforcement. The average cell area and crack opening width were measured and compared to those of unreinforced specimens. Due to fibers, an evident reduction in the total cracked area has been observed in fiber-reinforced clay. The fiber inclusion decreased the crack width and also the cell area, hence increasing the relative integrity of the specimen relatively. Except when longer fibers were used, fiber reinforcement was found to be effective in reducing desiccation cracking.*

Key Words: Expansive clay, Natural Fibers, Desiccation cracking, Fiber reinforcement, Digital image analysis .

1. INTRODUCTION

Clayey soil swells in the presence of water and shrinks in the absence of it, resulting in desiccation cracks that have a significant impact on its mechanical and hydraulic performance. Clay-rich soils with low hydraulic conductivity could be used as a barrier material in waste containment systems such as landfill liners and covers. These soils are prone to severe desiccation cracking due to their shrink-swell nature, causing distress in landfill lining systems' impervious barriers. The exothermic decomposition taking place inside the landfill as well as the external heat from the sun contribute to the desiccation cracking of the clayey soil. Desiccation cracking affects the long-term sealing effect of impervious barrier layers in landfill lining systems, allowing rainwater, snowfall, etc. to leak through. These cracks could also lead to the escape of gases inside the landfill including methane gas, which may even lead to severe explosions, causing great distress to the surrounding environment and mankind. The hydraulic conductivity of the clay layer rises by an order of three as a result of cracking because the cracks act as drainage channels for water penetration.

2. RELATED WORKS

Uma Chaduvula et al (2017) concluded from their experiment that the crack intensity and shrinkage strain for fiber-reinforced soil were found to be substantially less than those of unreinforced soil. Brian A. According to Albrecht et al. (2001),Because the cracks act as drainage paths for water infiltration, cracking increases the hydraulic conductivity of the clay layer by an order of three. Maher et al (1990) stated that the main advantage of discrete reinforcement of soil with fibers over conventional geosynthetic sheet reinforcement is the absence of a single potential plane of failure. B.V.S. Viswanadham et al. (2009) investigated the effects of discrete geo-fiber reinforcement on the swelling behaviour of a locally available expansive soil.Due to the presence of the fibers, the swelling potential and swelling pressure were found to be significantly reduced. Divya et al (2014) and According to B.V.S. Viswanadham et al. (2011), the delay in cracking of fiber reinforced soil increased significantly as the fiber content increased. Fiber inclusion reduces soil desiccation cracking and improves mechanical performance, according to Tri Harianto et al (2008) and Carol J. Miller et al (2004). M. Olgun (2013) concluded that the content and length of fibers played an important role in the change of strength values. Chao-Sheng Tang et al (2012) stated that fiber inclusion increased the crack resistance significantly due to increased tensile strength of the soil.

In this study, we mainly focus on 1) To control desiccation cracking in clayey soil. 2) To study the behaviour of desiccation cracking. 3) Effect of fiber content and fiber length in reducing crack formation. 4) Sutability of banana fiber and pineapple fiber. 5) To maintain a long term sealing effect. 6) An eco-friendly alternative.

3. METHODOLOGY

3.1 Sample Preparation

Firstly, the clayey soil collected from Tripunithura metro site was oven-dried and pulverized. Preliminary lab tests such as specific gravity, size fraction, and Atterberg limits of the clayey soil were determined. Different fiber contents (0%, 0.25%, 0.5%, 0.75%, 2%, 2.5%, 3%, 4%, 4.5% by dry weight of the soil) were used for fiber lengths of 15 mm, 30 mm, and 50 mm in the preparation of fiber-reinforced clay specimens. Initially, a mix of dry clay and fiber was prepared. To this water is gradually added to make a slurry. It is then mixed with a spatula for approximately 10 minutes. All specimens were prepared close to the liquid limit of the clayey soil. The prepared slurry was then poured into a borosilicate glass container having 120 mm diameter. The slurry was poured until it reached a height of 15mm. To compare the effects of fiber content and fiber length, a specimen height of 15 mm was used to produce distinguishable crack patterns. The air bubbles in the soil slurry container were then tapped out.

3.2 Experimental Setup

The prepared specimen was then placed in the test setup (Figure 1) and desiccated under three 200 W lamps. A schematic representation of the test setup is shown in Figure 3.2. All tests were performed at a fairly constant temperature of 50°C. The temperature was monitored using an infrared thermometer. The specimen was dried for 10 hours and weighed every hour to measure the amount of loss in moisture. A camera was used to capture images of the drying soil specimen every hour.

Fig-1: Actual experiment setup

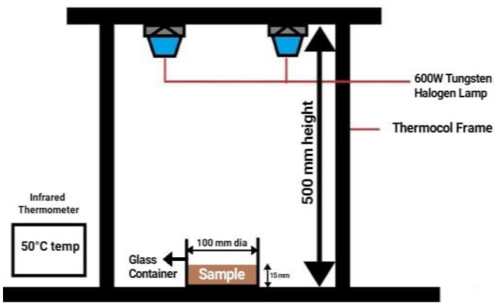


Fig-2: Schematic diagram of test setup

3.3 ImageJ Software

The images captured were then analyzed using ImageJ software. Crack area and crack width of plain and natural fiber (banana and pineapple fiber) reinforced samples were obtained with the help of this software and compared. After comparison, the reinforced sample with the minimum crack area and crack width was determined. The type of fiber, fiber content, and fiber length in that sample was proposed as the best alternative in restraining desiccation cracking in clayey soil.

3.4 Soil Properties

Table-1: Soil properties

SIZE FRACTION	ATTERBERGS LIMIT	SPECIFIC GRAVITY
Gravel = 1% Sand = 5% Silt = 34% Clay = 60%	Liquid Limit = 76% Plastic Limit = 25.35% Shrinkage Limit = 20%	2.65

3.5 Characteristics of Fiber

(Source: Fiber Region, no. 36&37, Valasaravakkam, Chennai - 60087)

Fig–3: Banana Fibers

Fig–4: Pineapple Fibers

3.5.1 Physical Characteristics

3.25.1.1 Banana Fiber

Table-2: Physical characteristics of banana fiber

Appearance	Gold Brown Fiber
Length (Ft)	3 - 5 Ft
Diameter (mm)	1 - 3 mm

Density (g/cm3)	1.3
Tensile Strength	650 - 780 Mpa

3.5.1.2 Pineapple Fiber

Table-3: Physical characteristics of pineapple fiber

Colour	Natural
Size/Length (cm)	110-130
Diameter (mm)	0.35
Density (g/cm3)	1.22
Fiber Strength(N)	880

3.5.2 Chemical Characteristics

3.5.2.1 Banana Fiber

Table-4: Chemical characteristics of banana fiber

Tenacity	29.98 g/denier
Fineness	17.15
Moisture Regain	13.00%
Elongation	4%
Alco-ben extractives	1.70%
Total cellulose	65.00%
Lignin	21.00%
Alpha cellulose	61.50%
Residual Gum	41.90%

3.5.2.2 Pineapple Fiber

Table-5: Chemical characteristics of pineapple fiber

Cellulose	65%
Hemicelluloses	12%
Lignin	9.9%
Waxes	2%
Total	100%

3.6 OBSERVATIONS

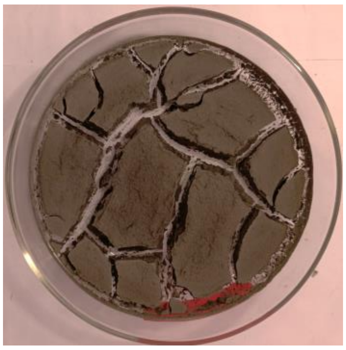
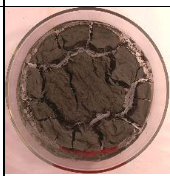
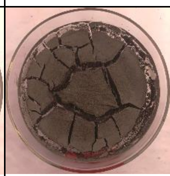
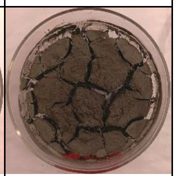
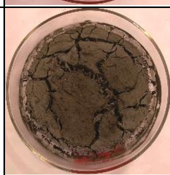
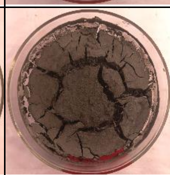
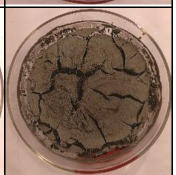
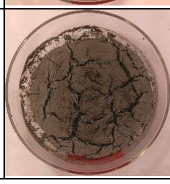
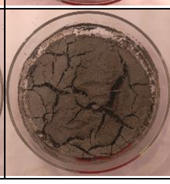
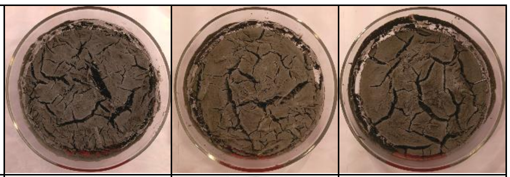
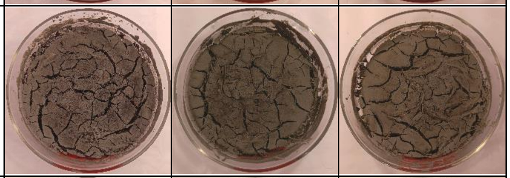


Fig-5: Unreinforced clay sample after 10hr desiccation

3.6.1 Banana Fiber Reinforced Samples

Table-6: Banana fiber reinforced samples after 10 hours

Fiber content	1.5cm	3cm	5cm
0.25%			
0.5%			
0.75%			

2%	
2.5%	
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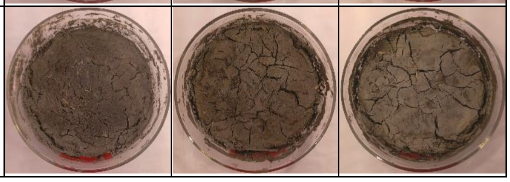
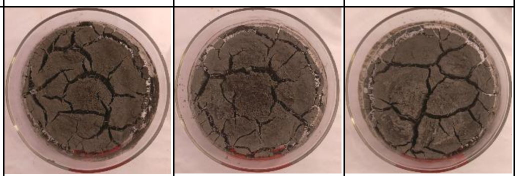
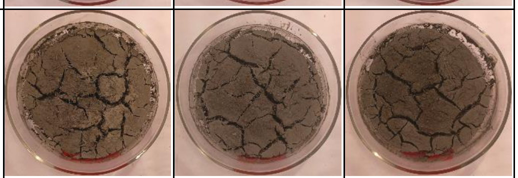
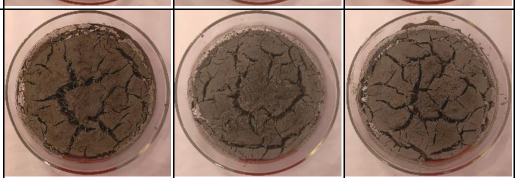
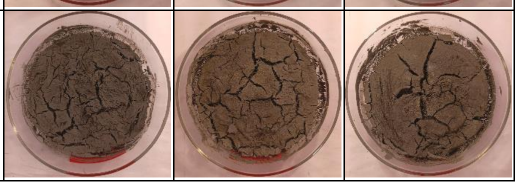
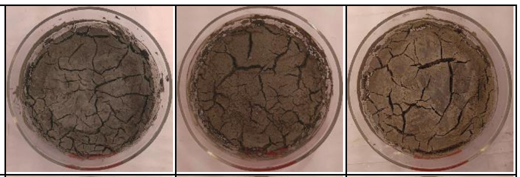
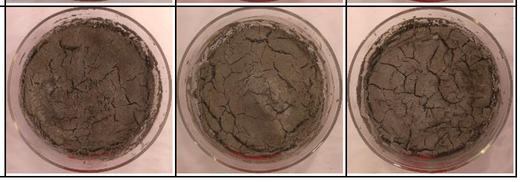
4.5%	

3.6.2 Pineapple Fiber Reinforced Samples

Table-7: Pineapple fiber reinforced samples after 10 hours

Fiber content	1.5cm 3cm 5cm
0.25%	
0.5%	
0.75%	
2%	
2.5%	
3%	
4%	
4.5%	

4. Result

The crack area and crack width of all the samples after 10 hours was determined using ImageJ software and the following results were obtained.

4.1 Crack Width

The crack opening width was found by measuring the largest distance between one randomly chosen point on one cell's boundary and the opposite cell's boundary. As the soil desiccation progresses, the crack width increases for all specimens until it becomes generally stable at the end of desiccation for the given environment.

4.1.1 Banana Fiber Reinforced Sample

Table-8: Crack width of Banana fiber reinforced sample after 10 hours

BANANA	0%	0.25%	0.50%	0.75%	2%	2.5%	3%	4%	4.5%
1.5cm	1.086	0.636	0.572	0.399	0.248	0.243	0.19	0.09	0.07
3cm	1.086	0.652	0.595	0.529	0.373	0.293	0.258	0.154	0.12
5cm	1.086	0.771	0.623	0.59	0.506	0.421	0.334	0.266	0.184

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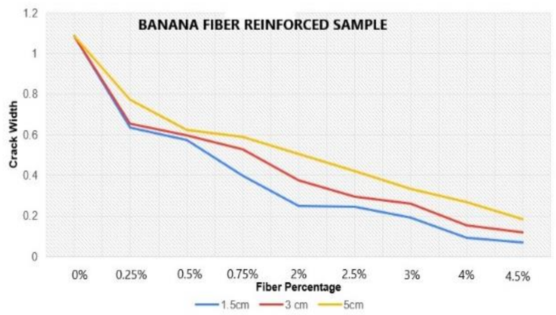

Fig-6: Variation of crack width with respect to fiber percentage

4.1.2 Pineapple Fiber Reinforced Sample

Table-9: Crack width of Pineapple fiber reinforced sample after 10 hours

PINEAPPLE	0%	0.25%	0.50%	0.75%	2%	2.5%	3%	4%	4.5%
1.5cm	1.086	0.499	0.444	0.353	0.305	0.206	0.192	0.121	0.095
3cm	1.086	0.543	0.527	0.433	0.38	0.232	0.199	0.188	0.12
5cm	1.086	0.58	0.556	0.441	0.394	0.282	0.262	0.211	0.198

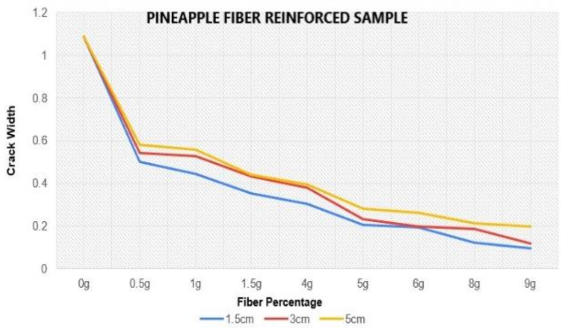

Fig-7: Variation of crack width with respect to fiber percentage

4.2 Crack Area

4.2.1 Banana Fiber Reinforced Sample

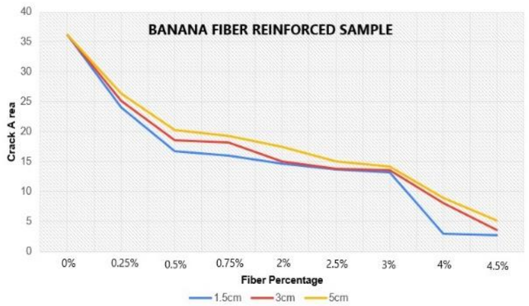

Fig-8: variation of crack area with respect to fiber percentage

4.2.2 Pineapple Fiber Reinforced Sample

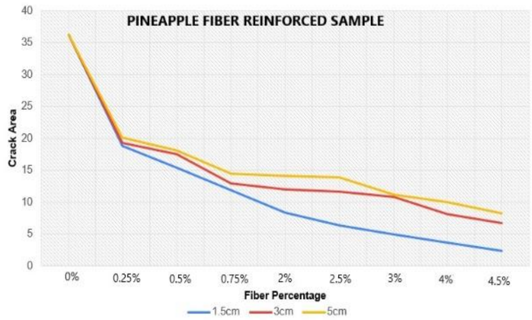

Fig-9: variation of crack area with respect to fiber percentage

5. CONCLUSIONS

In clayey soil, 1.5 cm length and 3% banana fibers, as well as 3 cm length and 3% pineapple fibers, are ideal for reducing desiccation cracking. As the length of fibers increased, the width and area of cracks also increased as shown in Figure 4.1, Figure 4.2, Figure 4.3, and Figure 4.4. This is due to the non-uniform distribution of fiber. The crack width and area were reduced as the percentage of fiber was increased. We discovered that the optimal fiber content for both banana and pineapple fibers was 3 percent by analyzing the width of the cracks in the specimen after 10 hours.

In our experiment, both fibers significantly reduced the formation of desiccation cracks in clayey soil. As a result, both fibers can be used to prevent desiccation cracks. As the percentage of fibers was increased, after a certain value, there was no significant reduction in crack width. Hence further addition of fibers was not relevant. A 5 cm long fiber length prevented proper fiber dispersion in the clay mass. This is due to flocculation and non-uniform dispersion, as a result, the longer fibers were unable to provide the necessary interlocking. Tang et al. (2012), on the other hand, found that as fiber content increased, crack reduction increased as well, but there was no significant effect due to fiber length on crack reduction in fiber reinforced soil. The longer fibers are too long and form a cluster, leaving a large portion of the soil unreinforced. The fiber content affects the cracking behaviour of fiber-reinforced soil. According to Uma Chaduvula et al. (2017), the average effective contact area between the soil and the fiber increases (per unit mass of soil) as the fiber content increases. While unreinforced soil forms wide crack widths, the addition of fibers controlled the crack width opening through the bridging action of fibers. Uma Chaduvula et al. (2017) said that the effect of fibers at longer lengths and higher fiber contents was insignificant in restraining desiccation cracking. They also stated that the distribution of fibers throughout the clay mass was found to be uniform in soil specimens reinforced with 1.5 cm and 3 cm fibers. They also mentioned that the image processing technique proved effective in quantifying crack feature measurements and providing useful information. The fiber inclusion undoubtedly facilitates crack reduction. Fiber length and content are important factors in reinforcement.

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