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**Research Article**

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# Shear Strength of Fiber Reinforced Silty Sand

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**Abstract** Synthetic fibers are widely used in soil improvement in the recent years. Soil improved by randomly distributed fibers is approximately a homogeneous media in contrary to the other methods of mechanically stabilizing systems that is the main advantage of using this method. Since the orientation and location of fibers between soil particles are completely random parameters therefore extensive laboratory tests are required to estimate the mechanical behavior of these soils. In this study the shear strength of a silty sand reinforced by glass fibers is investigated in the laboratory. The effect of fiber content and fiber length on the cohesion and friction angle of the improved soil was investigated using large scale direct shear test on soil specimens prepared with 0.1, 0.2, 0.3, 0.4, 0.5 and 0.6% fiber contents with different lengths of 5, 10, 20 and 30mm with optimal water content and 85% of maximum dry density. The results of the laboratory tests indicate that the addition of glass fibers increases the shear strength of the soil increasing both cohesion and internal friction angle. There are optimal fiber content and fiber length to achieve maximum shear strength parameters. The optimal fiber content and fiber length in these experiments were about 0.4% and 10mm respectively. The values of cohesion and friction angles were increased by approximately 40% and 30% respectively in optimal conditions.

**Keywords** Shear strength; Silty sand; Fiber; Direct shear test; Reinforced;

## Introduction

Mechanical properties of granular materials are dependent on the material properties of solid particles, the quality of the contacts between their solid particles and the interaction between void, solid and liquid phases. Shear strength of granular material is provided by cohesion and frictional resistance at the interparticle interfaces. These materials have relatively good resistance against compression forces and low resistance against tensile forces. Granular materials are ductile and their failure is achieved by frictional shear forces therefore, their strength increases as the confining forces increase. Since soil layers with desired mechanical properties are rarely found in the filed consequently soil improvement is an inevitable part of any construction project.

There are several soil improvement methods utilized in the recent years including chemical or mechanical methods. Admixtures such as cement, lime, fly ass and gypsum changes mineralogical structure of the soils and improve their strength and stiffness. Chemically improved soils by cement or lime have brittle behavior [1]. Mechanical soil improving includes using geosynthetics such as geotextiles, carbon and glass fiber resin polymer sheets (CFRP/GFRP) and geocells as reinforcements in soils. Due to the high tensile capacity of fiber resin sheets, numerous theoretical and experimental studies about their usage in reinforcing structures especially concrete have been performed. The results showed that CFRP is almost five to ten times stronger than steel in tension therefore, it is possible to use CFRP as reinforcement in soil [2]. The fiber sheet reinforced soil is a nonhomogeneous material with a distinctive interface region between soil and the carbon fiber sheet [3]. High strength carbon or glass fiber sheets used in soil improvement have large tensile strength and require long length to prevent pullout that could be a design concern.

Randomly distributed short discrete fibers could be used for soil reinforcement instead of continuous planar sheets. The history of utilization of randomly distributed short discrete fibers in construction projects goes back to ancient times. A mixture of soil and straw as a construction material was used in ancient India and Iran [4]. Short discrete fibers are easily added and mixed randomly with soil in the same way as cement, lime or other additives. Fiber reinforced soil show more ductility and small losses of peak strength compared to unreinforced material [5]. Discrete fibers as reinforcement have advantages over planer sheets of reinforcements including simple adding and mixing with soil, limited potential plans of weakness that can develop in the direction of planer reinforcement (because there is not a distinctive interface) and less environmental impact on the soil [6]. Because of these advantages, the mechanical properties of discrete fiber reinforced soil have been widely investigated in the recent years.

Al-Refeai [7] and Al-Refeai and Al-Suhaibani [8] studied the static and dynamic behavior of sand reinforced by polypropylene fibers. They found that there were two modes of failure, fiber-sand bond failure and fiber failure, and the internal friction angle depended on the mode of failure. Yetimoglu and Salbas [9] studied the shear strength of fiber reinforced sand by direct shear test device. The results of the tests indicated that peak shear strength and initial stiffness of the sand were not affected significantly by the fiber reinforcement. They concluded that the fiber reinforcements, however, could reduce soil brittleness providing smaller loss of post-peak strength. Consoli et al. [10] studied the behavior of fiber reinforced sand under distinct stress paths in triaxial condition and concluded that a bilinear failure envelope would be appropriate for these soils. Sadik et al. [11] studied the shear strength of fiber reinforced fine and coarse sand by direct shear test device. Results indicate the existence of a fiber-grain scale effect which may depend on the test setup and the procedure used for mixing the fibers. The inefficacy of fiber addition to the soil reported by Yetimoglu and Salbas [9] could be the result of fiber-grain scale effect reported by Sadek et al. [11]. Al-Adili et al [12] used papyrus fibers to reinforce soil. They conducted shear tests and consolidation tests and concluded that not only the shear strength of the fiber-soil is maximum at an optimal fiber content but also the elastic modulus is maximum at an optimal fiber content. Lirer et al. [13] suggested a theoretical method to estimate improved shear strength fiber reinforced soils. Krishna and Nasr [14] studied unconfined compressive strength and California Bearing Ratio of linen fiber reinforced silty sand. The results of their experiments showed that adding linen fibers increased the stiffness and the ductility of the reinforced soil. Anagnostopoulos et al. [15] conducted several direct shear tests on fiber reinforced sands. Their laboratory results showed that fiber reinforcement improved the residual strength of fine sands of medium dense state while reinforced sands of high dense state appeared to exhibit negligible strength increment. Shukla et al' [16] studied the compressibility and permeability of fiber reinforced. They stated that The results indicate that the void ratio of fiber reinforced soils is dependent on the volume ratio of fiber-soil solid. Noorzad and Zarinkolaei [17] compared the results of triaxial and direct shear tests on fiber reinforced sand. The comparison revealed that due to better fiber orientation toward the direction of principal tensile strain in triaxial test as compared to direct shear tests, the fiber efficiency and its effect on soil behavior is much more significant in triaxial specimens. Claria and Vettorelo [18] studied the shear strength of fiber reinforced loose sands. They found that the internal friction angles measured by direct shear tests were higher than those obtained from triaxial tests which was in contrast with the results obtained by Noorzad and Zarinkolaei [17]. Tang et al. [19] studied the tensile strength of fiber reinforced cohesive soils. They concluded that fiber reinforcement increases peak tensile strength and ductility and decreases post-peak tensile strength.

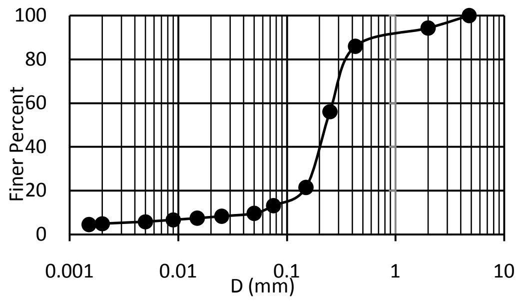
Literature review reveals that there are several parameters affecting the mechanical properties of fiber reinforced soils. In some cases, the results of previous studies are in contrast with each other that can be the effect of uncontrolled parameters. One of the most important parameters that affects the results of the soil fiber reinforcement, is the scale of the samples. Scale effect of the sample referred by Sadek et al. [11], could be originated from fiber-grain size ratio or fiber-grain-shear band size ratio.

In this study the shear strength of silty sand reinforced by randomly distributed discrete fibers is investigated in the laboratory using a large scale 30*30 cm direct shear test device. The effects of fiber length and fiber content on the shear strength of the soil were studied. Large size specimens are more realistic and their behavior is more compatible with the real behavior of the soil in the field.

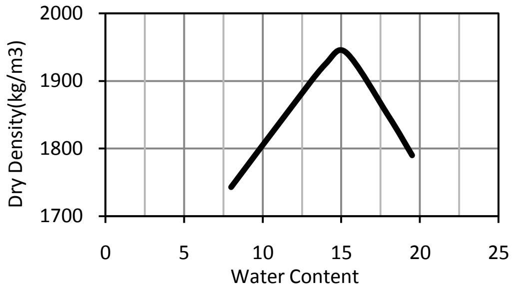
## Materials and Methods

### Soil

The soil used in this study was collected from UMA campus. The specific gravity of solid particles of the soil was determined as 2.67 according to ASTM D854 [20]. The soil was air-dried, crushed, and sieved. The soil was classified as SM in unified system according to ASTM D2487-11 [21]. The compaction curve determined by proctor test according to ASTM D1557 [22]. The optimum water content and maximum dry density is approximately 15.3% and 1,925 kg/m3. Particle size distribution and compaction curve of the soil are shown in Figure 1(a) and (b) respectively.




(a) Particle size distribution curve




(b) Result of compaction test

*Figure 1: Sieve analysis and compaction test results on the soil*

**Fiber**

The fibers used in this study was glass fiber reinforcement polymer (GFRP). The fibers were cut in 4 different lengths including 5, 10, 20 and 30mm. The mechanical properties of the used fiber are according to Table 1.

**Table 1:** Mechanical properties of GFRP.

| Elastic Modulus (GPa) | Tensile Strength (MPa) | Ultimate Strain (%) | Density (kG/m$^3$) |
|---|---|---|---|
| 70 | 2200 | 3 | 1.6 |

**Specimes Preparation**

Randomly distributed desecrate fiber reinforced soil specimens were prepared manually mixing dry soil, water, and fibers. The water used was distilled. Since mixing the fibers with dry soil was difficult, required amount of water was added to the dry soil prior to adding fibers. Then Fibers were gradually added to the soil in small increments. The specimens were controlled visually to ensure that the fibers are distributed randomly and uniformly. It should be noted that mixing long fibers were more difficult than mixing short ones. Soil-fiber mix is illustrated in Figure 2a. After mixing soil and fiber and adjusting the water content equal to its optimum value (15.3%) the material was placed in the shear box and compacted to reach 85% of its maximum compaction ration then shear tests conducted.

**Direct shear tests**

Large scale 30*30cm Direct shear test device was used in this study to evaluate the shear strength of randomly distributed discrete fiber reinforced soil according to ASTM D3080 [23] standard. Used direct shear test device is illustrated in Figure 2b.

(**a**)

(**b**)

**Figure 2:** (**a**) Soil and fiber mixing; (**b**) Large scale (30cm*30cm) direct shear test device.

Shear tests conducted under three different normal stresses including 50, 100 and 200kPa. The tests were strain controlled with strain rate of 0.5mm/sec.

**Results**

Shear displacement-stress behavior

The results of direct shear tests on unreinforced specimens and 5mm fiber reinforced specimens with different fiber contents under normal stresses of 50, 100 and 200kPa are illustrated in Figure 3.

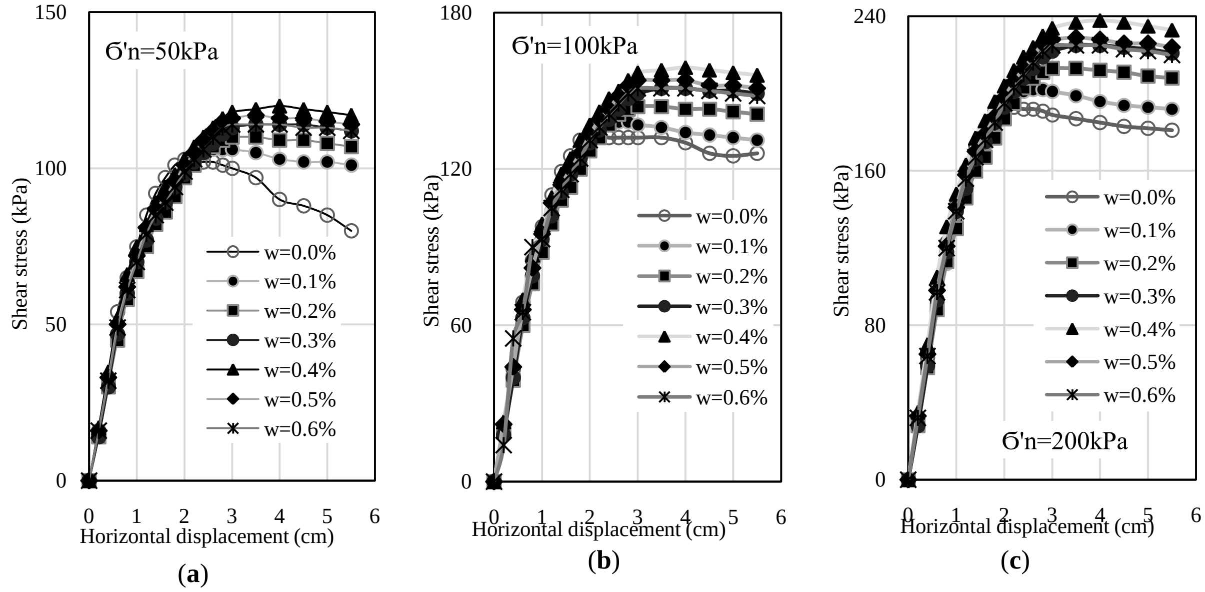



*Figure 3: Results of direct shear tests for unreinforced soil, 5mm fiber reinforced soil with different fiber contents under (a): 50kPa normal stress; (b) 100kPa normal stress; (b) 200kPa normal stress.*

It can be seen in Figure3 that the shearing behavior of unreinforced soil is relatively brittle (softening behavior) because the shear stress decreased after failure. The softening behavior is more evident in 50kPa stress however there is also strength loose after failure under 100 and 200kPa normal stresses. As reported in the previous researches, fiber reinforced specimens have more ductile behavior. As shown in Figure 3, fiber reinforced specimens did not show significant strength loose after failure. Also the horizontal displacement at the peak shear strength increased from about 2mm for unreinforced specimens to 4mm for specimens reinforced with 0.6% fiber content. The result of these tests is in accordance with findings of other studies [5, 9, 10, 14, 19].

**Effect of fiber reinforcment on shear strength of soil**

Shear strength of specimens with different fiber contents and lengths are illustrated in Figure 4. The vertical axis of these charts are the ratio of the weight of the fibers to the dry weight of specimens. Zero fiber content indicates unreinforced specimens. It can be inferred from Figure 4 that the addition of fiber has increase the shear strength of samples. For all fiber contents the shear strength of fiber reinforced specimens is more than that of unreinforced specimens.

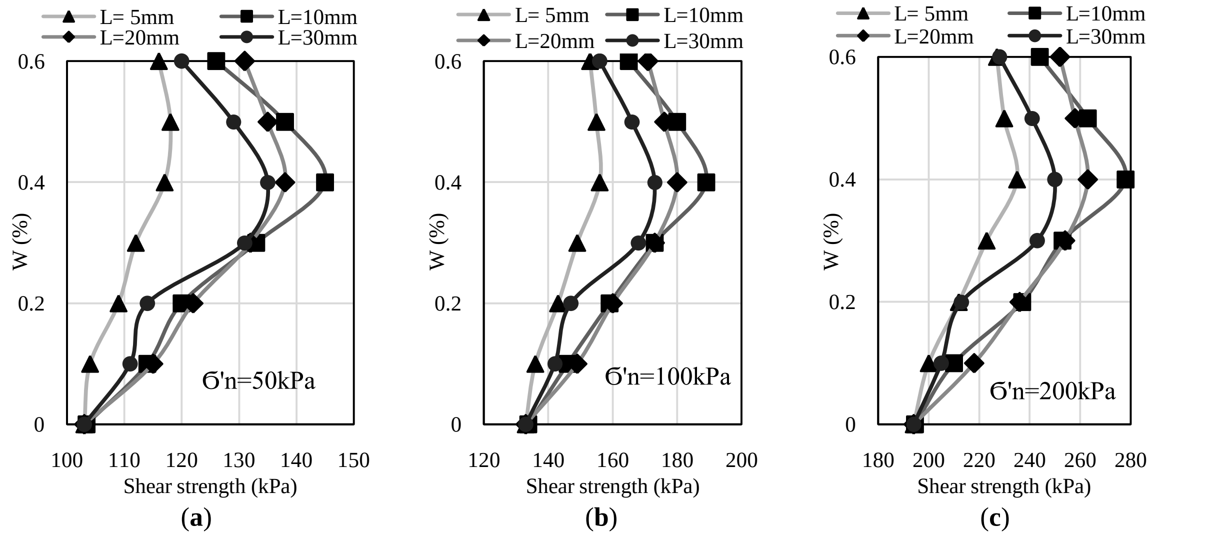



*Figure 4: Peak shear strength of unreinforced soil, 10mm fiber reinforced soil with different fiber contents under (a): 50kPa normal stress; (b) 100kPa normal stress; (b) 200kPa normal stress*

**Failure Envelope of Fiber Reinforcmed Soil**

Mohr-Coulomb failure envelope for specimens with fiber lengths of 5, 10, 20 and 30mm and fiber content of 0.1, 0.2, 0.3, 0.4, 0.5 and 0.6% are illustrated in Figure 5. As mentioned before, it can be concluded from this figure that the fiber reinforcement increased the shear strength of the soil. Comparing the failure envelopes of fiber reinforced specimens with failure envelope of unreinforced specimens, indicates that the fiber reinforcement improved both slope and intercept of failure envelopes. It means that fibers have increased both friction angle and cohesion of the soil. It should not be overlooked that the maximum increase of shear strength parameters of the soil was not essentially occurred for maximum fiber content or maximum fiber length.

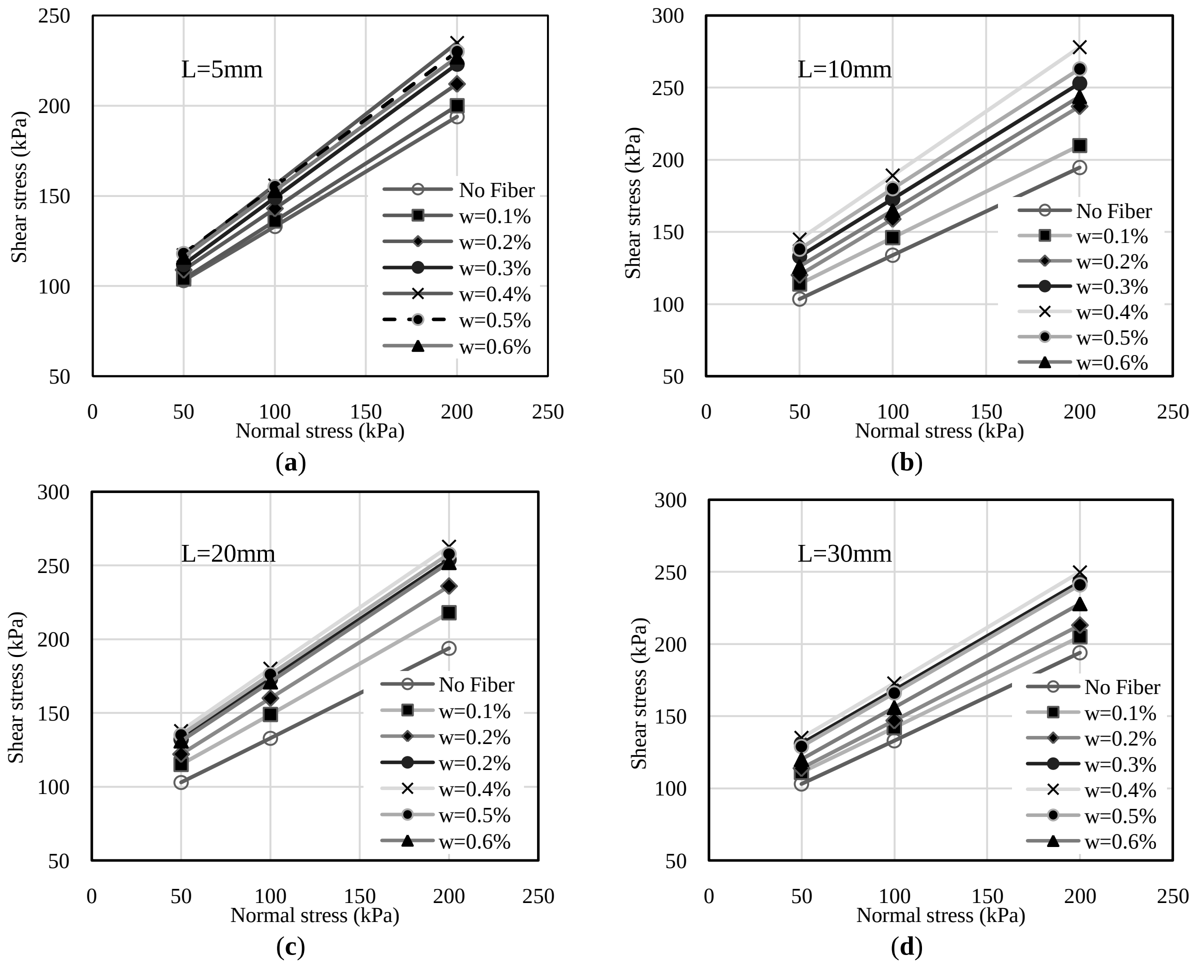
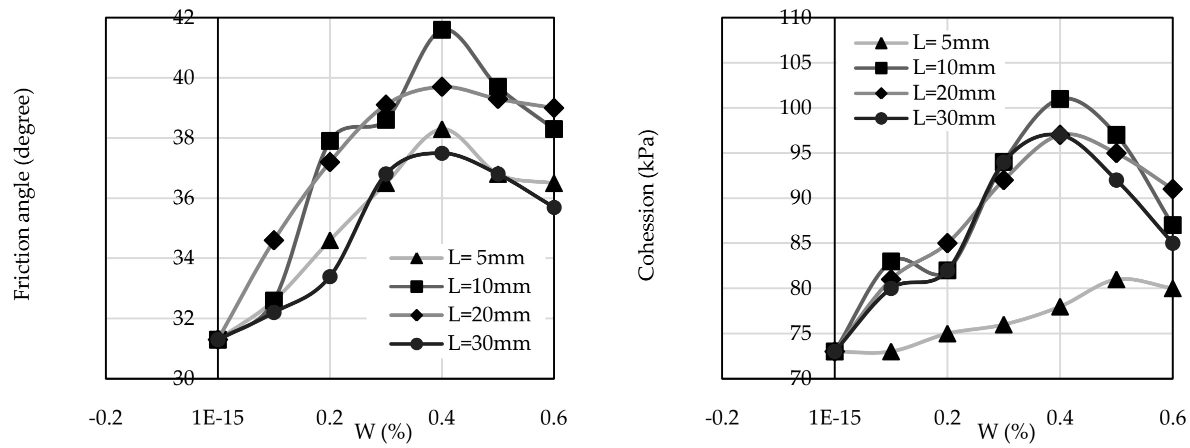



*Figure 5: Failure envelope for specimens reinforced with different fiber contents and fibers with (a): 5mm; (b): 10mm; (c): 20mm; (d): 30mm length.*

**Effect of Fiber Reinforcment on Friction Angle and Cohesion of Soil**

Friction angle and cohesion of fiber reinforced specimens calculated from direct shear tests results are illustrated in Figure 6a and 6b respectively. The results of these tests show that fiber reinforcement has increase both friction angle and cohesion of the soil. It can be seen that increasing the fiber content up to 0.4% has increased both friction angle and cohesion but further increment in fiber content decreased both friction angle and cohesion. Friction angle of unreinforced soil was 31.3 degrees. The maximum friction angle of fiber reinforced soil reached to 41.6 degrees with 0.4% of fiber content fiber length of 10mm. Comparing its value with the friction angle of unreinforced soil shows 33% increment. Cohesion of unreinforced soil was 73kPa. Its value increased for fiber reinforced soil in its maximum state to 101kPa. The maximum increment of the cohesion of fiber reinforced soil was 38% that was also achieved with 0.4% of fiber content and 10mm fiber length.

Similar to the fiber content, using longer fiber reinforcements increases the shear strength of the soil up to a certain limit. Using fiber longer than a certain length did not increase the shear strength of the soil. It means that there is an optimal fiber content and fiber length for maximum increase in shear strength parameters of the reinforced soil which is in agreement with the other studies [7, 8, 12].




**(a)** **(b)**

*Figure 6: Effect of the fiber reinforcement on: (a) Friction angle of the soil; (b) Cohesion of the soil.*

**Conclusion**

This paper presents the results of an experimental investigation on the effect of the randomly distributed discrete glass fiber reinforcement on the shear strength of a silty sand. The tests conducted using direct shear test on specimens prepared with 85% of their maximum dry density. The results of conducted tests indicated that fiber reinforcement increases the ductility and shear strength of the soil. The specimens used in this study were compacted approximately 85% of maximum density that means they were relatively dense specimens. The results of direct shear tests conducted on unreinforced specimens showed strength loses about 5% to 22% of peak strength that means the specimens were dense. Therefore, it could be concluded that fiber reinforcement increases the shear strength of relatively dense materials as well as lose materials. There was 38% increment in cohesion and 33% increment in friction angle of fiber reinforced soil that means the cohesion of the soil was more affected by the fiber inclusion. The other remarkable point observed in this study was the optimal effect of fiber reinforcement on the shear strength of the material. In this study the optimal quantities of fiber content and fiber length was 0.4% and 10mm respectively. These values cannot be retained for other soils and fibers and further studies are required. The inefficacy of fiber content higher than optimum amount and optimum length could be related to balling effect.

**References**

[1]. Sariosseiri, F. and Muhunthan, B. (2009), “Effect of cement treatment on geotechnical properties of some Washington State soils.”, *Engineering Geology*, 104(1-2), 119-125, DOI: 10.1016/j.enggeo.2008.09.003

[2]. Ouria, A.; Toufigh, B; Desai, C.S.; Toufigh, V. and Saadatmanesh, H. (2016), “Finite element analysis of a CFRP reinforced retaining wall.” Geomech. and Eng., 10(6), 757-774, DOI:10.12989/gae.2016.10.6.757

[3]. Toufigh, V.; Ouria, A.; Desai, C.S.; Javid, N.; Toufigh, V. and Saadatmanesh, H. 2016, “Interface behavior between carbon-fiber polymer and sand.” J. Test. Eval., 44(1), 385–390, DOI:10.1520/JTE20140153

[4]. Toufigh, V.; Saeid, F.; Toufigh, V.; Ouria, A.; Desai, C.S. and Saadatmanesh, H. (2012), “Laboratory study of soil-CFRP interaction using pull-out test.” Geomechanics and Geoengineering, 9(3): 208-214, DOI: 10.1080/17486025.2013.813650

[5]. Chegenizadeh, A. and Nikraz, H. (2016), “Performance of fiber reinforced clayey sand composite.” Front. Struct. Civ. Eng., 6(2): 147–152, DOI: 10.1007/s11709-012-0158-6

[6]. Li, J.; Tang, C.; Wang, D.; Pei, X. and Shi, B. (2014), “Effect of discrete fibre reinforcement on soil tensile strength.” Journal of Rock Mechanics and Geotechnical Engineering, 6(2), 133–137, DOI: 10.1016/j.jrmge.2014.01.003

[7]. Al-Refeai, T. (1991), “Behavior of granular soils reinforced with discrete randomly oriented inclusions.” Geotextile and Geomembranes, 10(3), 319-333, DOI:10.1016/0266-1144(91)90009-L

[8]. Al-Refeai, T. and Al-Suhaibani, A. (1998), “Dynamic and static characterization of polypropylene fiber-reinforced Dune Sand.” Geosynth. Int. 5(5), 443-458, DOI: 10.1680/gein.5.0132

[9]. Yetimoglu, T. and Salbas, O. (2003), “A study on shear strength of sands reinforced with randomly distributed discrete fibers”, Geotext. Geomembranes, 21 (2003) 103–110, DOI:10.1016/S0266-1144(03)00003-7
[10]. Consoli, N.; Heineck, K.; Casagrande, M. and Coop, M. (2017), “Shear strength behavior of fiber-reinforced sand considering triaxial tests under distinct stress paths.” J. Geotech. Geoenviron. Eng., 133(11), 1466-1469, DOI: 10.1061/(ASCE)1090-0241(2007)133:11(1466)
[11]. Sadek, S.; Najjar, S. and Freiha, F. (2010), “Shear strength of fiber-reinforced sands.” J. Geotech. Geoenviron. Eng., 136(3), 490-499, DOI: 10.1061/_ASCE_GT.1943-5606.0000235
[12]. Al-Adili, A.; Azzam, R.; Spagnoli, G. and Schrader, J. (2012), “Strength of soil reinforced with fiber materials (Papyrus)”, Soil Mech. Found. Eng., 48(6), 241-247, DOI: 10.1007/s11204-012-9154-z
[13]. Lirer, S.; Flora, A. and Consoli, N.C. (2011), “On the strength of fibre-reinforced soils.” Soils Found., 51(4), 601–609, DOI: 10.3208/sandf.51.601
[14]. Krishna Rao, S.V and Nasr, A.M.A. (2014), “Laboratory study on the relative performance of silty-sand soils reinforced with linen fiber.” Geotech. Geol. Eng., 30,63–74, DOI 10.1007/s10706-011-9449-2
[15]. Anagnostopoulos, C.A.; Papaliangas, T.T.; Konstantinidis, D. and Patronis, C. (2013) “Shear strength of sands reinforced with polypropylene fibers”, Geotech. Geol. Eng., 3, 401–423, DOI 10.1007/s10706-012-9593-3
[16]. Shukla, S.K.; Shahin, M.A. and Abu-Taleb, H. (2015), “A note on void ratio of fibre-reinforced soils.” Int. J. of Geosynth. and Ground Eng., 1(29), 1-5, DOI 10.1007/s10706-012-9593-3
[17]. Noorzad, R.; and Zarinkolaei, S.T.G. (2015), “Comparison of mechanical properties of fiber-reinforced sand under triaxial compression and direct shear.” Open Geosci., 1, 547–558, DOI 10.1515/geo-2015-0041
[18]. Claria, J.J. and Vettorelo, P.V. (2016), “Mechanical behavior of loose sand reinforced with synthetic fibers.” Soil Mech. Found. Eng., 53(1), 12-18, DOI 10.1007/s11204-016-9357-9
[19]. Tang, C.; Wang, D.; Cui, Y.; Shi, B. and Li, J. (2016), “Tensile strength of fiber-reinforced soil.” J. Mater. Civ. Eng., 28(7), 04016031-1-04016031-13, DOI: 10.1061/(ASCE)MT.1943-5533.0001546.
[20]. ASTM D1557-12e1, Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort, ASTM International, West Conshohocken, PA, 2012. Available online: http://www.astm.org/Standards/D1557.htm
[21]. ASTM D2487-11: Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System), ASTM International, West Conshohocken, PA, 2011. Available online: http://www.astm.org/Standards/D2487.htm
[22]. ASTM D3080: Standard Test Method for Direct Shear Test of Soils under Consolidated Drained Conditions, Annual Book of ASTM Standards, ASTM International, West Conshohocken, PA, 2004. Available online: https://www.astm.org/Standards/D3080.htm
[23]. ASTM D854-14, Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer, ASTM International, West Conshohocken, PA, 2014. Available online: http://www.astm.org/Standards/D854