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The effect of fiber reinforcement on the behavior of cemented sand

L' effet du renforcement de fibre sur le comportement du sable cimenté

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ABSTRACT: Unconfined compression tests were performed to determine the benefit of using randomly distributed polypropylene fiber reinforcement mixed with Portland cement on the engineering behavior of sandy soils. Fiber length was 19 mm and the content of fiber was 0%, 0.1%, 0.3% and 0.5% by the dry weight of soil while the content of cement was 3%, 5% and 7% by the dry weight of soil. The samples were prepared at optimum water content and cured for 7 and 28 days in a moisture-curing tank. The results show that the addition of fiber reinforcement to the cemented soil results in increasing the unconfined compressive strength and axial strain at failure and it changed the behavior of the cemented soil from brittle behavior to a more ductile behavior.

RÉSUMÉ: Des essais de compression sans confinement ont été effectués pour déterminer l'avantage d'utiliser un renforcement de fibres de polypropylène à répartition aléatoire mélangé à du ciment Portland sur le comportement technique des sols sableux. La longueur des fibres était de 19 mm et la teneur en fibres était de 0 %, 0,1 %, 0,3 % et 0,5 % en poids sec du sol tandis que la teneur en ciment était de 3 %, 5 % et 7 % en poids sec du sol. Les échantillons ont été préparés à une teneur en eau optimale et séchés pendant 7 et 28 jours dans un réservoir de durcissement à l'humidité. Les résultats montrent que l'ajout d'un renforcement de fibres au sol cimenté augmente la résistance à la compression non confinée et la déformation axiale à la rupture et modifie le comportement du sol cimenté du comportement fragile à un comportement plus ductile.

Keywords: Unconfined compressive strength; Sand; Cement; Fiber; Fiber reinforcement

1 INTRODUCTION

The increasing demand for housing caused by urbanization lead to an expansion toward some areas that are not feasible for any kind of engineering constructions because of its problematic soils. Hence, the need for soil stabilization has arisen to improve the physical properties of the soil to support the foundations or the pavements by achieving the desired compressibility and strength in order to improve the load-bearing capacity of the soil. Soil stabilization can be used to treat a wide range of soils including cohesive soils and non-cohesive soils and mainly has two types, which are mechanical stabilization, chemical stabilization, or in some cases a combination of both techniques.

Cement stabilization is a type of soil stabilization and it is a fast process, well accepted among geotechnical engineers and it can be used for a broad range of soils. The addition of cement to the soil showed noticeable improvement in unconfined compressive strength, workability, shear strength and resistance to liquefaction of the sandy soils. The increasing of cement content results in a brittle, stiffer, and stronger material and at the same time increasing the cement content results in an increase of cohesion for the soil. (Abdulla and Kiousis, 1997). The sand cement mixture is widely used for stabilizing sandy soils. There are many applications for this mixture such as subgrades, subbases, bases, slope and trench protection, foundations, and recently mixed-in-place piles and walls. (Maher & Ho, 1993).

However using only cement with sandy soil results in a brittle behavior for the cemented soil but this problem can be solved easily by adding fibers to the cemented soil because it can change the behavior of the cemented soil from brittle behavior to more ductile behavior and at the same time it can increase the peak shear strength and the residual shear strength of the cemented soil. (Consoli et al., 1998; Hamidi & Hooresfand, 2013). The main purpose of this study is to evaluate the behavior of cemented soil mixed with 0%, 0.1%, 0.3% and 0.5% fiber by dry weight of sand therefore a series of tests were performed to determine the unconfined compressive strength taking into consideration the effect of curing time for 7 days and 28 days.

2 EXPERIMENTAL PROGRAM

In this paper a series of unconfined compression tests were performed on the fiber reinforced cemented sand samples as a part of the study. The properties of sand, fiber and cement used will be given in this section.

2.1 *Sand*

The used sand was obtained from Akpinar, Turkey and the sand was classified according to the unified soil classification system (USCS) by using sieve analysis as poorly graded sand (SP). The grain size analaysis results and the physical properties of the soil are presented in Table 1.

Table 1. The physical properties of the sand

Properties	Units	Value
D_{10}	mm	0.21
D_{30}	mm	0.26
D_{60}	mm	0.31
Cu	-	1.48
Cc	-	1.04
e_{max}	-	0.733
e_{min}	-	0.523
Gs	-	2.6
$\gamma_{d(max)}$	gr/cm³	1.68
$\gamma_{d(min)}$	gr/cm³	1.48
Permeability (k)	m/s	$7.69*10^{-5}$
	Grain size analysis	
Gravel (%)	%	0.7
Sand (%)	%	97
Silt + Clay (%)	%	2.3
Soil type	-	SP

2.2 *Fiber*

The fiber is a polypropylene fiber and its length is 19 mm. The technical properties of the fiber are mentioned in BASF (2017), and they are presented in Table 2.

Table 2.Technical properties about the used Fiber

Properties	MASTERFIBER 15 MF
Purity	100% PP
Length	19 mm
Cross-section	Circular
Elongation	25%
Specific density	0,91 gr/cm³
Color	Transparent (natural)
Tensile stress	500-700 N /mm2
Softening	145° C
Melting	160° C
Compatibility with cement	Excellent
Hygroscopic coefficient	70%

2.3 Cement

The cement that was used in this study is Portland cement CEM IV/B(P) with a specific gravity around 3.15.

2.4 Unconfined compression test machine

This machine consists of two loading plates, upper and lower plate. The used sample is a cylindrical undisturbed sample, which has a ratio of height to diameter between 2 to 3 and it was prepared by using Harvard miniature apparatus.

In this experiment, a load will be applied gradually on the specimen until it reaches failure and then a stress-strain curve should be plotted.

The peak of this curve is defined as the unconfined compressive strength (qu). The test was done according to the ASTM (2006) standard by using two kinds of rings.

2.5 Sample preparation

The prepared samples for unconfined compression test had a 10 cm height and 5 cm diameter. The cement percentages that were used for preparing the samples were 3%, 5% and 7% by dry weight of sand and the percentages of the fiber were 0.1%, 0.3% and 0.5% by dry weight of sand. The oven-dried sand was mixed with cement, then the optimum water content was added to the mixture, and after that, the fiber was added to the mixture. The mixing of the cement, sand, water and fiber was done in a way that they were evenly distributed through the sample. The used mold consists of two connected parts that can be separated from each other. Before preparing the samples, the mold should be lubricated carefully to extract the samples easily.

The mixture was mixed in a pan and then the soil was placed in the mold in 3 layers, each layer was compacted carefully using compaction apparatus.

After preparing the cemented samples, the samples were sealed by using a nylon tape and placed in a closed plastic bag and after that the bag that contain the samples was placed in a container which has water to provide 100% humidity.

In this study a curing time of 7 and 28 days were applied to the samples to observe the effect of the curing time on the samples.

The percentages of the additives were determined by the dry weight of the sand. The percentage of cement was 3%, 5% and 7% by dry weight of sand. The percentage of fiber was 0.1%, 0.3% and 0.5% by dry weight of sand. The cement ratio ρc, the fiber ratio ρf were defined as follows:

$$\rho_c = \frac{W_c}{W_s} * 100(\%) \tag{1}$$

$$\rho_f = \frac{W_f}{W_s} * 100(\%) \tag{2}$$

Where in the equations (1) and (2) W_c (gr) is the weight of cement, W_f (gr) is the weight of fiber and W_s (gr) is the weight of sand.

3 RESULTS AND DISCUSSION OF UNCONFINED COMPRESSION TEST

The unconfined compression test was performed for cemented sand samples and fiber reinforced cemented sand samples taking into consideration 7 days and 28 days curing time for the samples after they were prepared by using a compaction device and being compacted in three layers. Each case was performed three times to confirm the results that were obtained from the experiments.

3.1 Unconfined compression test results for cemented sand

Unconfined compression tests were performed after preparing samples of sand mixed with different cement content without fiber. After curing the samples for 7 days, the effect of increasing the cement content can be seen easily on the soil behavior as shown in Figure 1.

By increasing the cement content, the peak stress increased dramatically and the cemented sand expressed a marked stiffness and brittle behavior. The axial strain at failure ranged between 1.25% to 2.25% while unconfined compressive strength (qu) was between 2.19 to 11.49 kg/cm².

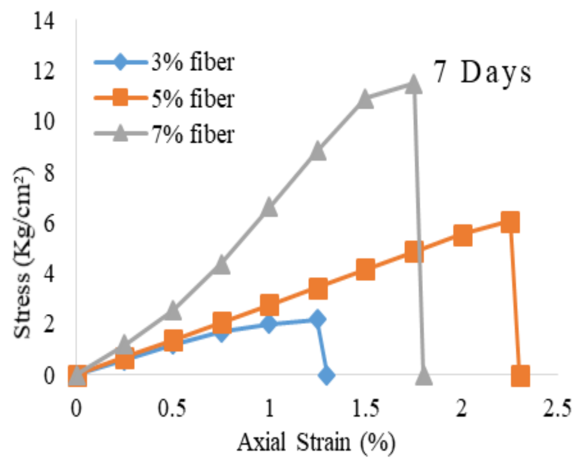

Figure 1. Stress-strain curves with different cement content after curing for 7 days

After curing the samples for 28 days. Unconfined compression tests were performed as shown in Figure 2 and it was seen that similarly to 7 days cured samples, the increasing of cement content increased the peak stress dramatically and the samples have shown more stiffness and brittle behavior. The unconfined compressive strength was between 2.54 to 15.6 kg/cm² and the axial strain at failure ranged between 1.25% to 2.75%.

The effect of 28 days curing time for cemented sand samples was obvious. The unconfined compressive strength and axial strain at failure has increased compared to the samples that were cured for 7 days.

3.2 Unconfined compression test results for fiber reinforced 3% cemented sand

The samples were prepared by mixing sand with 3% cement with 0, 0.1%, 0.3% and 0.5% fiber and later preserved in a moisture tank. Stress-strain curves for fiber reinforced cemented sand samples, which is cured for 7 days are presented

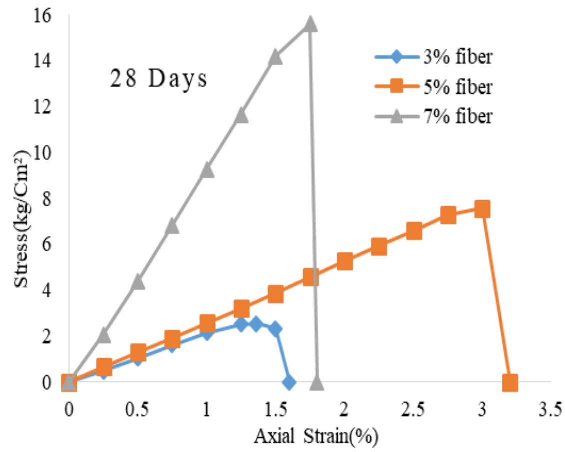

Figure 2. Stress vs strain curves with different cement content after curing for 28 days

in Figure 3. By comparing the cemented sand curve in Figure 1 with fiber reinforced cemented sand curves in figure 3. It can be seen that an increase in axial stress peak can be observed easily. In Figure 3 the unconfined compressive strength ranged between 2.24 to 4 kg/cm² and axial strain at maximum unconfined compressive strength ranged between 1.5% to 3.25%. Stress kept increasing with axial strain until it reached its peak and after that a sudden drop to zero has occurred for the cemented sand samples with no

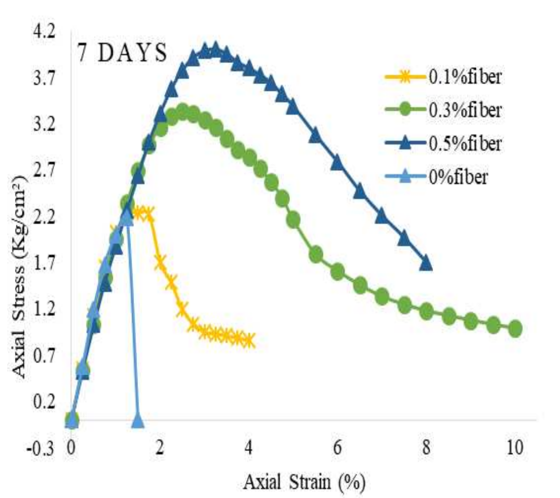

Figure 3. Stress-Strain curve for sand with 3% cement and different fiber ratios after curing for 7 days.

fiber while for the fiber reinforced cemented sand samples a gradual reduction in stress appeared after the addition of fiber.The change in behavior from brittle behavior to a more ductile behavior can be observed in Figure 3.

Sand was mixed with 3% cement and with fiber in different ratios such as 0%, 0.1%, 0.3% and 0.5% and later the samples were kept in a moisture tank to be cured for 28 days. The stress-strain behavior curves were presented in Figure 4 to show the behaviors of the cemented sample and fiber reinforced cemented samples.

Unconfined compressive strength ranged between 2.7 to 4.6 kg/cm² and axial strain at maximum unconfined compressive strength ranged between 1.75% to 3.5 %. However, it was conducted that the fiber reinforced cemented samples, which are cured after 28 days shows significant improvement compared to cemented sand samples and compared to 7 days fiber reinforced cemented sand samples. As in 7 days cured sample, the stress of 28 days cured samples increases with the increase of axial strain until it reaches its peak then it dropped suddenly to zero for cemented sand sample while a gradual reduction in stress appeared after reaching the peak for the fiber reinforced cemented samples.

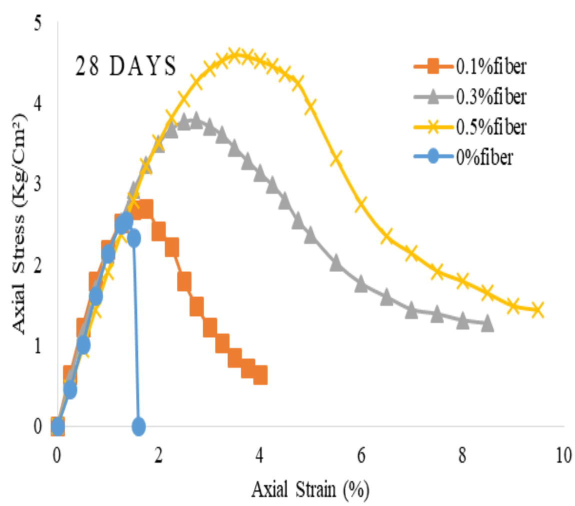

Figure 4. Stress-Strain curve for sand with 3% cement and different fiber ratios after curing for 28 days.

3.3 *Unconfined compression test results for fiber reinforced 5% cemented sand*

The samples were prepared by mixing sand with 5% cement by dry weight and optimum water content after that fiber with different ratios (0%, 0.1%, 0.3% and 0.5% by dry weight) was added to the mixture. Three samples were prepared for each case and preserved in moisture tank for 7 days to be cured. The stress-strain behavior is shown in Figure 5 and unconfined compressive strength values were between 6.06 kg/cm² to 8.27 kg/cm² while axial strain values at maximum unconfined compressive strength ranged between 2.25% to 4%. The increase in fiber ratio increased unconfined compressive strength and samples undergo failure at large strain level compared to cemented samples with no fiber which collapsed immediately by reaching peak stress.

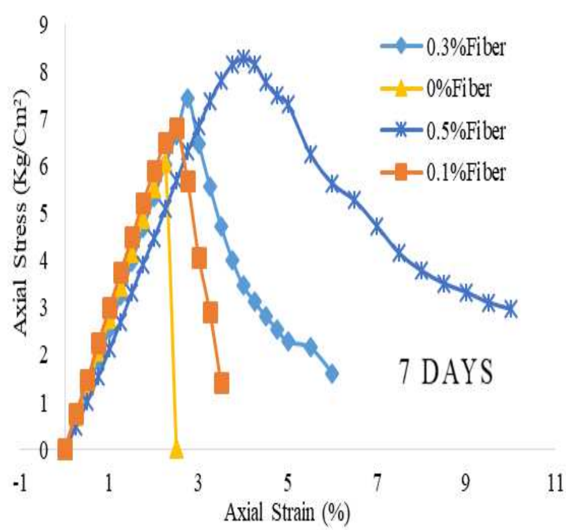

Figure 5. Stress-Strain curve for 5% cemented sand with different fiber ratios after curing for 7 days.

Samples were prepared by mixing sand with 7% cement and optimum water content, after sufficient mixing (0%, 0.1%, 0.3% and 0.5%) fiber were added to the mixture. For each study case, three samples were prepared and kept in a moisture tank for 28 days to be cured. Figure 6 illustrate the stress-strain behavior of the tested samples. It can be acquired from the figure that increasing the fiber ratio resulted in high strain level at failure and increasing the peak stress.

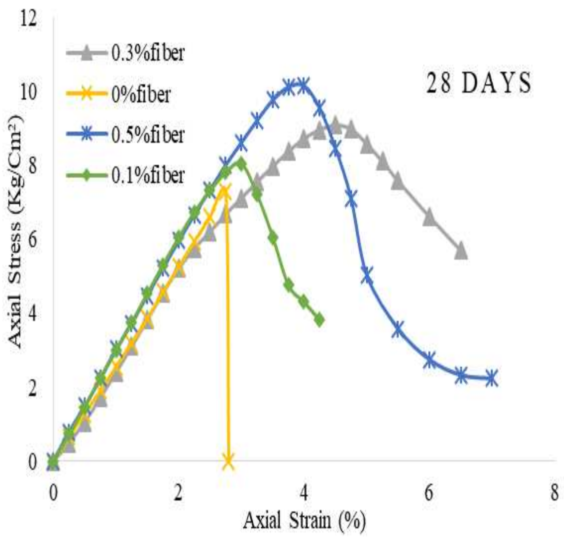

Figure 6. Stress-Strain curve for sand with 5% cement and different fiber ratios after curing for 28 days.

3.4 Unconfined compression test results for fiber reinforced 7% cemented sand

Sand was mixed with 7% cement by dry weight of sand and 0%, 0.1%, 0.3% and 0.5% fiber ratios by dry weight of sand, optimum water content was added to the mixture to insure maximum dry density, and the samples were cured for 7 days in a moisture tank. For each percentage of fiber, three samples were prepared to ensure that the prepared samples could be assessed with high accuracy. Figure 7 presents the stress-strain behavior of the soil. The maximum unconfined compressive strength was obtained and it ranged between 11.49kg/cm² to 15.9kg/cm² while the axial strain at maximum unconfined compressive strength ranged between 1.75% to 2.5%.

Increasing the fiber content resulted in increasing the unconfined compressive strength and in behavior that is more ductile compared to the cemented sand samples.

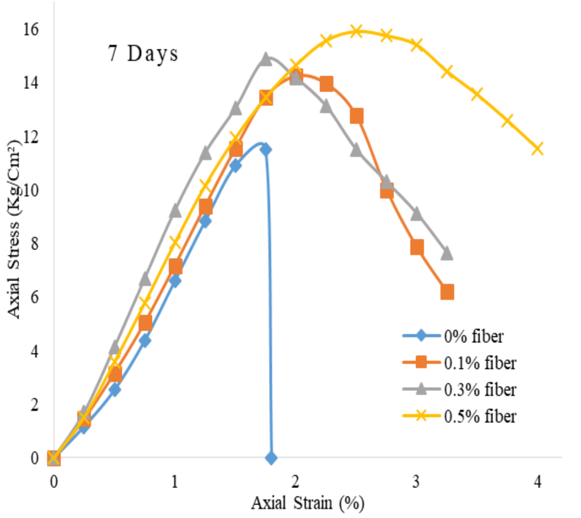

Figure 7. Stress-Strain curve for sand with 7% cement and different fiber ratios after curing for 7 days.

Sand was mixed with 7% cement by dry weight of sand, optimum water content was added to samples, and after that the mixture was mixed with different fiber ratios (0%, 0.1%, 0.3% and 0.5% by dry weight of sand). The samples were preserved in moisture curing tank for 28 days. For each percentage of fiber, three samples were prepared to ensure the precision of the obtained results. Figure 8 shows stress-strain behavior for the tested samples and as it shown from the figure the unconfined compressive strength was obtained between 15.61kg/cm² to 18.65kg/cm² and the axial strain at maximum unconfined compressive strength was between 1.75% to 2.7%. Depending on the acquired results, the behavior of the samples with 0.1%, 0.3% and 0.5% fiber changed from brittle to ductile behavior while the behavior of the samples with 0% fiber was brittle behavior. The peak stress increased after adding fiber by almost 19%, but the increase in fiber content did not increase the peak stress and it almost kept a steady value for the unconfined compressive strength.

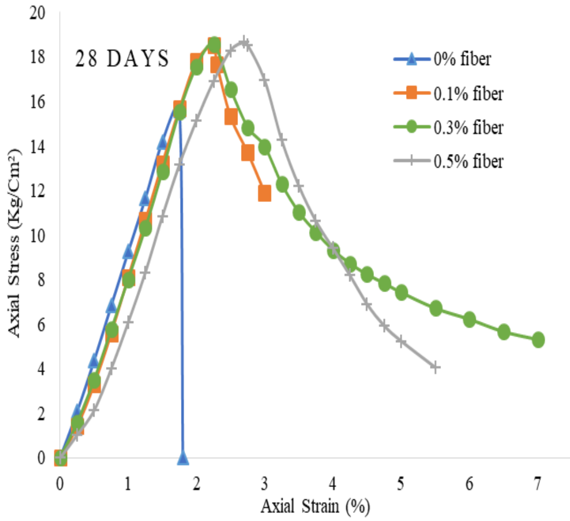

Figure 8. Stress-Strain curve for sand with 7% cement and different fiber ratios after curing for 28 days.

4 CONCLUSIONS

Unconfined compressive strength is increased by increasing the cement content in the prepared samples. The behavior of the samples was a brittle behavior since the samples were reaching the peak stress and collapse directly after reaching it. For the fiber reinforced cemented sand, it was obvious that adding fiber to the cemented sand samples increased the unconfined compressive strength and changed the behavior of the samples from brittle behavior for the cemented samples to a ductile behavior for the fiber reinforced cemented samples.

The axial strain for the fiber reinforced cemented sand at failure increased dramatically after adding the fiber to the cemented samples and the effect of the fiber decreased with the increment of the cement content. Fiber insertion had more impact on the samples, which were mixed with 3% cement than the samples mixed with 7% cement. The 28 days cured samples had a bigger value for unconfined compressive strength compared to 7 days cured fiber reinforced cemented samples. These results can be used to improve the physical properties of the soil to support the foundations or the pavements by achieving the desired strength.

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