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Effect Of Fly Ash and Synthetic Fibres on The Desiccation Cracking Of Expansive Clay

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Abstract. Expansive clays are abundant in many strategically important places in India. They undergo volumetric changes by swelling and shrinkage upon seasonal moisture variations. The hysteresis of swelling and shrinkage leads to desiccation cracking, loss of shear strength, change in consolidation characteristics, increase in permeability and seepage characteristics. Generally, these soils are replaced with a more desirable material for construction. This study aims at sustainable use of expansive clay from Surat in barrier systems as the clay possesses permeability of the desirable range of 1 x 10^{-9} m/s. Expansive clay was mixed with fly ash and reinforced with discrete and randomly distributed polypropylene fibers of length 12mm and varying fiber contents. The tensile strength behavior of fiber reinforced expansive clay was studied by performing desiccation cracking and direct tensile strength tests. The desiccation cracking tests were performed under controlled environmental conditions. The results indicate 89.9% of crack reduction due to the presence of reinforcing fibers and fly ash. The bridging action of fibers increases the tensile strength of clay and prevents cracking of expansive clay, thereby maintaining the integrity of the clay layer.

Keywords: Expansive clay, fiber reinforcement, crack resistance, desiccation cracking

1 Introduction

Black cotton soil is one of the major regional soil deposits in India, covering an area of about 3.0 lakhs sq.km [1]. In India, the area covered by expansive soils is nearly 22.2% of the total land area. The desiccation of clay and swelling pressure lead to structural distresses. Desiccation cracking is a common problem found in fine grained soils especially expansive soils. Quantification of cracking properties like crack intensity, crack dimensions, crack initiation, and crack pattern is an important aspect to study behaviour of cracked soil. Desiccation alters the properties of soil adversely viz. the seepage, consolidation, and compressibility and shear strength characteristics of the soil [2]–[4].

One of the most important pillar of Sustainable development goals in to use locally available material and use of industrial waste. Waste containment systems use clay-rich soils having low hydraulic conductivity as landfill liners and covers. Since expansive clays have a high clay content and low hydraulic conductivity (in the order of 1x10^{-9}m/s,) they can potentially be used as an impervious barrier material in landfill lining systems. However, due to their shrink-swell nature, they have a tendency of severe desiccation cracking leading to distress in impervious barriers of landfill lining systems. In recent times, the concept of reinforcing the soil by including randomly distributed fibers is being investigated. One of the main advantages of randomly distributed fibers over conventional geosynthetic reinforcement is the absence of potential plane of weakness[5], [6]. However, more recently there has been an increasing interest in studying the behaviour of fiber reinforced soil to increase the desiccation cracking resistance [7]–[12]. It is found that geofibers reduce the soil cracking. This study experimentally investigates the use of fly ash and fiber reinforced expansive clay as a barrier material with an emphasis on desiccation cracking. The objective of this study is to identify the potential of randomly distributed discrete fiber reinforcement in mitigating desiccation cracking of barrier systems.

2 Materials

2.1 Soil

In the current study, expansive clay collected from a construction site near the city of Surat, Gujarat, was used. When the soil's Atterberg Limits were examined, it was discovered that the Liquid Limit and Plasticity Index were 52 and 22, respectively according to ASTM D 4318-93 (1994) and ASTM D 427-93 (1994). The Free Swell Index for it was found to be 50. As a result, the black cotton soil utilized in the study was categorized as high plasticity clay under the Unified Soil Classification System. The grain size distribution of the soil used is provided in Table 1.

Table 1. Particle size Analysis of soil used

Particle	**Value**
Gravel	2%
Coarse Sand	5%
Medium Sand	8%
Fine Sand	9%
Silt + Clay	76%

2.2 Fly ash

The fly ash used in the present study was collected from nearby Thermal Power plant in Gandhinagar, Gujarat. The properties of Fly Ash are provided in Table 2.

Table 2. Physical properties of Fly Ash used

Parameters	Test Result
SiO_2	51.40%
Al_2O_3	18.74%
Fe_2O_3	13.89%
CaO	4.35%
MgO	1.12%
Na_2O	0.11%
SO_3	0.65%
LOI	7.28%
Specific gravity	2.24

Bulk density	1545 kg/ m^3
Porosity	20.74%
Water absorption	7.62%

2.3 Fibers

Polyester (PET) fibers commercially available as Recron3s, Reliance Industries Ltd. were used in this study. The specific gravity of the PP fibers is higher than water.

Table 3. Properties of Polyester fiber used

Properties	Value
Specific gravity	1.35
Effective diameter (μm)	40
Linear density (tex)	0.331
Breaking force for single filament(mN)	112.72
Tenacity (mN/tex)	340.56
Strain at break (%)	45.53
Fusion point (°C)	165

2.4 Sample preparation

The soil sample was broken into smaller pieces using a compaction machine which was further broken down into fine clay using the Jaw Crusher machine. A mixture of fine dry clay, fly ash and fibers with varying amount were prepared as shown Table 4, to which water was gradually added to make a slurry and mixed for approximately 10 min. All specimens were prepared near soil's liquid limit. To obtain a specimen thickness of 15 mm, the produced slurry was put onto a glass petri dish with a 100 mm diameter. To get rid of the air bubbles, the soil slurry container was gently pounded on a wooden platform. To ensure a homogeneous drying surface, the interior surface of the glass containers utilized in the study was free of any scratches, protrusions, or depressions.

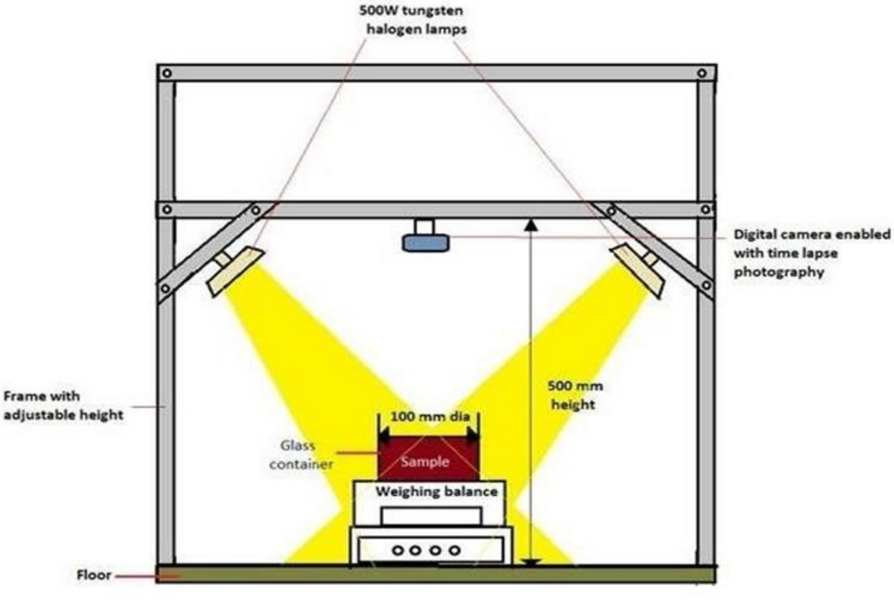
2.5 Test Setup and Procedure

The test setup mainly consists of a soil sample, Adjustable stand, Two Halogen lamps each of 500 W, a digital camera and a 100 mm diameter dish for keeping the soil sample as shown in the schematic setup in Fig. 1. The main objective of this setup is to measure the crack width, length and area of the soil sample in presence of proper heat and light with and without synthetic fibers.
The sample was kept under the observation of the halogen lamps of 500 W and a digital camera for 8 hours at a height of 50 cm. The camera captured the picture of the specimen in every one hour. The weight for each specimen was individually weighed to see how much moisture was being lost and recorded.

Sr No.	Experiment	Soil (%)	Fly ash (FA)(%)	Fibre Content(%)
1	Unreinforced (UR)	100	0	0
2	UR+7%FA	93	7	0
3	0.25%FR+7%FA	93	7	0.25
4	0.50%FR+7%FA	93	7	0.5
5	0.75%FR+7%FA	93	7	0.75
6	UR+10%FA	90	10	0
7	0.25%FR+10%FA	90	10	0.25
8	0.50%FR+10%FA	90	10	0.5
9	0.75%FR+10%FA	90	10	0.75

Table 4. Soil Samples with varying amount of additive

Fig. 1. Schematic Diagram of the test setup



Digital image analysis was used to analyze the images captured during the drying process. Studies have been ongoing for the past several years to determine the exact dimensions of cracks. Image analysis is the best method out of all those that are accessible. It is a relatively quicker procedure and measuring cracks and shrinking takes less time. For picture processing and quantification of surface cracks and shrinkage in the specimens, a Java based software ImageJ, Version 1.50a, was used to measure the crack features during all stages of tests through image analysis [16], [17].

3 Results and Discussion

In order to expedite the drying process, halogen lamps were used during the study. From the lab experiment, a few pictures were chosen to demonstrate how the expanded clay behaved as it dried. The performance of each of the chosen improvement methods was investigated using the information gathered throughout the image analysis process. Figure 2 shows the cracking pattern of the soil specimen during time interval of every 2 hours. It is clear that specimens lacking fiber exhibited cracks that were longer and wider but less numerous. With increasing fiber content, cracks become more prevalent. A higher fiber content, however, causes cracks to be narrower and shorter.

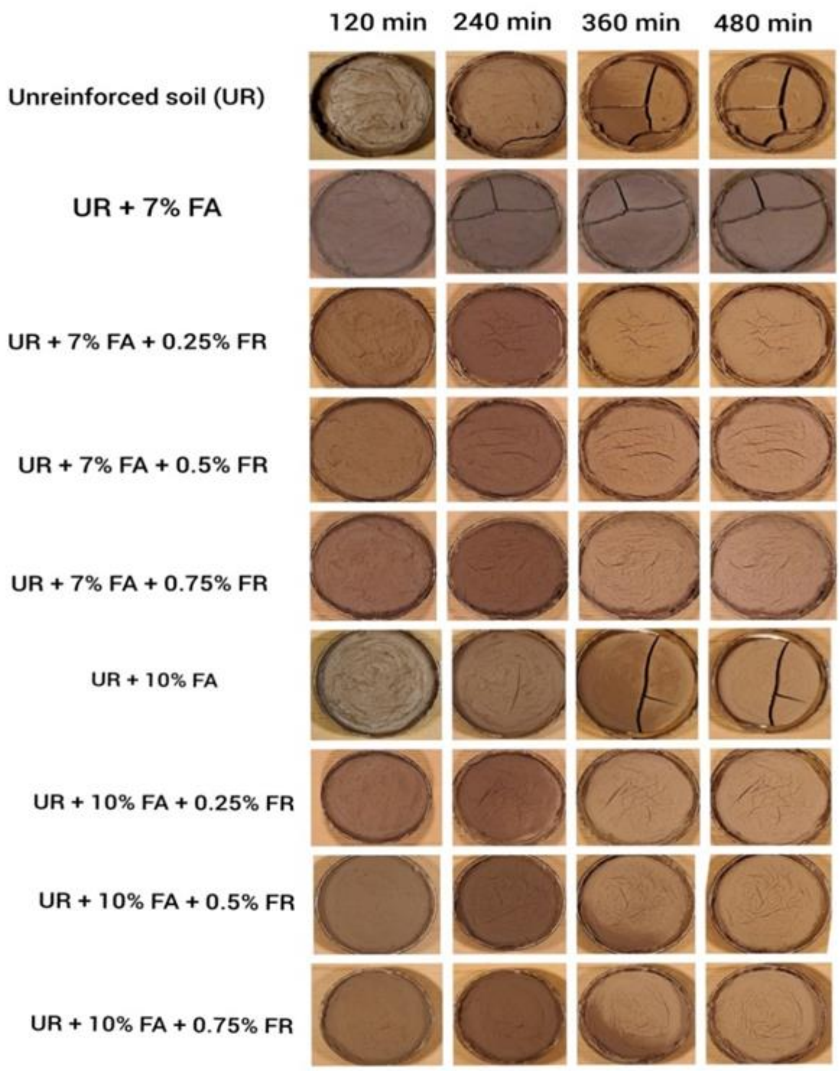


Fig. 2. Desiccation test results for every two hours

At the end of the experiments, the crack width, crack length, crack area and final crack intensity factor (CIF) for all the soil specimen were determined using digital image analysis as given in Table 5.

Experiment	Crack Width (mm)	Crack Length (mm)	Crack Area	CIF %
UR	4.2	31.8	284.6	3.6
UR+7%FA	2.9	39.8	275.5	3.5
0.25%FR+7%FA	0.6	15.4	100.0	1.2
0.50%FR+7%FA	0.6	11.7	73.3	0.9
0.75%FR+7%FA	0.4	9.1	65.5	0.8
UR+10%FA	4.1	56.0	82.2	1.0
0.25%FR+10%FA	0.5	16.4	27.4	0.3
0.50%FR+10%FA	0.5	4.5	12.3	0.1
0.75%FR+10%FA	0.3	1.7	7.2	0.09

Table 5. Crack Parameters for all Soil Samples

As observed from the table, the CIF is highest for the unreinforced sample whereas it is lowest for the sample whose content for soil, fly ash and Fiber are 90%, 10% and 0.75% respectively. With the increase of additives, the crack parameters are decreasing which shows that the additives were effective for the reduction of cracks.

3.1 Crack Width

Crack Width is obtained by measuring the shortest distance between the boundaries of the crack in the captured images using the distance measurement tool in ImageJ software. The addition of fly ash and fibers reduces the crack width of the soil. The variation of crack width with varying fiber content is shown in Fig. 3. The crack width is increasing in case of 10% Fly ash and 0.5% fiber content but is then decreased at drastic rate.

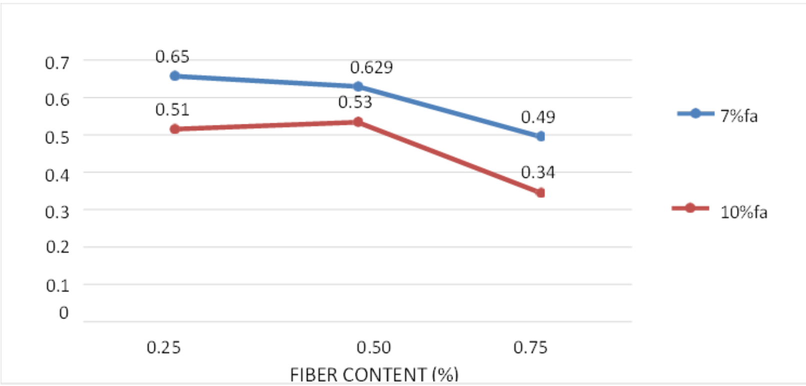


Fig. 3. Variation of Crack Width with Fiber Content

3.2 Crack Length

Crack length is the length of the crack which changes by varying the content of Fly ash and fibers as shown in fig. 4.

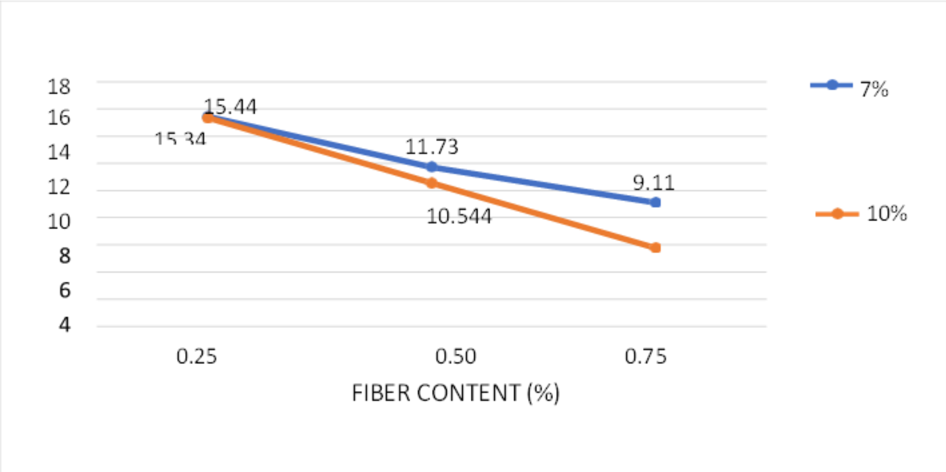


Fig. 4. Variation of Crack Length with Fiber Content

4. Conclusion

Over the past several decades, numerical researchers have given close attention to the cracking behaviour and mechanisms in clayey soils connected to desiccation. According to the results of the experiments conducted for this study, inclusion of fly ash and fiber decreased cracking. The largest crack width was found in the unreinforced soil, which was reduced by the addition of fly ash and further reduced by the addition of fibers.

In unreinforced specimens, large cracks developed that extended all the way to the glass dish's bottom. When fiber was added, surface cracks developed because the polyester fibers had a propensity to hold the cracks from enlarging. Fibers altered the soil's characteristics, causing a decrease in tensile strength and swelling pressure. The image processing technique proved to be effective in measuring crack feature measurements and giving meaningful data. In this study, 89.9% crack reduction was achieved from the range of fiber lengths and fiber contents used. Crack features such as crack width, crack spacing, and cell area became narrower with the addition of fibers.

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