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Laboratory Study on the Swelling, Cracking and Mechanical Characteristics of the Palm Fiber Reinforced Clay

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ABSTRACT

Presence of clayey soil strata beneath the structural foundation or road pavements would severely lead to many problems such as swelling, low bearing capacity or many others. Therefore, many scientific or nonscientific methods have been used during past centuries to defeat these problems. One of these methods would be soil reinforcement in order to improve most of the soil mechanical properties. Natural fibers are used widely in soil reinforcement procedure all around the world during many centuries and one of the most durable and applicable of these materials is the palm fiber. This study have considered the application of the palm fibers` effects on the behavior of the west Kerman`s surface clays. The results show that this kind of randomly distributed reinforcement would significantly affect and alter the characteristics of the reinforced soil, but not always by improving them.

KEYWORDS: soil reinforcement, swelling potential, shrinkage cracks, unconfined compressive strength, shear strength.

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INTRODUCTION

Clayey soils are applied or faced vastly in most of the engineering projects. The problem initiates when the water approaches the clay strata. The clayey particles start to absorb the water and consequently become more and more bulky due to the swelling phenomenon. Moreover, if the swelled strata losses the included water and gets dry, the shrinkage phenomenon leads to extensive cracks which thoroughly decrease the mechanical properties of shrunk soil (Saleh Zade H. 1995).

Completely various methods have been used during the centuries to reduce the unpleasant effects of these natural phenomena. Some of them would be mentioned like compaction, chemical soil stabilization, soil replacement and soil reinforcement. Although, any of cited methods has its own advantages but in some special cases the undesired disadvantages would be accompanied by awful disasters (Tabatabaee A.M. 1985).

In recent decades many scientific methods have been tested to reduce or completely remove the swelling potential of clayey soils, such as a research on changes in swell behavior of expansive clay soils from dilution with sand (Hudyma N. and Burcin Avar B. 2006). Chemical stabilization method would alter this potential by means of the cation exchange reactions. Some of the recent studies on this method would be mentioned as a study on the optimization of cement-lime-chemical additives to stabilize Jordanian soils (El. Ravi N.M. and Al-Samadi M.M.Y. 1995); stabilization of clayey soils with high calcium fly ash and cement (Kolias S. et al. 2005); Mechanism of stabilization of Na-montmorillonite clay with cement kiln dust (Peethamparan S. et al. 2009); Although the application of chemical stabilizers would work really properly to decrease swelling and shrinkage consequences, but they would both cause environmental problems or high performance costs.

In recent studies, the effects of reinforcement on swelling behavior of clays have been considered by scientists like, effects of fiber reinforcement on strength and volume change in expansive soils (Puppala A.J. and Musenda Ch. 2000); reduction of soil swell potential with fiber reinforcement (Loher J.E. et al 2000); swelling behavior of a geofibers-reinforced expansive soil (Viswanadham B.V.S. et al. 2008); and effect of fibers on swelling characteristics of bentonite (Banu Ikizler et al. 2009).

Soil reinforcement by the application of natural fibers has been utilized since ancient time in Persian Empire to reduce the shrinkage cracks in clayey structural elements. This application would have the least environmental nuisances and almost low performance costs. Therefore, so many studies have been performed in recent years such as (Sivakumar Babu J.L. et al. 2008) use of coir fibers for improving the engineering properties of expansive soils.

Palm fibers are obtained from the wastes of palm skin which is called “Sisi” by the natives in Kerman`s area and also have acceptable mechanical properties and durability in natural conditions. Thus, in recent years the application of this material in soil reinforcement has been under the concentration of research in this area like strength and ductility randomly distributed palm fibers silty sand soils (Marandi S.M. et al. 2008) and some graduation thesis have been also performed on such a case (Zare H. 2006, and Kamali B. 2006).

As a result, this study has been performed in order to figure out the effects of palm fibers application in randomly distributed reinforcement of clayey soils. Uniaxial swelling values of reinforced and unreinforced cylindrical samples were measured and cracking attributes of each sample type were studied carefully. Unconfined compressive tests have been performed on cracked samples to find out the effect of reinforcement after shrinkage cracking. In order to clarify the effects of including fibers on shear strength, direct shear tests have been carried out on regenerated samples.

MATERIAL USED

This research has been carried out in order to study the swelling, shrinkage cracking and the mechanical behavior of cracked reinforced clayey soils. Therefore, a clayey soil with Ferrous

Kaolinite minerals of west Kerman`s surface clay has been elected for this purpose which had the following properties:

Liquid Limit (L.L.) = 37.8%, Plastic Limit (P.L.) = 20.52% and Plasticity Index (PI) = 17.28%.

The particle distribution diagram of the applied soil is given in Figure 1.

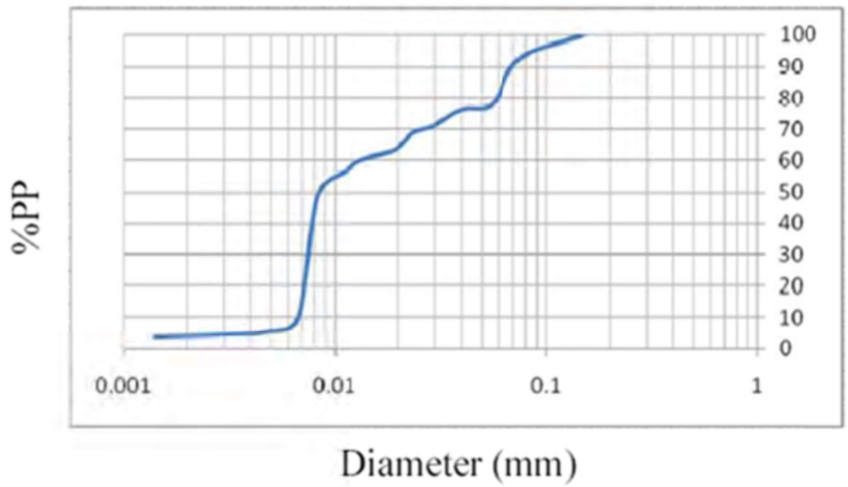

Figure 1: Particle distribution curve of used materials

Reinforcing fibers were gained by cutting the palm waste skin to achieve the average length of about 30 millimeters. Applied fibers had the specific gravity of 0.92, ultimate tensile strength of 63.2 MPa, elasticity modulus of 600.8 MPa and average diameter of about 0.35 millimeter (see Fig. 2).

Figure 2: Applied palm fibers

MIX DESIGN AND SAMPLE PRODUCTION

Four different values of fibers` weight ratio were utilized in production of samples to clarify the results that the changes would turn out. First sample series were made with no reinforcement to indicate the pure soil behavior in compaction, swelling, shrinkage cracking and uniaxial tests procedures. Then, some amounts palm fibers were appended to the soil mixture with different main values of 0.25%, 0.5% and 1% of the dry soil weight.

Adequate numbers of samples were produced by compaction of the soil and randomly distributed fibers` mixture with the optimum compaction moisture content of 15 percents. Then, the samples sides were isolated to prevent the collapse of the cylinders as they are submerged under the water. Samples were set on a fixed porous stone to be able to absorb the water from both top and bottom sides. The just free axis of swelling for each sample was each sample`s vertical axis.

TESTING PROCEDURE

Produced samples by the cited method, were submerged for 72 hours to be completely saturated and also had enough time to enlarge due to the swelling procedure. The volume changes of the samples were accurately measured after the test time had finished. The changes` information is given in Table 1.

Table1: swelling tests results

Sample Type	Fiber Ratio	Initial Sample`s Height (mm)	Sample`s Height After Swelling	Volume Change
A	0	51.1	55.8	9.19%
B	0.25%	50.1	55.3	10.48%
C	0.5%	51.3	57.3	11.69%
D	1.0%	50.1	59.5	18.77%

Then, the samples were left in laboratory weather condition for a week to be dried and among this period of time the shrinkage and cracking procedures were studied precisely. The form of cracks and their dimensions are also included in Table 2.

Table 2: shrinkage cracks characteristics

Sample Type	Top Surface				Side Surface			
	Crack Type	Number of Cracks	Crack`s Length (mm)	Crack`s width (mm)	Crack Type	Number of Cracks	Crack`s Length (mm)	Crack`s width (mm)
A	Radial	2	23-28	0.5-1.2	Directional	2	300	2
	Distributed	-	-	-	Distributed	-	-	-
B	Radial	4	17-30	0.5-1.5	Directional	2	150-270	1.8
	Distributed	Rarely cracked	6 by 12	0.3	Distributed	-	-	-
C	Radial	6	10-25	0.5-1.5	Directional	3	100-120	1.0
	Distributed	moderately cracked	14 by14	0.7	Distributed	Rarely cracked	10 by10	1.0
D	Radial	-	-	-	Directional	-	-	-
	Distributed	severely cracked	20 by20	1.5-2.5	Distributed	Rarely cracked	10 by10	0.5-0.8

At last, after monitoring of the physical changes thoroughly, unconfined compressive tests were performed on the cracked samples in order to find out what are the differences in the mechanical behaviors between the reinforced and unreinforced samples. The unconfined compressive strengths, elasticity modulus and ultimate strains were obtained from the tests results. The results are given in Table 3.

Table 3: Unconfined compressive tests results

Sample Type	Compressive Strength (kgf/cm^2)*	Ultimate Strain (mm/mm)*	Elasticity Modulus(kgf/cm^2)*
A	6.89	0.082	84.08
B	9.28	0.087	106.67
C	9.98	0.088	112.83
D	15.86	0.132	131.96

* The given values in this column are the average of each sample series.

Direct shear tests have been performed on reinforced and unreinforced samples in addition, in order to find out the effects of reinforcement on shear strength parameters of treated soil. However, it must be considered that samples reconstruction for shear tests would not lead to reliable results. The included fibers would be completely horizontally oriented during the compaction of the soil mixture in shear test bar. This phenomenon will make the shear strength lower and lower by the increment of fibers` application ratio, because this would make too many weak discontinuity surfaces between homogenous cohesive soil particles.

DISCUSSION

Although, the first thing that would be expected after reinforcing clayey soils is that most of the mechanical and behaving characteristics of the reinforced soil must be improved. However, this would not be always right in any condition. The reinforcement type must be considered very carefully to be completely effective in the condition that it is applied against.

In this study, application of palm fibers has been considered in order to clarify its effects on the characteristics of swelling clays. As it has been observed from the data, given in Table 1, how much the amount of the fibers increases the value of volume change would increase as well. This phenomenon would be interpreted in this way that as the fibers are gained from natural woods, they can absorb water very fast and carry it through the length of fibers thoroughly like a conducting pipe. In the other words, this kind of reinforcement would increase the soil permeability significantly (see Fig. 3).

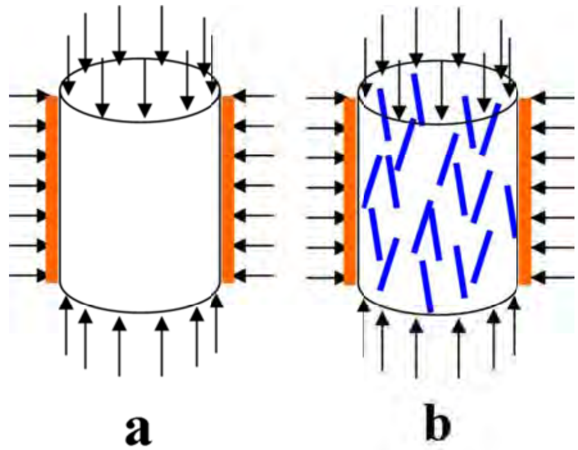

Figure 3: (a) Water penetration paths to the pure soil sample with isolated sides, (b) fibers working as conducting pipes inside a reinforced sample

Moreover, when the fibers absorb the saturating water, they would swell as well as clayey particles and the water which has coated the common surfaces of the fiber and soil particles will undoubtfully decrease the friction angle between soil and fibers on common surfaces (see Fig. 4). The simultaneity of these two phenomena would cause more and more enlargement as the amount of the reinforcing elements increases in reinforced soil.

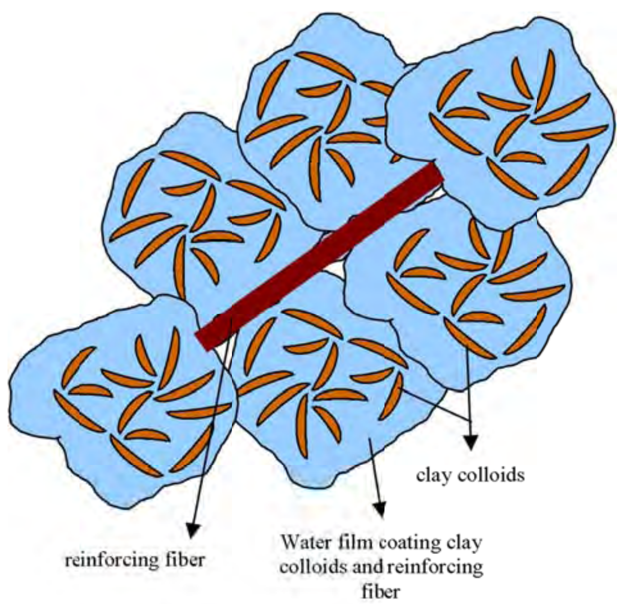

Figure 4: Free water film covering clay colloids and reinforcing element

On the other hand, when saturated soil starts to lose its moisture content, as the fibers and soil particles get dry, they would be cohered strongly to gather which will withstand against the production of severe structural cracking (see Fig. 5). How much the amount of reinforcing elements enhances, cracks` types are revised from long and wide cracks to distributed and tiny cracks, as it is observed in Table 2. This indicates that presence of reinforcing fibers would make the shrinkage cracked soils more homogenous.

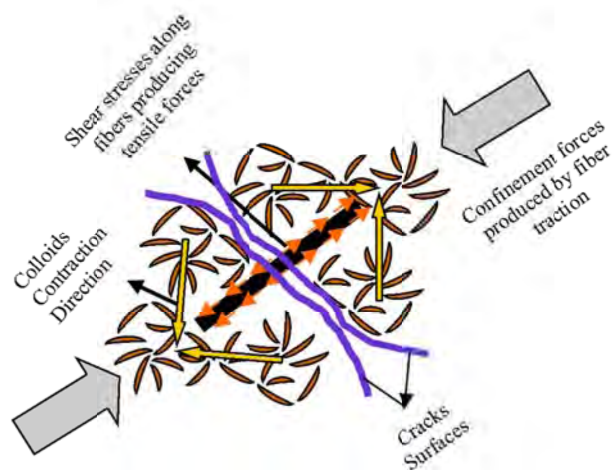

Figure 5: Schematic of the fibers effects on shrinkage cracks

The unconfined compressive tests results show that the more reinforcing elements, the more strength, the more elasticity modulus and the more ultimate strain can the reinforced soil samples have, even after shrinkage cracking. However, the more reinforcement value led to more volume change and even more shrinkage cracks; but, when the soil mass is supposed to get dry and clayey colloids are going to out distant from each other, significant tensile stress would be appeared in these applied reinforcing elements. This would cause great tensile forces which pushes the colloids surfaces roughly to gather and works like external confinement pressure and this will surely improve the mechanical characteristics of reinforced soils.

CONCLUSION

This study has been performed in order to clarify the effects of palm fiber reinforcement on the swelling and shrinkage comportments of clayey soils. Different fiber ratios were applied to make the study more accurate. Adequate samples were produced and submerged under water to be swelled freely. Then, swelled samples were led to be dry in laboratory condition and get shrunk due to the loss of moisture content. During these procedures the samples were precisely studied. After that the samples were completely dried and cracked, unconfined compressive tests were performed on both reinforced and unreinforced samples. Some direct shear tests have been also performed on the regenerated samples.

The research results show that palm fiber reinforcement not only doesn`t improve the swelling characteristics, it would significantly make it really worse as well as the ratio of reinforcing elements increases. The more applied palm fiber ratio the more volume change would occur by water absorption in a fixed test time because of the alterations in soil permeability.

On the other hand, after that the shrinkage procedure came to the end, the reinforcement advantages became obviously clear. The cracks revised from deep, wide and long ones to completely distributed cracks by increment in included fibers ratio.

All mechanical properties of the reinforced samples under the unconfined compressive tests would be significantly improved by increment in fibers ratio. The compressive strength, elasticity modulus and the ultimate strain increases when more reinforcing elements are applied.

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