

Desiccation characteristics and direct tension attributes of thin clayey soil containing discrete natural fibers

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Article

Keywords

Desiccation coefficient
Desiccation crack
Fiber reinforcement
Tensile strength
Toughness

Abstract

The use of thin clayey soil as a liner plays an important role in many geotechnical and geo-environmental engineering applications, such as open channel and reservoir sealant, contaminant barrier etc. Their functional performance and sustainability depend primarily on the desiccation characteristics of these liners and barriers. A number of studies have been undertaken to quantify the degree of improvement achieved by using natural and synthetic fiber reinforcement. However, there is a lack of studies to understand the desiccation behavior of reinforced clay. This study aimed to explore the desiccation and cracking behavior of clayey soil reinforced with two natural fibers (coir and jute fiber) in addition to the degree of improvement in tensile strength. A series of direct tension and desiccation cracking tests have been conducted in the laboratory on clay-coir and clay-jute fiber mixes. The results demonstrate that when coir and jute fibers are used, the tensile strength of fiber-reinforced soil rises by up to 475 percent and 215 percent, respectively, when compared with the tensile strength of unreinforced soil at the same moisture content. Desiccation test results also show that blending of fibers reduces the breadth and depth of cracks significantly. The characteristics of unreinforced and fiber-reinforced clayey soil under desiccation and direct tension are briefly discussed in this paper. Findings of the present study will be important for professionals dealing with clay liners and trying to reduce cracking problems associated with drying soil.

1. Introduction

Desiccation cracking of clayey soils is a worldwide problem in many engineering applications such as earthen embankments for roads and dams, open channels, reservoirs, sanitary landfill barriers, etc. Such cracking causes notable problems with earthen roads, embankments, slopes, and foundations (Li et al., 2009). Desiccation cracks in clay liners underlying sanitary waste landfills cause serious geo-environmental concerns (Daniel & Brown, 1987; Peron et al., 2009b). Failures of clay levees are found to be initiated by penetrating water into desiccation fissures (Utili et al., 2008). As documented in literature, desiccation cracks are initiated when the minor principal stress exceeds its tensile strength (Albrecht & Benson, 2001; Konrad & Ayad, 1997).

Many researchers investigated the mechanism of cracking of unreinforced clay under various conditions (Lau, 1987; Morris et al., 1992; Colina & Roux, 2000; Vogel et al., 2005; Kodikara & Choi, 2006; Peron et al., 2009a; Tang et al., 2011a; Li & Zhang, 2011; Lakshmikantha et al., 2012;

Costa et al., 2013; Li, 2014; Shokri et al., 2015; Khatun et al., 2015). The factors influencing desiccation cracking are soil mineral composition, clay content, initial moisture content and soil density (Albrecht & Benson, 2001; Tang et al., 2008; Shinde et al., 2012; Silva et al., 2013; Lu et al., 2015; Jayanthi et al., 2017). The boundary conditions, temperature and humidity also have influences on the desiccation cracking behavior of unreinforced clay (Tang et al., 2010; Uday & Singh, 2013; DeCarlo & Shokri, 2014; Uday et al., 2015; Lakshmikantha et al., 2018).

The desiccation rate of unreinforced clay is higher at smaller thicknesses. Cracking water content is higher for thicker clay layers (Nahlawi & Kodikara, 2006; Tang et al., 2011c; Tollenaar et al., 2017). The average length and width of cracks as well as crack density increase with the increase in clay layer thickness (Tang et al., 2008; Guo et al., 2018). Initiation of desiccation crack will be delayed due to the inclusion of fiber reinforcement in clayey soil. The addition of discrete fiber in clayey soil reduces shrinkage, extent of desiccation cracking and total cracked area (Chaduvula et al., 2017; Jayasree et al., 2015; Ziegler et al., 1988). A number of

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researchers (Anggraini et al., 2015a, b; Capilleri et al., 2019; Correia et al., 2015; Enokela & Alada, 2012; Li et al., 2014) investigated the strength and toughness of fiber reinforced clayey soil in direct and indirect tension. A significant improvement in the tensile strength and toughness of reinforced soil has been reported from their studies.

It is evident that a number of studies have been undertaken to realize the extent of desiccation cracking of fiber reinforced clayey soil. But, the desiccation characterization of clayey soil mixed with randomly distributed fibers is yet to be explored. An understanding of desiccation and direct tension behavior of thin clayey soil containing fiber reinforcement will be helpful for proper use of discrete fiber as reinforcement in clay liners and covers. In this paper, the desiccation rate, cracking water content, tensile strength, toughness etc. of thin clayey soil of varying thicknesses with a range of fiber contents are presented. Relationships among the reinforced clay layer thickness, cracking water content, and desiccation rate have been developed. Details of the investigation program and outcomes are presented in the following sections.

2. Materials and methods

2.1 Materials

The raw materials used for the current investigation were clayey soil, coir and jute fiber. The clayey soil was collected from the marshy land of Gazipur City Corporation, Bangladesh. The properties of the soil are shown in Table 1. Coir was extracted from coconut husks. The collected coir was cleaned with potable water without the use of chemical additives and dried at room temperature. Before fixing the length of fibers, different lengths of fiber were used in the trial samples. Based on their consistent results, the length of the fibers has been fixed. Then the fibers were cut into the required lengths by scissors. The jute fiber used in this study was collected from the local market and cut into desired lengths. Figure 1 and Figure 2 show the coir and jute fibers used in the present study. The properties of coir and jute fiber are listed in Table 2.

2.2 Direct tension sample preparation and testing

This study aimed at exploring direct tension behavior at and around the optimum moisture content of reinforced

clayey soil. So, a number of compaction tests are conducted following the ASTM standard method (ASTM, 2007) on base soil and soil-fiber mixtures to determine the *OMC*. The test results of compaction tests are summarized in Table 3. The direct tension test is an appropriate method to determine the tensile strength of clayey soil as the tensile stress and strength can be directly obtained (Tang et al., 2015). A simplified direct tension test mold was fabricated for this study. A photograph of the direct tension test mold is shown in Figure 3(a). The length and thickness of the test specimen are 90 mm and 25.5 mm respectively. The cross-



Figure 1. A photograph of the coir used in this study.



Figure 2. A photograph of the jute fibers used in this study.

Table 1. Properties of soil used in this study.

Item	Natural moisture content (%)	Specific gravity	Liquid limit (%)	Plastic limit (%)	Optimum moisture content (%)	Maximum dry unit weight (kN/m ³)	Unconfined compressive strength (kN/m ²)	Unified soil classification
Symbol	w_n	G_s	LL	PL	OMC	$\gamma_{d(max)}$		-
Result	23.6	2.63	38	21	17	16.67	73.2	CL

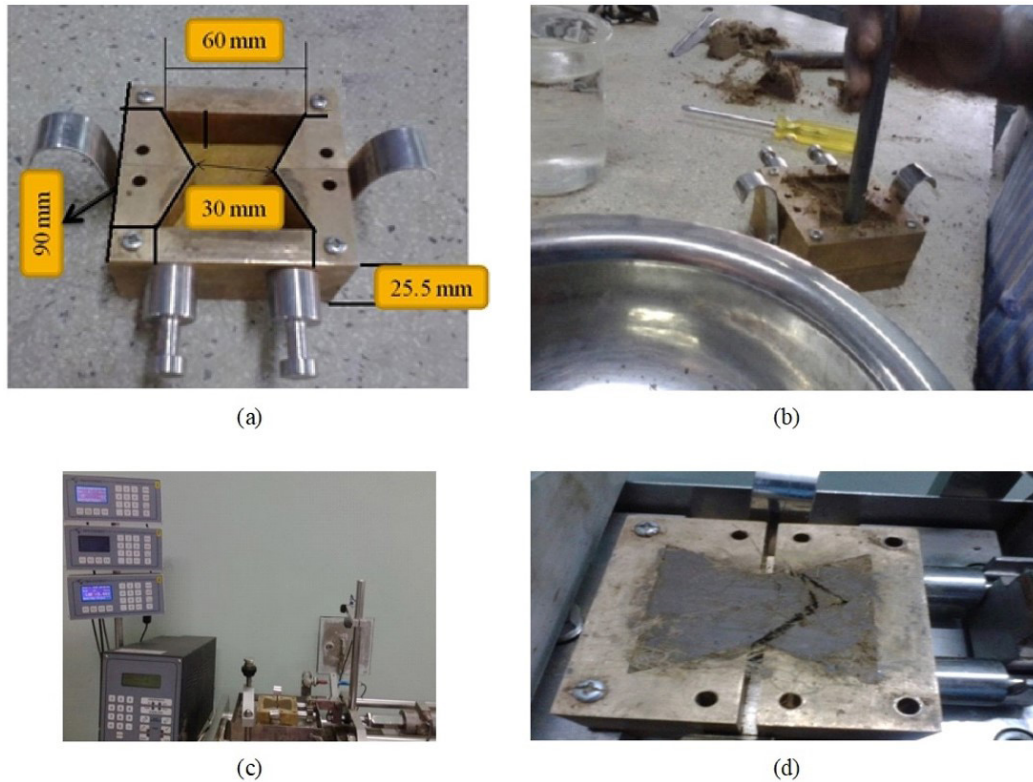


Figure 3. (a) Dimensions of direct tension test mold, (b) compaction in the mold, (c) sample placed in direct tension test device, and (d) sample after test.

Table 2. Properties of coir and jute fiber used in this study.

Fiber type	Color	Mean diameter (mm)	Average length (mm)	Aspect ratio	Fiber contents (%)
Coir	Brown	0.25	25	100	1.0, 2.0, 3.0
Jute fiber	Brown	0.1	30	300	0.5, 1.0, 2.0

Table 3. Summary of compaction tests.

Specimen type	Maximum dry unit weight (kN/m ³)	Optimum moisture content (%)
Base Soil	16.67	17.0
Soil + 1% Coir	16.32	18.0
Soil + 2% Coir	15.21	19.0
Soil + 3% Coir	14.10	20.0
Soil + 0.5% Jute Fiber	16.58	18.5
Soil + 1% Jute Fiber	16.00	20.0
Soil + 2% Jute Fiber	15.33	22.0

sectional dimension of the specimen at the neck is 30 mm × 25.5 mm. To minimize friction between the soil and the bottom surface of the mold, the bottom surface of the mold was lubricated prior to placement of the testing materials at the time of preparing the test specimen. After the specimen was compacted, the sample with the compaction mold was placed into the testing equipment. Figure 3(b) to Figure 3(d)

show the compaction of the specimen, test equipment and specimen after failure respectively. The stress and strain readings are recorded at an interval of 15 seconds. And, the rate of deformation was maintained at 1 mm/min throughout the test to have a sufficient number of readings to capture the shape of the stress-strain curve accurately. The total loading time required for the tests on reinforced samples was about 8 minutes. Finally, the tensile strength (σ_t) was calculated by dividing the maximum tensile load (P_{max}) by the cross-sectional area (i.e., 30 mm × 25.5 mm).

2.3 Desiccation testing procedure

The desiccation cracking tests were conducted using metal molds with a rectangular cross section. To induce parallel cracking during the drying of soil, the lengths of the molds were significantly larger than the widths. Table 4 shows the mold dimensions. The room temperature was maintained at 30 °C to 35 °C during these tests. During this testing, the relative humidity was kept between 62 percent and

Table 4. Summary of desiccation cracking tests.

Mold type	Mold dimensions ($L \times W \times D$) (mm)	Number of molds used	Initial water content (%)	Relative humidity (%)	Materials of mold used
A	600×25×30	5	38	62-65	Metal
B	600×25×20	5	38	62-65	Metal
C	600×50×10	5	38	62-65	Metal
D	600×25×5	5	38	62-65	Metal

Legend: L = Length, W = Width and D = Depth.

65 percent. To ensure moisture uniformity, the base soil and soil-fiber mixtures were completely mixed with water up to the liquid limit of the base soil and enclosed in an air-tight bag for 24 hours. Using a spatula, the soil mixes were then pressed into the molds to their full depth. The side walls of the mold were lubricated before the soil was placed to reduce soil adherence to the side walls. Five rectangular molds were utilized in each experiment. Some of these molds were utilized for crack initiation and evolution, while others were used to measure moisture content during drying. The formation of cracks is checked manually and their moisture contents have been determined at different intervals of time. The width of cracks is measured with the help of steel wires of various diameters. Throughout the test period, the moisture content at the top and bottom of the desiccation test specimens varied. Because the specimens were thin, the moisture content was calculated as the average moisture content based on the total weight of the specimens.

2.4 Toughness behavior at direct tension

The toughness behavior of reinforced soft clay in the post peak zone is studied for all the direct tension test specimens. The toughness index is determined from normalized curves. The load and the deformation axes were normalized with respect to the load and deformation respectively at the peak load. A dimensionless direct tension toughness index (TI) is defined in Equation 1 to understand the post peak behavior as proposed by Sobhan & Mashnad (2002).

$$TI = \frac{A_d - A_p}{\frac{d}{d_p} - 1} \quad (1)$$

where d_p = deformation at peak load P_{max} ; d = any deformation that is greater than the d_p value; A_p = area under the normalized curve up to the peak; and A_d = area under the normalized curve up to the deformation ratio d/d_p .

2.5 Desiccation rate and desiccation coefficient

The moisture content at any time is proposed by Equation 2 given below for analysis of desiccation test data obtained from the current study. It is an exponential function, and is

similar to that of Nahlawi & Kodikara (2006) except that the final moisture content term is factored by $\frac{2}{3}$.

$$w = \frac{2}{3} w_f + \left(w_0 - \frac{2}{3} w_f \right) e^{-kt} \quad (2)$$

Where, w = moisture content at any time, t of the desiccation test (%)

k = Coefficient of desiccation (per day)

w_0 = initial moisture content of the desiccation test (%)

w_f = final moisture content at the end of the desiccation test (%)

The desiccation rate may be defined as a change in moisture content with respect to time (i.e., $\frac{dw}{dt}$) can be expressed by Equation 3 given below. It is also an exponential function.

$$\frac{dw}{dt} = -k \left(w_0 - \frac{2}{3} w_f \right) e^{-kt} \quad (3)$$

3. Results and discussion

3.1 Tensile strength and toughness

The effect of fiber content on tensile strength of fiber reinforced soils is demonstrated in Figure 4. It is seen in Figure 4, that the tensile strength increases from 33 kPa to 71 kPa on increasing coir content from 0% to 2.0% for samples prepared at OMC . Similarly, the tensile strength increases from 76 kPa to 148 kPa when the coir content increases from 0% to 2.0% for samples compacted at water content of 5% less than OMC . Likewise, the tensile strength increases from 11 kPa to 59 kPa, for a change in coir content from 0% to 2.0% and compaction water content of $OMC+5\%$. Figure 4 also shows that the tensile strength of jute fiber reinforced clay increases from 33 kPa to 55 kPa, 76 kPa to 161 kPa and 11 kPa to 23 kPa for samples prepared at OMC , $OMC-5\%$ and $OMC+5\%$ respectively on using 1% jute fiber. While comparing the tensile strength of coir reinforced clay with unreinforced clay, it can be seen that tensile strength increased by up to 214%, 232% and 475% for samples prepared at $OMC-5\%$, OMC and $OMC+5\%$ respectively. Meanwhile, the tensile strength of jute reinforced clay is observed to be increased by up to 132%, 168% and 215%

respectively for samples at *OMC-5%*, *OMC* and *OMC+5%*. Therefore, it can be apprehended that the effect of coir is greater than the effect of jute fiber on increasing the tensile strength of clayey soil.

In comparison to the tensile strength of reinforced soils at different molding moisture contents, the impact of fiber is observed more for samples with higher moisture content. Figure 4 also indicates that the addition of discrete fibers up to 2% of coir and 1% of jute fiber increases the tensile strength of clayey soil significantly. An increase in tensile strength is caused by resistance to the slip of fibers in the soil matrix at the time of tensile loading. Li et al. (2014) studied the tensile strength of polypropylene fiber reinforced clay and reported that tensile strength is increased by the interfacial mechanical interactions between the fiber surface and soil particles. Conversely, a further increase in fiber content decreases the tensile strength of the soil-fiber matrix due to a reduction in bonding between fiber and soil. Therefore, the optimum fiber content for maximization of tensile strength of clayey soil can be considered as 2% for coir and 1% for jute fiber. Anggraini et al. (2015b) found maximum tensile strength at 1.5% coir content for soft marine clay, which is similar to that observed in the present study.

The average values of *TI* obtained from the direct tension test on laboratory-made samples are plotted against moisture content in Figure 5. For the purpose of *TI* calculation, the *d/dp* value was chosen up to 3 for all the specimens. Figure 5 indicates that the effect of moisture on the *TI* of studied fiber reinforced soil is negligible when compared to that of original clay. The *TI* of soft clay increases notably with an increase in moisture content. Whereas, such an increase in *TI* is not present in the case of the same clay reinforced with coir and jute fiber. Besides, the *TI* increases notably with a small amount of coir (1%) and jute fiber (0.5%) for samples prepared at their *OMC-5%* and *OMC*. But, the *TI* is observed to decrease by a small amount for the samples prepared at *OMC+5%* moisture content. The change in *TI* on further inclusion of fiber is insignificant.

The absolute toughness (*T*) of fiber mixed soft clay is defined as the area under the load-deformation curves up to failure, and it indicates the total energy absorbed by the material before failure. The variations of *T* with variation of moisture content are presented in Figure 6. It indicates that *T* decreases almost linearly with an increase in moisture content for both coir and jute fiber-reinforced clayey soil. This figure demonstrates that *T* increases with an increase in coir content of 2% and jute fiber content of 0.5%. Further increase in fiber decreases *T* at all the studied moisture content of coir-reinforced clay. This decrease in *T* is observed for the jute fiber reinforced sample prepared at *OMC-5%* only. A minor change in *T* for jute fiber reinforced samples at *OMC* and *OMC+5%* is observed for fiber content greater than 0.5%. The maximum improvement in the absolute toughness that is found for 2% coir-reinforced soil is 10 to

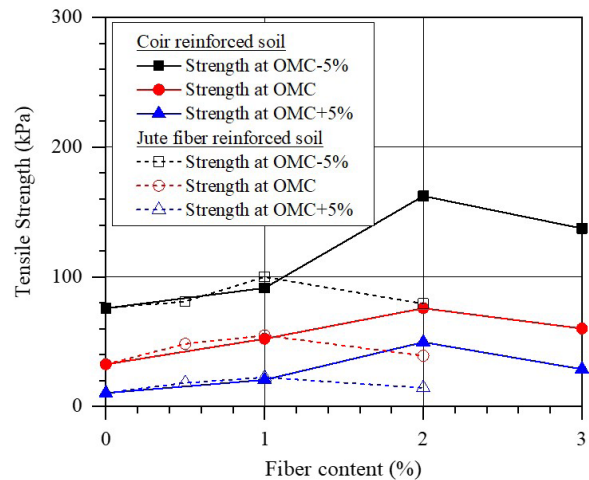


Figure 4. Effect of fiber content on the tensile strength of soil samples at various moisture and fiber contents.

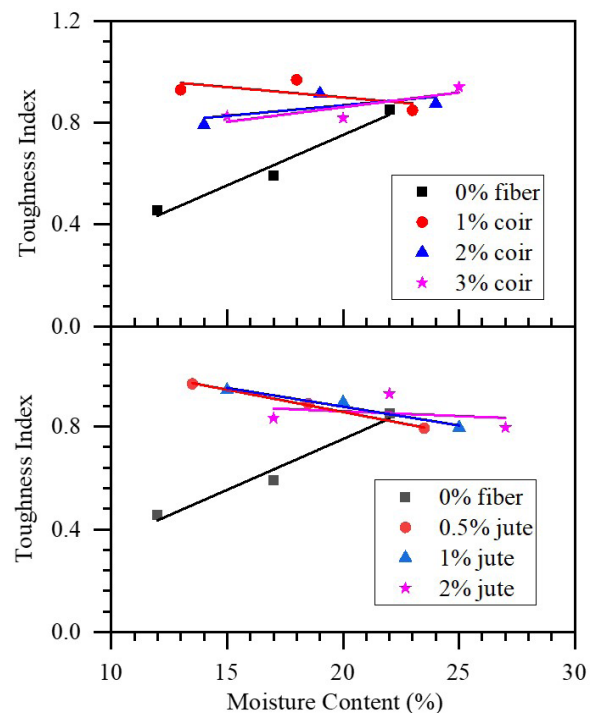


Figure 5. The effect of moisture content on the toughness index of coir and jute fiber reinforced soil (from laboratory tests on soil samples at various fiber contents).

17 times greater when compared with that of unreinforced soil in the studied range of moisture content.

3.2 Desiccation cracking of reinforced and unreinforced soil

Figure 7 displays typical cracking patterns observed at the end of desiccation cracking tests for clayey soil without any reinforcement and with different percentages of fiber reinforcement. It is evident from these photographs that the

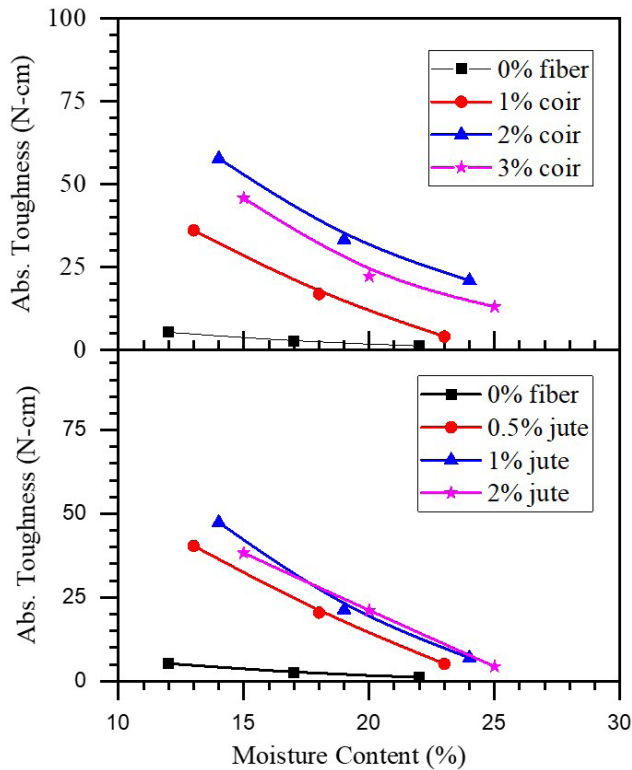


Figure 6. Effect of moisture content on the absolute toughness of coir and jute fiber reinforced soil (from laboratory tests on soil samples at various fiber contents).

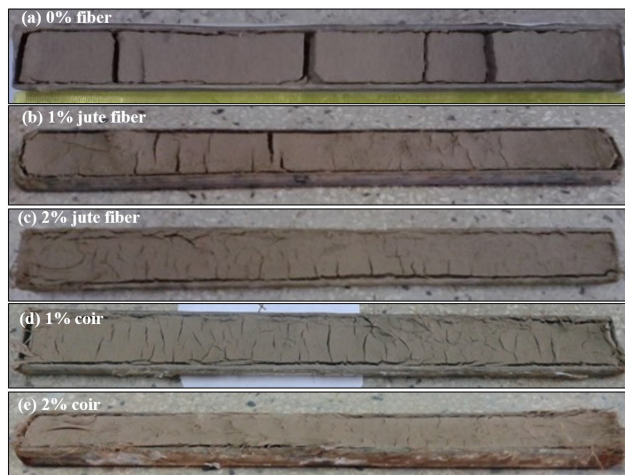


Figure 7. The cracking pattern of clayey soil of different fiber content after a desiccation cracking test.

crack width of unreinforced samples is higher than the crack width of reinforced samples. The number of cracks is fewer in the case of unreinforced samples compared to the number of cracks in reinforced samples. It is also remarkable that the crack width becomes smaller with an increase in fiber content. The length of cracks was smaller for higher fiber content. Chaduvula et al. (2017) studied the desiccation cracking

behavior of polyester fiber reinforced clay and observed similar results. Comparing Figure 7(b) with Figure 7(d) and Figure 7(c) with Figure 7(e), it can be said that coir controls the crack more efficiently than jute fiber.

3.3 Desiccation characteristics of reinforced and unreinforced soil

The variation of moisture content with desiccation time is shown in Figure 8 for unreinforced Gazipur clay. It indicates that the moisture content reduces rapidly at the initial stage of desiccation and decreases slowly towards the end of the desiccation test. Past studies (Corte & Higashi, 1964; Nahlawi & Kodikara, 2006) on the desiccation characteristics of slurry clay reported similar results. Desiccation curves for thin (5mm and 10mm thick) samples are very close to each other, while significant differences can be observed for thick (20mm and 30mm thick) samples. It can be seen that desiccation ended earlier for thinner samples. It may be due to desiccation starting at the top surface first and then it propagating toward the bottom of the samples. Lifting up of the cracked cells with respect to middle cracked cells at the latter stages of desiccation was observed. This behavior indicates differential desiccation rates between the top and bottom parts of the soil layer at different stages of desiccation. Figure 9 shows desiccation curves for coir and jute fiber reinforced clay. Comparing Figure 9(a) to Figure 9(d), the effect of fiber content is more prominent for samples of 10mm to 30mm in thickness. Fiber causes delay in the drying process of reinforced clay. It can be seen from Figure 9(d) that the effect of thickness is very small for thicknesses of 10mm to 30mm. However, the desiccation curves in the compacted clay tests mentioned here appear to approach identical water content at the end of the testing. This is because the soil finally reaches a moisture content that is in balance with the surrounding environment, as measured by relative humidity and air temperature. Final moisture content (w_f) is observed more for greater thickness and larger fiber content. Exponential desiccation curve fitting has been conducted for all the samples. The resulted desiccation equations are shown with respective plots. The first derivatives of these equations (i.e., dw/dt) are considered as the desiccation rate at any time of desiccation.

Figure 10 and Figure 11 represent computed desiccation rate versus time plots obtained from fitted curves. It can be seen from these figures that the rate of desiccation is very high at the initial stage compared to that at finishing time. The more the thickness, the less the desiccation rate at the initial stage. But, the desiccation rate is higher for thicker samples at the end of the test. It may be caused by the higher moisture content of the thicker samples at the end of the test evaporating more than the thinner samples. At the initial stage of the tests, desiccation rates of 5mm thick jute fiber reinforced clay were higher than unreinforced clay, but desiccation rates of thicker (10mm to 30mm thick) jute

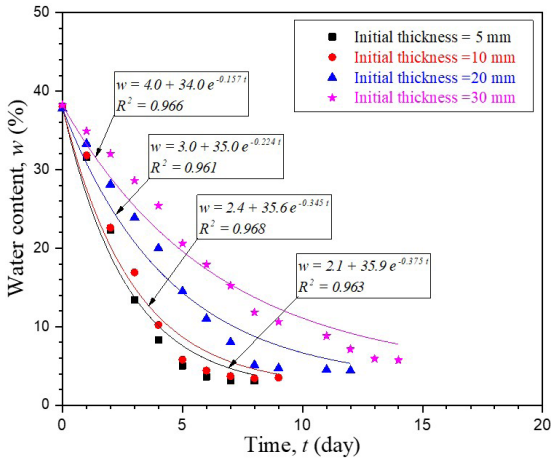
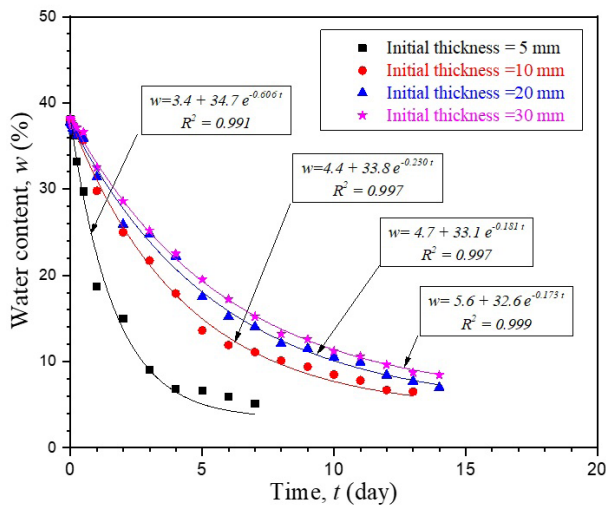


Figure 8. Desiccation curves for unreinforced Gazipur clay.

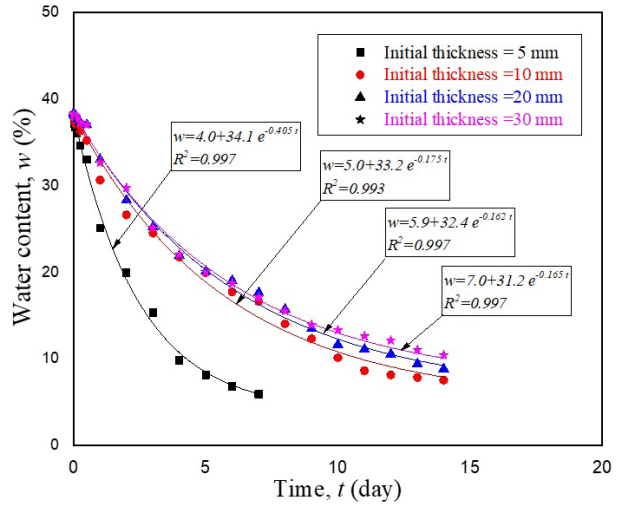
fiber reinforced clay samples were lower than unreinforced samples. The desiccation rates of coir reinforced clay, on the other hand, are shown to be lower than the unreinforced samples of all thicknesses at the initial stage of desiccation.

3.4 Effect of layer thickness on desiccation and cracking

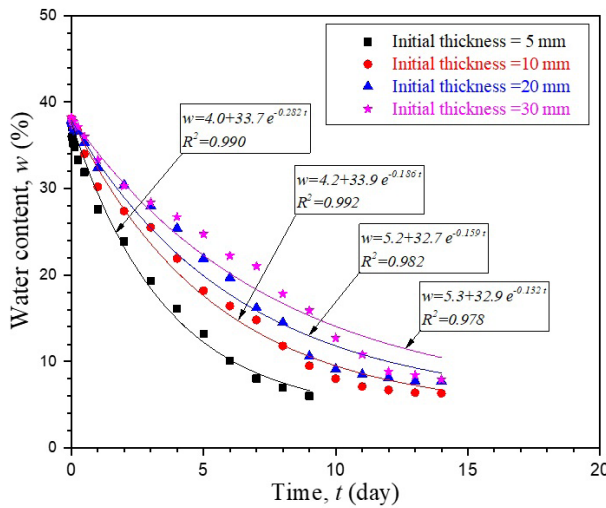
Figure 12 and Figure 13 present the effect of thickness on the desiccation coefficient of unreinforced and fiber-reinforced clayey soil respectively. The main variables in these tests are the thickness of the soil specimen (initial thicknesses are 5mm, 10mm, 20mm and 30mm) and fiber content (0%, 1% and 2%). It can be seen that the specimens with larger depths generally exhibited a smaller desiccation coefficient for unreinforced and reinforced clayey soil. This occurs because



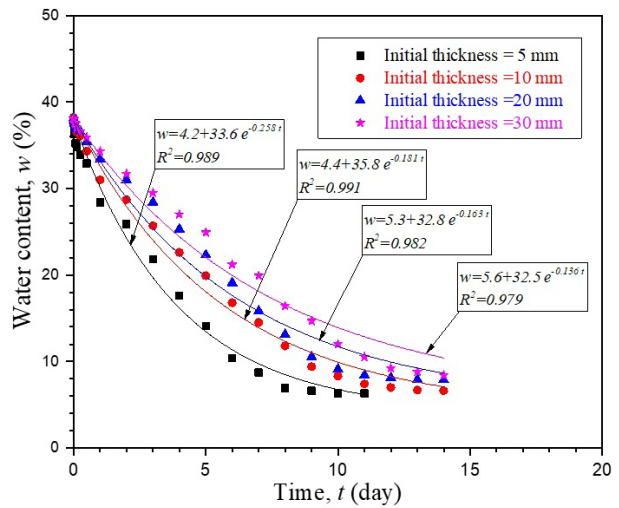
(a) 1% jute fiber



(b) 2% jute fiber



(c) 1% coir



(d) 2% coir

Figure 9. Desiccation curves for Gazipur clay with (a) 1% jute fiber, (b) 2% jute fiber, (c) 1% coir and (d) 2% coir as reinforcement.

the distance that moisture must travel for evaporation at the surface increases as the soil thickness increases.

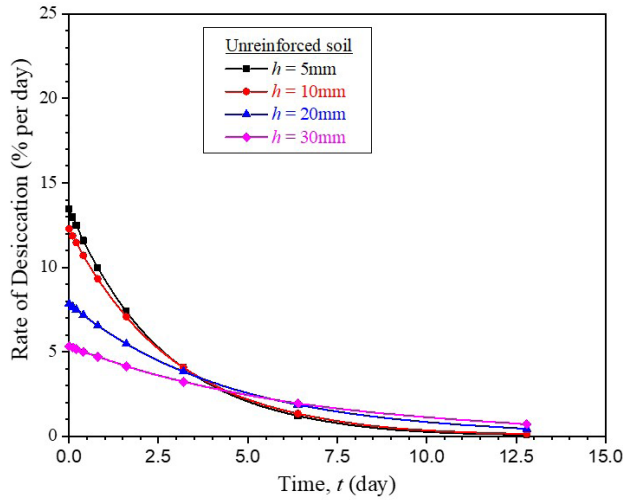


Figure 10. Desiccation rate for unreinforced Gazipur clay.

Figure 14 demonstrates the effect of sample thickness on the cracking water content of reinforced and unreinforced clayey soil. The cracking water content is less for reinforced clayey soil than for unreinforced clay. As a result, it can be claimed that employing discrete fibers as reinforcement can help to prevent cracks from forming in clayey soil. This is due to reinforced soil's higher tensile strength, which prevents the creation of cracks in soil that has reached a moisture content where unreinforced soil has cracked. A similar result was reported by Abu-Hejleh & Znidarcic (1995), where they reported that the soils start cracking during desiccation induced one-dimensional shrinkage when total lateral tensile stress at the crack tip reaches the tensile strength. It is also observed that the effect of coir is greater than jute fiber in resisting desiccation cracking. The effect of specimen thickness on the crack spacing to thickness ratio of unreinforced clayey soil is presented in Figure 15. The crack spacing to thickness ratio is calculated for the initial and final thickness of specimens. The crack spacing (s) mentioned here is the mean spacing, which is determined by the total spacing divided by the total number of cells when the soil was in dry condition.

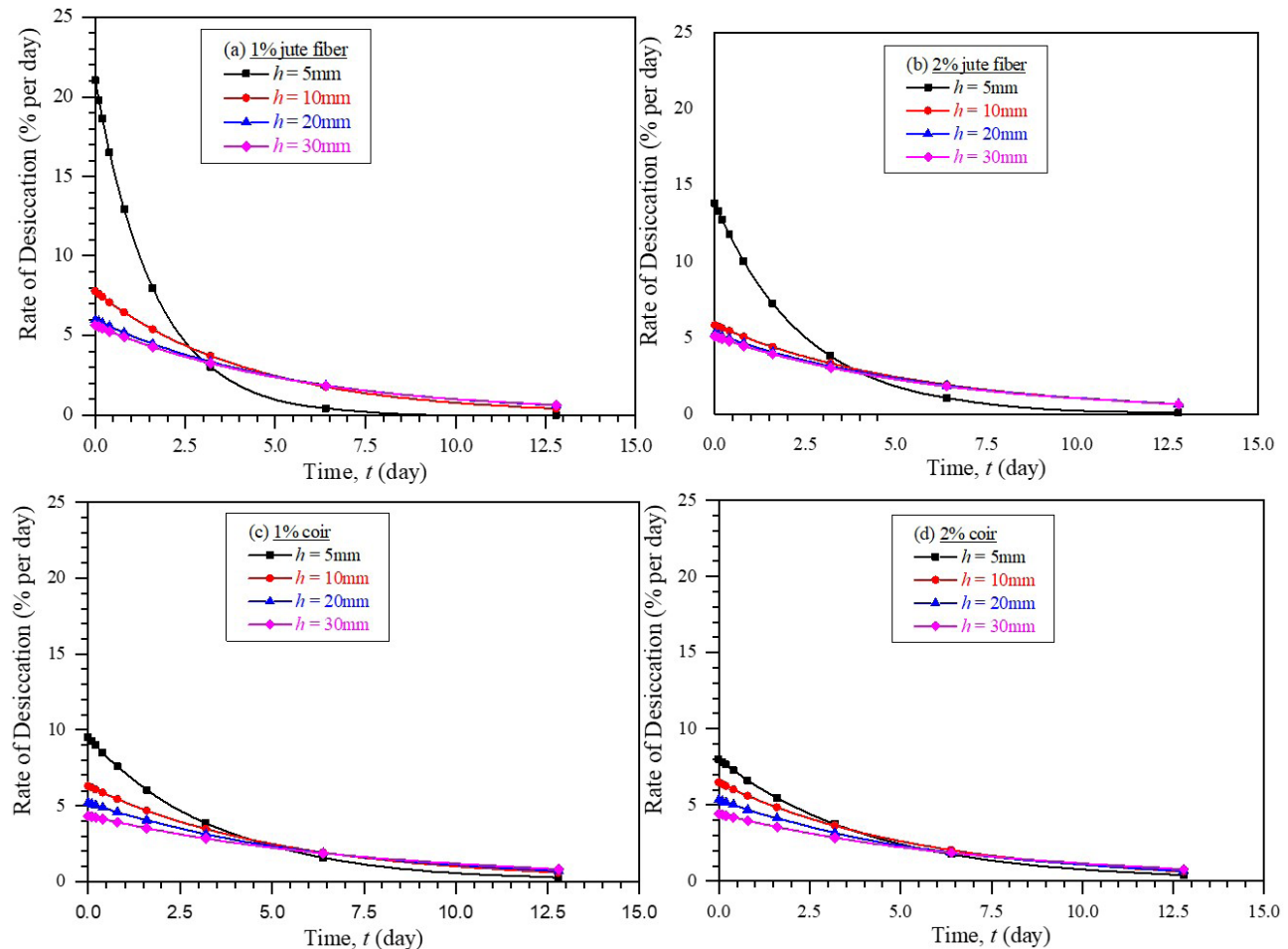


Figure 11. Desiccation rate for Gazipur clay with (a) 1% jute fiber, (b) 2% jute fiber, (c) 1% coir and (d) 2% coir as reinforcement.

This approach has been used to analyze the data of Corte & Higashi (1960) and Lau (1987). It can be marked that a straight line is obtained on a log-log plot for both cases.

3.5 Relation between cracking water content and desiccation coefficient

Figure 16 shows the relationship between desiccation coefficient (k) and cracking water content (w_c), where linear regression lines are obtained for unreinforced clay. Figure 17 and Figure 18 illustrate the plots of cracking water content versus desiccation coefficient of reinforced clayey soil. Exponential relationships are observed in this case. The values of R^2 are found within 0.96 to 1, which indicates a good correlation between the selected parameters. It is clear that the cracking water content is lower because of the higher desiccation coefficient that happens for thinner samples. When comparing the results of this study to the desiccation equations proposed by past researchers (Corte & Higashi, 1964; Nahlawi & Kodikara, 2006), the equation proposed in this study lies between Corte & Higashi (1964) and Nahlawi & Kodikara (2006). As indicated in Figure 16, there is no significant change in desiccation coefficient between 5mm and 10mm thick unreinforced soil samples. Figure 17 and Figure 18 show that the desiccation coefficient for 5mm and 10mm thick reinforced soil samples varies considerably. This difference in desiccation coefficient between unreinforced

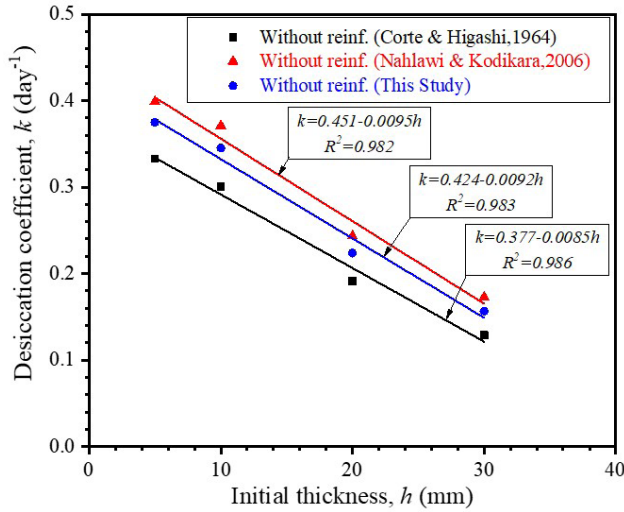


Figure 12. Effect of sample thickness on desiccation coefficient of unreinforced soil.

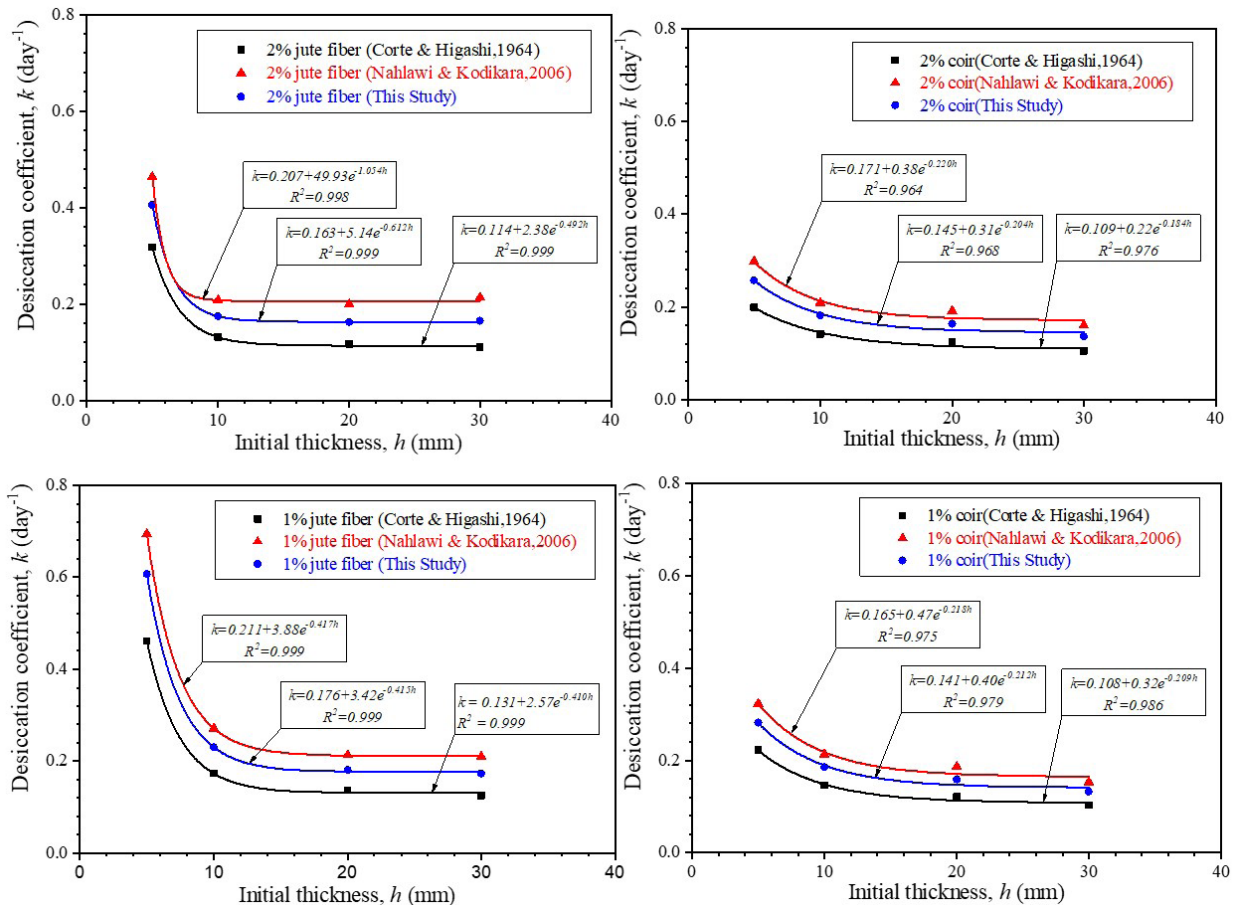


Figure 13. Effect of sample thickness on desiccation coefficient of reinforced clayey soil.

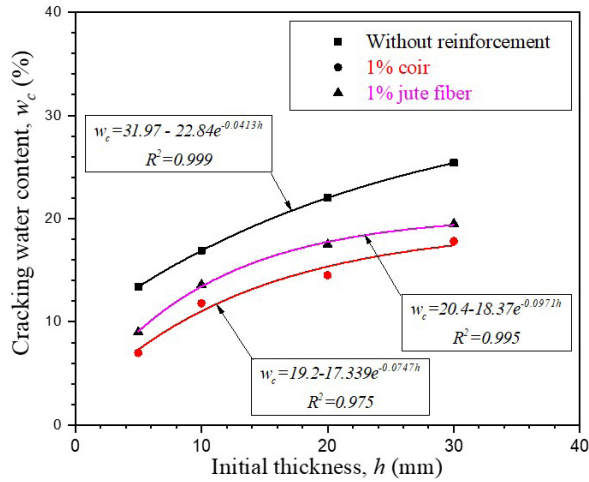


Figure 14. Effect of reinforcement and sample thickness on cracking water content of clayey soil.

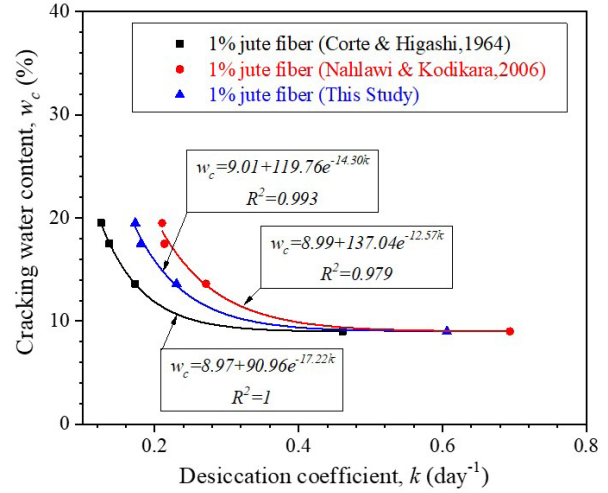


Figure 17. Relation between cracking water content and desiccation coefficient of 1% jute fiber reinforced clay.

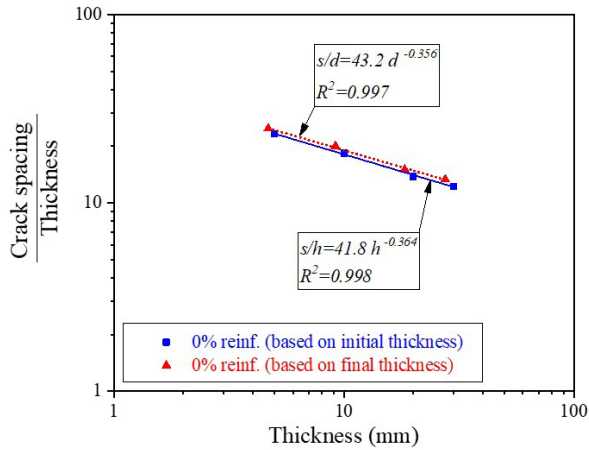


Figure 15. Effect of specimen thickness on the crack spacing to thickness ratio of unreinforced clayey soil.

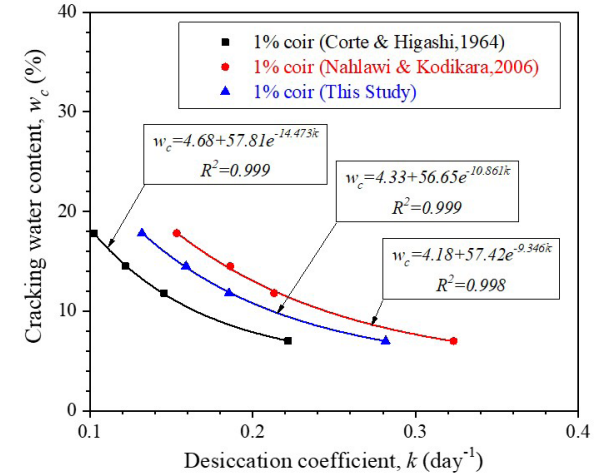


Figure 18. Relation between cracking water content and desiccation coefficient for 1% coir reinforced clay.

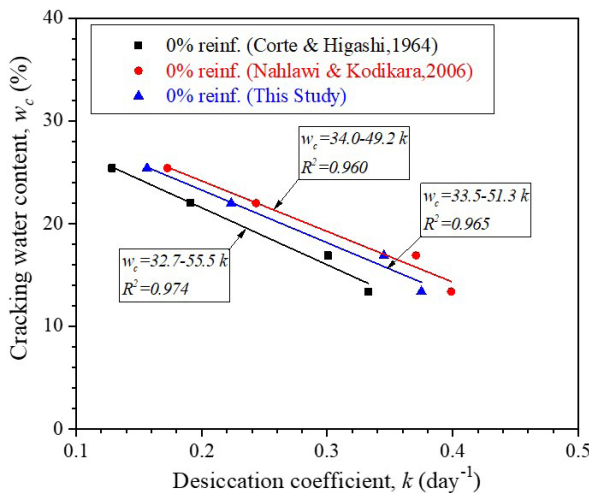


Figure 16. Relation between cracking water content and desiccation coefficient for unreinforced clayey soil.

and reinforced thin samples could be due to reinforced soil having less crack width and depth when compared to unreinforced soil.

4. Conclusion

A series of laboratory desiccation tests have been conducted in addition to direct tension tests on a clayey soil with various proportions of natural fibers (coir and jute fiber). The test results are presented in the above sections. On the basis of the test results, the following conclusions can be drawn.

- The tensile strength increases on using discrete fiber of coir up to 2% and jute fiber up to 1%. Thus, optimum fiber content may be considered as 2% for coir and 1% for jute fiber to achieve maximum tensile strength.

- The tensile strength of coir reinforced soil increased by up to 214%, 232% and 475% respectively for samples prepared at *OMC-5%*, *OMC* and *OMC+5%*. Similarly, the tensile strength of jute fiber reinforced soil increased by up to 132%, 168% and 215% respectively for samples prepared at *OMC-5%*, *OMC* and *OMC+5%*.
- The absolute toughness is greatly improved by using reinforcement in a random distribution of up to 2% coir and 1% jute fiber. As the moisture content rises, the absolute toughness of both reinforced and unreinforced samples decreases. The toughness index of unreinforced soil improves as the moisture content rises. The use of coir and jute fiber improves the toughness index at low moisture level (*OMC-5%*). But, the reinforcing effect on the toughness index at higher moisture content (*OMC+5%*) is negligible.
- Discrete natural fibers reduce the crack width and length considerably. The higher the fiber content, the narrower the cracks and the more cracks there are.
- The moisture content drops quickly at first and then gradually as the desiccation test progresses. The desiccation rate is lower for thicker samples during the initial stage of the test. However, for thicker samples, it is higher at a certain point near the end of the test.
- The initial desiccation rates of jute fiber reinforced clay of 5mm thickness are higher and of 10mm to 30mm thickness are lower than unreinforced samples. The desiccation rates of coir reinforced clay of all thicknesses are lower than the unreinforced samples.
- Thinner clayey soil samples, whether reinforced or unreinforced, show lower cracking water content. When compared to unreinforced clay, reinforced clayey soil has reduced cracking water content. This is due to reinforced soil's stronger tensile strength, which prevents cracks from forming in soil that has reached a moisture content where unreinforced soil has cracked.
- For unreinforced clay, the relationship between cracking water content and desiccation coefficient is linear; for reinforced clay, the relationship is exponential.

Declaration of interest

The authors have no conflicts of interest. There is no financial interest to report.

Authors' contributions

Abu Taiyab: conceptualization, methodology and laboratory setup development, supervision, review and editing of the content and finalization, critical analysis and visualization. **Nazmun Naher Islam:** methodology and

laboratory setup development, material collection, laboratory investigation, data analysis, writing draft and finalization.

Mokhlesur Rahman: conceptualization, supervision, finalization and approval of the content.

List of symbols

A_d	Area under the normalized curve up to deformation ratio d/d_p
A_p	Area under the normalized curve up to peak
d	Any deformation that is greater than d_p
D	Depth of the desiccation mold
d_p	Deformation at peak load P_{max}
dw/dt	Desiccation rate
G_s	Specific gravity of soil grain
q_u	Unconfined compressive strength
k	Desiccation coefficient
L	Length of the desiccation mold
LL	Liquid limit of soil
OMC	Optimum moisture content
PL	Plastic limit of soil
P_{max}	Maximum tensile load
T	Absolute toughness
TI	Toughness Index
w	Moisture content at any time t of desiccation test
W	Width of the desiccation mold
w_c	Cracking water content
w_f	Final moisture content of desiccation test
w_n	Natural moisture content
w_0	Initial moisture content of desiccation test
$\gamma_{d(max)}$	Maximum dry density
σ_t	Tensile strength

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