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Effect of strain level on strength evaluation of date palm fiber-reinforced sand

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Abstract. Conventional researches on the behavior of fiber-reinforced and unreinforced soils often investigated the failure point. In this study, a concept is proposed in the comparison of the fiber-reinforced with unreinforced sand, by estimating the strength and strength ratio at different levels of strain. A comprehensive program of laboratory drained triaxial compression test was performed on compacted sand specimens, with and without date palm fiber. The fiber inclusion used in triaxial test specimens was form 0.25%-1.0% of the sand dry weight. The effect of the fiber inclusion and confining pressure at 0.5%, 1.0%, 1.5%, 3.0%, 6.0%, 9.0%, 12%, and 15% of the imposed strain levels on the specimen were considered and described. The results showed that, the trend and magnitude of the strength ratio is different for various strain levels. It also implies that, using failure strength from peak point or the strength corresponding to the axial strain of approximately 15% for evaluating the enhancement of strength or strength ratio, due to the reinforcement, may cause hazard and uncertainty in practical design. Therefore, it is necessary to consider the strength of fiber-reinforced specimen at the imposed strain level, compared to the unreinforced specimen.

Keywords: date palm fiber; reinforced sand; triaxial test; strain level; strength

1. Introduction

Nowadays, there is a greater awareness about containment and the increasing demand for using more economical and environmentally friendly materials. As one of these materials, natural fiber is widely used for improving the soil properties in geotechnical engineering applications. Many studies have been conducted on the fiber-reinforced and unreinforced soil, in order to determine the strength properties in the strain corresponding to the failure point. The evaluation of the shear strength of fiber-reinforced, regardless of the different levels of strain, can be hazard.

Several researchers presented the general characteristics of discrete fiber-reinforced granular soils. In direct shear test of specimens, Gray and Ohashi (1983) placed different types of fibers in sandy soils in particular directions. They concluded that, the shear strength was increased when the angle of the fiber was 60° to the shear surface.

Also, Al-Rafeai (1991) carried out triaxial tests on sandy-grained soils with glass and polypropylene fibers, which it was indicated that the strength and the deformability of the specimens were improved by increasing the fiber inclusion. In addition, Ranjan *et al.* (1996) conducted an extensive laboratory study with more than 500 triaxial tests performed on the cohesionless reinforced soil with both natural and synthetic fibers, which were randomly distributed. They developed a mathematical model to determine the characteristics of fiber. Moreover, Michalowski and Cermak (2002) stated that, when the fibers are placed in the direction of the largest extension of the composite, the contribution of their direction to the composite strength is the largest when. Using triaxial test results and statistical analysis, researchers have demonstrated that, both the peak shear strength and initial stiffness are increased by increasing the randomly distributed fiber content (Michalowski and Zhao 1996, Michalowski and Cermak 2003).

Consoli *et al.* carried out triaxial tests, isotropic compression, large shear strain, and plate loading test on fiber-reinforced sand in several studies (Consoli *et al.* 1998, 2003, 2005, 2007, and 2009). They revealed that, the stiffness and peak shear strength were significantly increased by increasing in fiber inclusion. They also considered the behavior of the reinforced sand with fibers at large strains, to investigate the effect of fiber inclusion, fiber length, and relative density of sand. Furthermore, a review study, including 190 published papers on the soil improvement using natural and synthetic fibers was presented (Hejazi *et al.* 2012). In this study, it has been indicated that, the increased stiffness and shear strength of reinforced soils depend on the properties of fibers, sand, and test conditions.

A research suggested that, the fiber content significantly increased the soil peak strength, reduced the post peak strength, and changed the brittle tensile failure to a more ductile behavior (Tang *et al.* 2016). Claria and Vettorelo (2016) preformed triaxial and direct shear tests on fiber-reinforced sand, in order to determine the effect of fibers on the shear strength and the deformational modulus in different strains. Also, a damaged strain-softening model was presented for the prediction of the shear behavior of

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soil structure interfaces (Long *et al.* 2017). Shukula (2017) stated the basic principles of the analysis, design, characteristic details, performance mechanism, and the applications of fiber-reinforced soils. Moreover, Mirzababaei *et al.* (2018) preformed a series of multi-stage direct shear tests on the reinforced soft clay specimens. They prepared the soil specimens, including polypropylene fibers, in 6, 10, and 19 mm length and 0.25%- 0.5% of fiber inclusion. The shear strength of the soft clay specimens, blended with the polypropylene fibers, was approached to the shear strength of the soil specimens, regardless of the fiber content. Güllü and Fedakar (2017a) reported that, sludge ash could be successfully reused for stabilizing marginal sand by reinforcing with propylene fiber.

Consoli *et al.* (2019) investigated the effect of sodium chloride and fiber-reinforcement on the durability of sand-coal fly ash-lime mixtures under thawing freezing and thawing cycles. They showed that, the fiber content on the same blends provided a greater durability, regarding those specified with NaCl.

It is noteworthy that, literature studies on soil treated by additives have been developed towards more economical and practical solutions. In this area, Güllü (2015) and Güllü *et al.* (2017) treated fine-grained soil with bottom ash and used cement-based grout with glass powder for deep mixing, respectively. The prediction methods have been implemented to find the rheological behavior of grout with bottom ash, jet grouting cement mixtures with various stabilizers, and geopolymer for grouting (Güllü 2016, 2017a, Güllü *et al.* 2019). Canakci *et al.* (2018) investigated the effect of glass powder added to grout for deep mixing of marginal sand with clay. In addition, the behavior of jet grout cement mixture and wave velocity of soil was predicted by genetic algorithm, using neural network method (Güllü 2013, 2014a, 2017b).

Current studies mainly emphasize on the strength of reinforced sand using randomly distributed fibers at failure point, whereas a concept can be determined for the strength of reinforced sand, considering the strength of reinforced specimen compared to unreinforced specimen at the imposed strain level. This research was conducted to study the behavior of fiber-reinforced and unreinforced sandy soil at various strain levels. Hence, a comprehensive program of laboratory triaxial compression test was performed on non-plastic Aeolian sand, with and without fiber. Also, the effect of fiber inclusion and confining pressure at different strain levels on strength and strength ratio were considered and described in this study.

2. Materials and methods

2.1 Soil characteristics

For the experiments, relatively uniform and clean sand was collected form the desert of the Bam city, located in the southeast of Iran. Furthermore, in order to identify the soil in depth, a geotechnical borehole was drilled and samples were taken from different depths. Fig. 1 shows the particle size distribution curves of soil in the site. In addition, Table 1 presents the soil characteristics. According to the Unified Soil Classification System, the soil classification in the zone was SP.

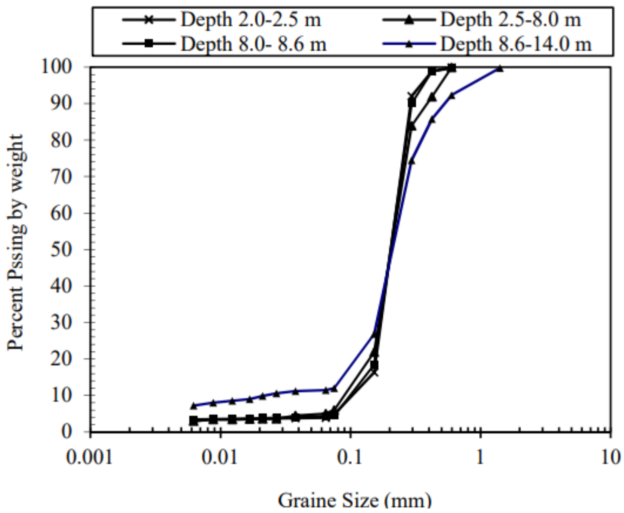

Fig. 1 Gradation curves of Bam sand

Table 1 Physical properties of sand

Characteristic	Value
Coefficient of uniformity, C_u	1.67
Coefficient of curvature, C_c	1.13
Medium grain size, D_{50} (mm)	0.21
In situ Dry unit weight	14.4 kN/m^3
In situ moisture content	3.2%
R_D (initial relative density)	23%
e (initial void ratio)	0.865
Specific gravity of solids (G_S)	2.689

2.2 Date palm fiber properties

The long filament date palm fibers were mainly obtained from date palm groves of Bam city. In Bam city, which is located in Kerman province, Iran, possess about 180,000 single roots of palm trees (Fig. 2). The fibers are low in price, abundant, highly durable and lightweight with high tensile force capacity, along with stringy texture.

Date palm fibers, due to their properties such as good environmental compatibility, eco-friendly, renewability and biodegradability can be used as a substitute for mineral fibers and glass, especially in lightweight composites. Date palm fibers are discarded as waste in the annual pruning of palm tree. Therefore, using it in areas with potential fiber production would be economically significant. Zarandi *et al.* (2012) showed that, about 70% of the date palm fibers have a diameter of 0.1-0.6 mm. For the teats, the filaments were cut into pieces with 20 mm length. The average weight of each piece was determined to be approximately 0.0044 g, using a sensitive scale. Fig. 3 shows the fibers prepared and used in this study.

Zarandi *et al.* (2012) demonstrated that, the waxy and resinous substances on the surface of the fiber lead to the prevention of moisture absorption. However, fibers of date

Fig. 2 Date palm trees

Fig. 3 Date palm fibers prepared in 20- mm length

Table 2 Date palm fiber characteristics (Azadegan *et al.* 2012)

Characteristics	Value
Ultimate tensile strength	63 MPa
Elasticity modulus	600 MPa

palm trees do not have uniform physical and mechanical properties, which this is due to the quality of the local agricultural soil, the position of the fibers in the tree, the age of the tree, and the weather conditions. Furthermore, the absorption of moisture by date palm fibers increases its length and increasing its percentage may dramatically affect the behavior of reinforced soil. Table 2 shows some of the characteristics of date palm fiber.

2.3 Preparation of the specimens

All the specimens were remolded under maximum dry unit weight (γ_{dmax}) and optimum moisture (ω_{opt}) content conditions and fiber contents of 0%, 0.25%, 0.50%, 0.75% and 1.00% were used, along with dry weight of sand. The specimens prepared for axisymmetric loading and drained triaxial tests were 70 mm × 140 mm in dimension. Table 3 provides the specifications of the specimen preparation.

Based on ASTM D 1557, compaction blows are applied to all layers at a fixed energy. Therefore, the energy

Table 3 Specifications of the specimen preparation

Fiber content (%)	Maximum dry unit weight (kN/m^3)	Optimum moisture content (%)	Relative Density (%)
0.0	18.15	12.55	94
0.25	18.11	12.59	93
0.50	18.05	12.63	92
0.75	17.98	12.74	91
1.00	17.95	12.79	91

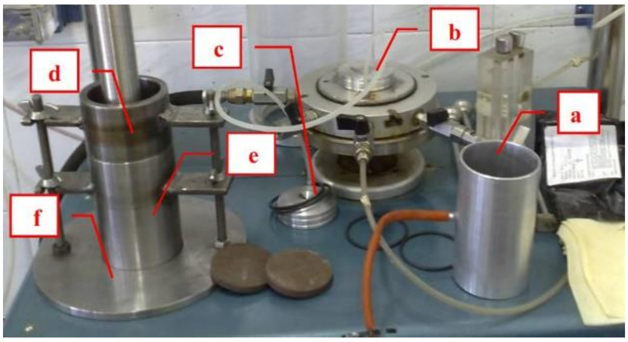

Fig. 4 Triaxial accessories for specimen preparation: (a) membrane suction tube, (b) specimen base, (c) specimen loading cap, (d) moveable connection tube, (e) specimen mold and (f) mold base

applied to the underlying layers of sand specimen is higher than the upper layers and as a result, the specimen's unit weight in the lower part of the specimen is higher than the upper part. Therefore, the under-compaction technique was used to avoid this problem. Ladd (1987) first used this compaction technique for preparation of the specimen.

Specimens for triaxial tests were prepared in a cylinder with 140 mm height and 70 mm diameter. In Ladd's method, each layer was compacted up to a specific energy, which was lower than that of the standard method, where the compaction energy applied to the specimen diminished from the bottom to top. Fig. 4 illustrates the required triaxial tests accessories designed to prepare and compact the specimens.

All specimens prepared for the drained triaxial test, were tested by a standard triaxial compression apparatus, made by ELE Co. with 100 kN capacity. The specimens were extruded using a hydraulic jack and then, the rubber membrane was placed around them. Subsequently, the specimens were saturated according to the BS 1377 and finally they were consolidated under effective confining pressure. Confining pressures (σ_3) of 70, 210, and 420 kPa were applied for all specimens. During vertical axial loading, a fixed vertical displacement rate of 0.50 mm/min was used, which was supplied by the gearbox of apparatus. Also, during the axial load application, drainage conditions were provided for the specimens. Axial loading were continued until the strain was reached to 15% for all the specimens.

3. Results and discussion

Figs. 5-7 present deviatoric stress (σ_d) versus axial strain

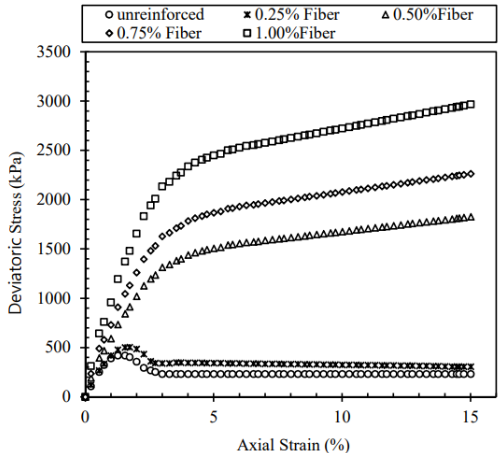

Fig. 5 The effect of fiber inclusion on the curves of σ_d versus ε_a under σ_3=70 kPa

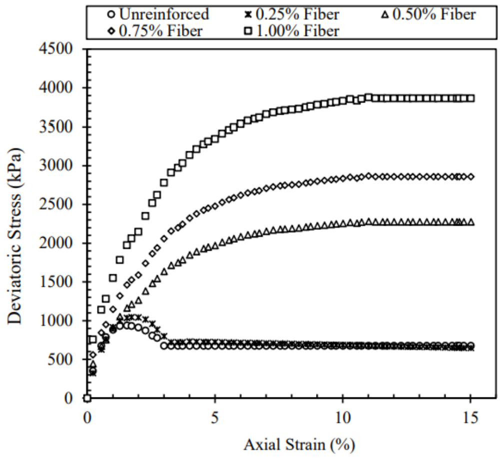

Fig. 6 The effect of fiber inclusion on the curves of σ_d versus ε_a under σ_3=210 kPa

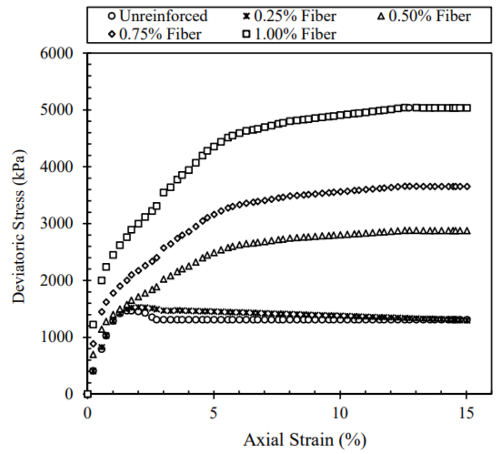

Fig. 7 The effect of fiber inclusion on the curves of σ_d versus ε_a under σ_3=420 kPa

Fig. 8 Dominant failure plane with 0.25% fiber inclusion

Fig. 9 Failure planes in specimens with 0.5% fiber inclusion

(ε_a) curves, obtained from the triaxial compression tests under confining pressures of 70, 210, and 420 kPa, with different fiber content. All of the figures indicate the shear strength and initial stiffness growth corresponding to the increase in fiber inclusion. It should be noted that, the post failure responses in fiber-reinforced sand were stated in two major behaviors, such that when the date palm fiber contents in specimen were reached to 0.5%, the behavior of fiber-reinforced sand in post failure was strain softening. In addition, when the date palm fiber contents were increased to more than 0.5%, the behavior beyond the yield point was significantly changed from strain softening to strain hardening. The amount of strain corresponding to the peak shear strength was small (up to 0.25% of the fiber inclusion), but after increasing the fiber to 0.5%, the deformability of the specimens was increased significantly.

This significant deformability of the specimens is due to the confining pressure and particularly increasing the percentage of date palm fiber. Fig. 8 demonstrates that, up to 0.25% of the shear strength of the specimens occurs in a dominant failure plane. However, in 0.50% fiber content and more, there are several failure planes, which greatly increased the shear strength and strain capacity (Fig. 9).

During the shear stage in the triaxial test, a large number of failure planes appeared in the specimens. It might be due to the fiber orientation and fixed direction of the principal stresses. One may conclude that compacting the fiber-reinforced sand during specimen preparation led to a preferred near-horizontal orientation for the fibers (Diambra *et al.* 2007). The failure planes in the specimens reinforced with jute fiber occur in the shear planes inclined from 0 to 70° (Güllü and Khudir 2014). During loading, the fiber-reinforced sand is under the influence of the dominant shear stresses towards failure in the dominant direction. However, due to the position of the fibers that are interspersed in the direction of the rupture plane, the dominant failure does not

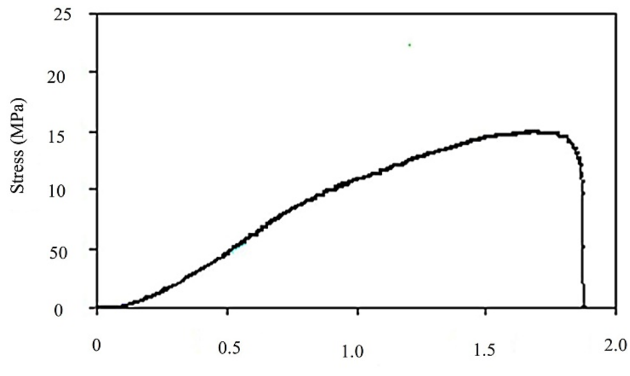

Fig. 10 Stress- Strain curve of date palm fiber

occur. As the load increases, the reinforced soil selects another plane for failure and again the fibers resist displacement of the soil particles due to the tensile strength of the fibers. Thus, the fiber-reinforced sand exhibits very high shear strength and deformability. The high ductility of fiber-reinforced soil improve other mixtures characteristics. Güllü and Khudir (2014) showed that the energy-absorption capacity, ductility, post-peak strength and strain-hardening behavior of native soil are best performed with the inclusion of the jute fiber alone at all freezing-thawing cycles.

Furthermore, Fig. 9 indicates that, the fibers did not fail during the shear loading stage. Therefore, the failure mechanism is expressed by the fiber resistance to the pull out strength. Although the fiber-reinforced sand tends to form a ruptured plane under stresses, the pull out strength of the fibers prevents the failure. As a result, the reinforced soil selects other planes for failure and the number of planes increases by increasing the fiber content.

The occurrence of a large number of failure planes in the specimens indicates the ability of fiber to withstand the strain. Fig. 10 illustrates the stress-strain behavior of date palm fiber (Zarandi *et al.* 2012).

The performance of failure axial strain in the present study was compared to the alternative material used by Güllü and Girisken (2013) in the treatment of silty soil. They used industrial wastewater sludge to treat silty soil and reported that, the failure axial stress was reached to an axial strain of approximately 1.4% in the untreated soil, whereas the failure strain was increased with the sludge inclusions and ranged from 2.8-5.1%. However, as it can be seen in Figs. 5-7, the failure strain in the unreinforced soil is changed from 1.5% up to 10% in the sand reinforced with 0.5% fiber inclusion. On the other hand, there are abundant date palm trees and sand in arid and semiarid areas, therefore it is technically and economically feasible to use date palm fibers in these areas for reinforcing sandy soil. Accordingly, its disposal in an environmentally friendly way has become more important.

The post peak behavior of the fiber-reinforced can be expressed by the brittleness index. The brittleness index (I_B) in Eq. (1), due to increasing in fiber inclusion values, is used to estimate the brittleness or ductility of the specimens (Consoli *et al.* 1998).

$$I_B = \frac{q_f}{q_u} - 1 \tag{1}$$

Table 4 Brittleness index of the specimens

Fiber Content (%)	σ_3 (kPa)		
	70	210	420
0	0.82	0.41	0.17
0.25	0.65	0.61	0.21
0.50	0	0	0
0.75	0	0	0
1.00	0	0	0

in which q_f and q_u are the peak shear strength and ultimate shear strength, respectively. As the brittleness index decreases toward zero, the failure behavior becomes increasingly ductile (Güllü 2014a, Güllü and Khudir 2014). Table 4 outlines the brittleness indices calculated for all results obtained from 3 different confining pressures, with the fiber inclusions of 0% and 1.0%.

The results presented in Table 4 show that, a small number of brittleness indices are greater than zero corresponding to fiber content up to 0.25%. When the fiber content is low, the specimen behavior tends to be unreinforced specimen and strain softening behavior appears afterwards. The brittleness coefficient for 0.5% fibers or more is equal to zero. By increasing the fiber inclusion, only strain hardening behavior occurs. In this case, the specimens exhibit a significant ductility.

The post failure advantages in fiber-reinforced included gaining a significant ductility and a high strain capacity after increasing fiber to 0.5%. By increasing the failure axial strain of reinforced sand, the energy adsorption capacity increases and becomes favorable against adverse responses of earthquakes. The energy adsorption capacity of fiber-reinforced soil inferred by the area under the deviatoric stress- axial strain curves. As shown in Figs. 5-7, it can be estimated that the area under stress-strain of unreinforced sand compared to reinforced sand inclusion 1% fiber content is about 3 to 5. This could be useful for the soil under adverse effects of earthquakes (Güllü and Pala 2014; Güllü *et al.* 2008).

There several studies conducted on the performance comparison of the advantages and disadvantages between date palm fiber and alternative materials as reinforced or treated agents. Güllü and Fedakar (2017b) conducted a study in order to find the optimum amounts of stabilizers Sewage Sludge Ash (SSA), Polypropylene Fiber (PF), and Curing Time (CT), that yield to maximum unconfined compressive strength (UCS) for stabilization of a marginal sand (poorly-graded sand). According to the results obtained from response surface methodology, it can be concluded that, SSA dosage rate in the design range (10-30%) did not affect UCS performance significantly ($P > 0.05$). On the other hand, PF (0-1%) and CT (0-14 days) have been found to be statistically significant ($p < 0.05$).

In the another investigation, Güllü and Fedakar (2017c) studied the reusability of sludge ash (SA) as an additive with PF to stabilize the marginal sand, based on the compressive strength performances from UCS tests. They also demonstrated that, the strain hardening behavior was achieved when 30% SA and 2% PF were used. In addition, at fiber content of 0.5%, this result is consistent with the results of the present study.

Canakci *et al.* (2019) investigated the potential application of a geopolymer, slag, glass powder, metakaolin, marble powder, bottom ash, rice husk ash, and silica fume to enhance the mechanical performance of clayey soil using a deep mixing technique. They also found various failure modes surveyed for soilcrete specimens. According to the results, there is a brittle behavior in stress-strain curves of all soilcrete specimens (Portland cement, geopolymer grouts). The post failure response was strain softening. This result is not consistent with the strain hardening behavior of the sand reinforced with fibers greater than 0.5%.

Güllü and Fedakar (2018) conducted another study on the effective dosages of SSA for subbase construction, using effect size estimation and factorial experimental approach. They also measured the parameters of energy absorption capacity and CBR value. Therefore, it is recommended to introduce SSA for treatment or replacement of sandy soil at the dosage rates of less than 50% in stabilization applications. In addition, alternative materials, such as randomly distributed fibers in the soil, can be used to improve soil condition.

In extending designs for alternative stabilizer to improve soils, it is always required to determine the effective amount of the stabilizer. Güllü (2014b) indicated that the bottom ash can be sufficiently added to the soil for proper stabilization (i.e., at 30% dosage) and replacement (i.e., below 30% dosage).

3.1 The effect of the fiber inclusion on strength at different strain level

Figs. 11-13 demonstrate the plots deviatoric stress values versus fiber inclusion at different strain levels of 0.5%, 1.0%, 1.5%, 3.0%, 6.0%, 9.0%, 12.0%, and 15% under different confining pressures of 70, 210, and 420 kPa.

It is revealed that, by increasing the fiber content, deviatoric stress (σ_d) is increased up to a specific fiber inclusion (this value of fiber inclusion varies with strain the level) and after that, either the value becomes almost

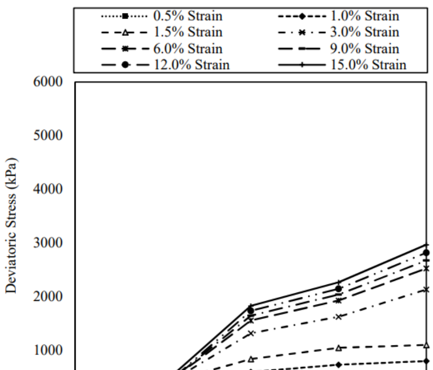

Fig. 11 The effect of strain level on the curves of σ_d versus fiber inclusion under $\sigma_3$3=70 kPa

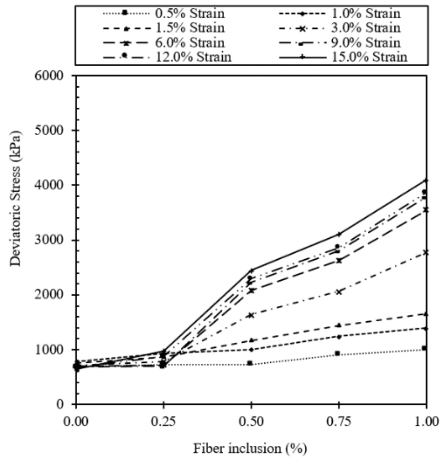

Fig. 12 The effect of strain level on the curves of σ_d versus fiber inclusion under σ_3=210 kPa

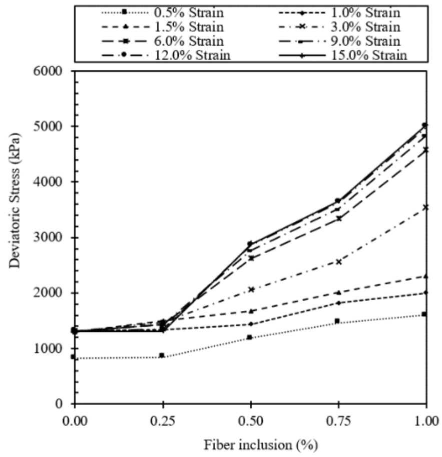

Fig. 13 The effect of strain level on the curves of σ_d versus fiber inclusion under σ_3=420 kPa

constant or the increase in σ_d is insignificant. The nature of the curves may be classified into two groups; one for the strain level of $\varepsilon \geq 3\%$ and another for $\varepsilon < 3\%$. For the first group (higher strain level), the fiber inclusion slightly increases the deviatoric stress. It means that the fiber content cause an internal confinement. Moreover, for the first group, the grow rate of σ_d is more than that of the second group, where the increase in the deviatoric stress is insignificant. Also, for lower values of strain ($\varepsilon < 3\%$), the σ_d value remains constant after reaching the maximum values. In this case, the optimum fiber content is up to 0.5% or 0.75% for different values of confining pressure.

In order to investigate the effect of different levels of strain on the shear strength of the fiber-reinforced and unreinforced sand, the ratio of the strength in the specified values of the strain was calculated by Eq. (2).

$$\text{Strength Ratio} = \frac{(\sigma_d)_{\varepsilon_i}^{Fiber-rein.}}{(\sigma_d)_{\varepsilon_i}^{unr.}} \tag{2}$$

In this equation, $(\sigma_d)_{\varepsilon_i}^{Fiber-rein.}$ and $(\sigma_d)_{\varepsilon_i}^{unr.}$ are the deviatoric stress for fiber-reinforced sand and unreinforced specimen at any strain level, respectively. According to Eq. (2), the strength ratios in the specified values of the strain can be calculated for various experimental cases. Figs. 14-16 demonstrate the results.

These figures show the similar trend of the curves for strength ratio versus fiber inclusion for different values of strain and under different values of confining pressure. The

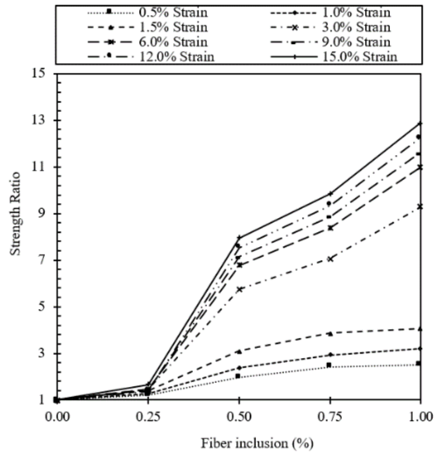

Fig. 14 Strength ratio versus fiber inclusion under 70 kPa confining pressure

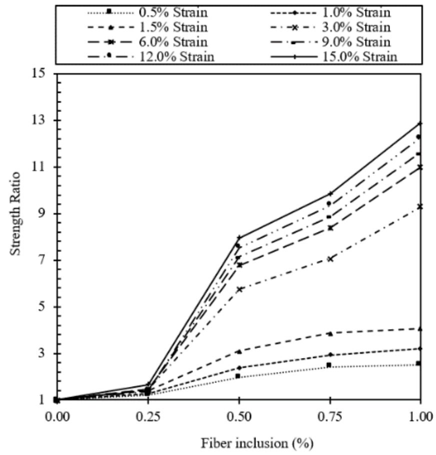

Fig. 15 Strength ratio versus fiber inclusion under 210 kPa confining pressure

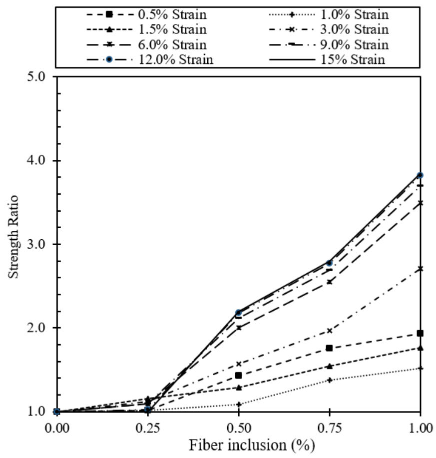

Fig. 16 Strength ratio versus fiber inclusion under 420 kPa confining pressure

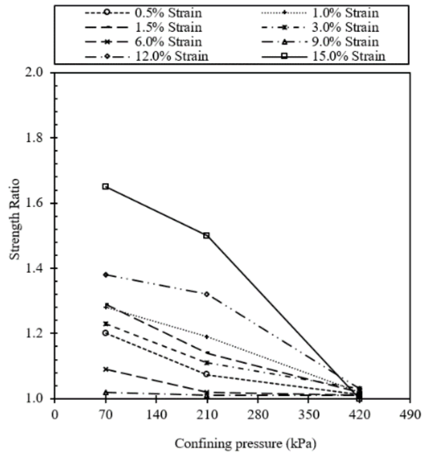

Fig. 17 Strength ratio versus confining pressure for 0.25% fiber content

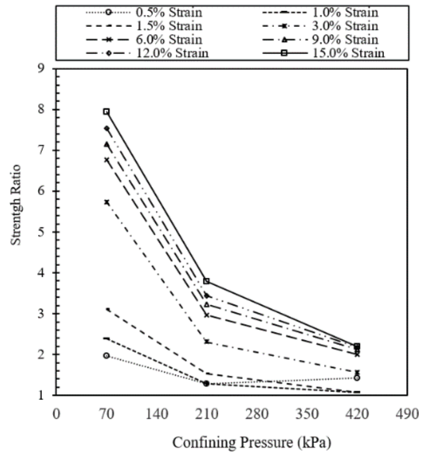

Fig. 18 Strength ratio versus confining pressure for 0.50% fiber content

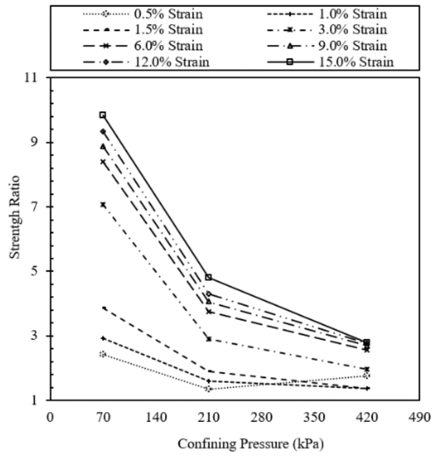

Fig. 19 Strength ratio versus confining pressure for 0.75% fiber content

graphs indicate that, there is a substantial increase in strength ratio due to the increase in the fiber content, irrespective of confining pressure. Furthermore, the increase rate is more clearly for high stain level. For example, in 0.5% fiber content under confining pressure of 50 kPa, the strength ratio increases about 179% (strength ratio =3.79)

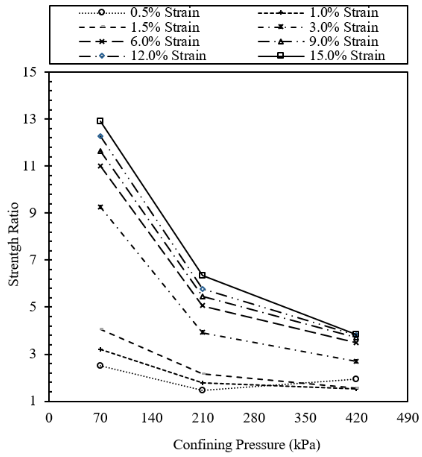

Fig. 20 Strength ratio versus confining pressure for 1.00% fiber content

for strain level 15%, whereas there is only 57% (strength ratio =1.57) increase under 1.5% strain level. Hence, the strength ratio (or strength) of fiber-reinforced sand compared to unreinforced sand should be considered at the specific level of strain, which is defined as allowable value to design.

3.2 The effect of confining pressure on strength at different strain levels

Figs. 17-20 show the variation of strength ratio versus confining pressure for different value of strain and different fiber inclusion. These figures illustrate that, for fiber content greater than 0.5% and higher value of strain ($\varepsilon \geq 3\%$), the strength ratio decreases by increasing the confining pressure.

For example, in 0.50% fiber inclusion and 3.0% strain level, the strength ratio increases about 472% (strength ratio = 5.72) under 70 kPa confining pressure, whereas there is only 57% (strength ratio = 1.75) increase under 420 kPa. This could be due to the decrease in the interaction between the date palm fibers and sand correlated with the increase in confining pressure. On the other hand, it indicates that, the fiber-reinforced is not very effective sand at high confining pressure (deep below the ground surface).

4. Practical application

The important aspect of specifying a maximum strength for a given soil by fiber reinforcing, is able to select a suitable relative density for the fiber content of sand at any confining pressure. Several studies have investigated the effect of fiber-reinforcement on shear strength of sand at failure strain. Evidently, in engineering application, the value of the strain (or settlement) should be limited to the value of the allowable strain.

Hence, the comparison of fiber-reinforced and unreinforced sand should be considered at different values of strain level. The results of this study indicate that, considering the level of strain imposed on the specimen play a considerable role on the behavior of fiber-reinforced sand. However, the obtained results can be applied for making initial estimates about the strength of the date palm fiber- reinforced sand in this study and the other studies with similar grading and characteristics.

The proposed strain values are subjected to limitations, such as fiber content, confining pressure, and safety factor. It seems that appropriate safety factor should be applied to the ultimate strength in order to calculate acceptable strength and to introduce corresponding strain as acceptable strain.

However, the results obtained in the present paper are encouraging to consider the role of strain on strength value of reinforced soil. Also, it should be noted that, as the triaxial specimens are relatively small to represent physical modeling of a reasonable prototype, the results obtained from these tests may not be representative of in situ performance, and these results were used in the context of a comparative study. Obviously, additional researches on larger scale tests, along with field tests would be required to extend the results to in-situ conditions.

5. Conclusions

This research was conducted to study the effect of strain level on strength evaluation of date palm fiber-reinforced sand. The results are summarized as follows:

1- The occurrence of a large number of failure planes in the fiber-reinforced sand specimens indicated the ability of fiber to withstand the strain.

2- The fiber inclusion, the levels of axial strain, and confining pressure are crucial quantities affecting the strength value of the fiber-reinforced sand. These factors can alter the strength value in the range of 10-1200%.

3- For fiber contents greater than 0.5% and strains higher than 3%, the strength ratio is decrease with an increase in confining pressure. It indicates that, the fiber-reinforced is not very effective at high confining (below the ground surface).

4- As the amount of palm fiber increased, several failure planes appeared in the specimens, which had a significant effect on increasing the energy absorption capacity, ductility, post-peak strength and strain-hardening behavior of fiber-reinforced sand.

5- The trend and magnitude of strength ratio can be changed by various strain levels. It implies that using failure strength from peak point or strength corresponding to the axial strain of approximately 15% for evaluating the strength ratio due to fiber-reinforced, may cause hazard and uncertainty in the practical design.

Consequently, the strength ratio at the imposed strain level should be considered.

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