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Research Article

Incorporating vegetal fibers for sustainable sandy soil

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Abstract: Incorporating fibers into the soil is a reinforcement remediation technique to improve its physical and mechanical properties. Depending on the type of fibers, synthetic fibers, have negative impacts on the environment linked to the waste of their chemical industry. Currently, vegetal fibers consider an economic and ecological alternative to soil reinforcement. Therefore, this study aims to evaluate the influence of two types of randomly distributed fibers (Alfa and Sisal fibers) on the mechanical properties of sandy soil. Direct shear tests were performed on Chlef sand at relative density (Dr = 75% and 40%) and of fiber contents varying from 1, 2, 3 and 4% for sand samples reinforced with Alfa fibers and 0.1, 0.3, 0.5 and 0.7% for sand samples reinforced with Sisal fibers. The test results show that the inclusion of vegetal fibers in sandy soil improves the peak and residual shear strength. In addition, soil resistance was found to attain a maximum with the optimums of 0.7% for sisal fiber content and 3% for Alfa fibers.

Keywords: Fiber reinforcement, optimum, sand, shear strength, vegetal.

1. Introduction

Earth reinforcement with synthetic materials has recently attracted the attention of geotechnical engineering researchers. Nowadays, the use of traditional geosynthetic materials (geotextile, geogrid, fiber, etc) is a reliable and effective technique in enhancing the strength and stability of soil. In particular, The use of randomly distributed fibers is considered a method of soil reinforcement, which contributes to the stability of the soil mass by increasing its resistance near the surface where the effective strength is low (Noorzad & Zarinkolaei, 2015). Fiber reinforcement technique has been investigated by various researchers (Ayhan & Edinçliler, 2010; Aziz, 2020; Benziane et al., 2022; D. Gray & Alrefeai, 1986; D. H. Gray & Ohashi, 1983; Maher & Woods, 1990; Prabakar & Ramachandran, 2002; Wiam, Della, Denine, Canou, & Dupla, 2018; Yetimoglu & Salbas, 2003) Through their experiments, they have shown that fiber reinforcement can significantly improve geotechnical proprieties of soil as strength and stiffness, mechanical characteristics, compaction characteristics and bearing capacity. The properties of reinforced soil by fiber are affected by different factors such as type of soil, type of fiber, fiber content, the density of fiber, fiber length, aspect ratio, and fiber soil surface friction (Diambra, Ibraim, Muir Wood, & Russell, 2010; Rajagopal, 2017). Previous experiments studies have shown that the inclusion of fiber in the soil can significantly increase the peak shear strength and limit the post-peak shear strength loss of soil as well as their mechanical characteristics. The types of fibers used in soil reinforcement can be classified into synthetic and natural fibers. Where each type has advantages and disadvantages. Though having the above-mentioned merits synthetic fibers have disadvantages, they are generally expensive and non-biodegradable (Maity, Chattopadhyay, & Mukherjee, 2012). On the other hand, plant fibers have many advantages such as low cost, easy processing, biodegradable and recyclable (Mavinkere Rangappa et al., 2022). Therefore, the use of plant fibers is an economical and environmental alternative to soil reinforcement, which makes it possible to combine environmental and technical performance. Previous studies and research have focused on the role of plant fibers such as coconut, jute, palm and sisal in the improvement of geotechnical characteristics of the soil.

Dasaka and Sumesh (2011) have been performed Triaxial compression tests on fine-grained soil (kaolin) reinforced by coir fiber with various contents and different lengths, showed that the addition of coir fibers improved shear strength parameters, The peak deviator stress and major principal stress at failure, and also increased the cohesion and friction angle. Prabakar and Ramachandran, Studied the effect of random inclusion of sisal fiber on the strength behavior of soil, reporting that the addition of sisal fiber reduces the dry density and improves the mechanical characteristics of the soil.

Alfa plant, also called Esparto or scientific name is Stippa-Tenacissima, is indigenous to northern Africa and southern of Europe (Cerdà, 1997) . It covers about 7,600,000 ha on the steppe region of Algeria, Morocco and Tunisia (Rhanem, 2009). This laboratory study focuses on investigating the efficient use of vegetal fiber reinforcement on the mechanical properties of sandy soil as an alternative to synthetic fibers. For this, a series of direct shear tests were carried out on Chlef sand reinforced with natural fibers such as sisal and Alfa fibers, were randomly distributed. In order to evaluate their shear strength behavior and to determine the contribution of these fibers to improve the mechanical properties of the soil. The obtained results have shown that the inclusion of vegetal fibers in sandy soil improves the peak and residual shear strength. Also, enhance the cohesion and friction angle.

2. Materials and methods

2.1. *Materials*

2.1.1. Sand

The soil used was mined in and around the Chlef river Chlef province, Algeria. Many studies were conducted on this soil and its physical and mechanical properties have been examined by numerous researchers (Adda Berkane et al., 2022; Bouri, Krim, Brahimi, & Arab, 2019; Della, Muhammed, Canou, & Dupla, 2016; Denine et al., 2021). The maximum void ratio (emax) corresponding to the loosest state of the soil sample and minimum void ratio (emin) corresponding to the densest state of the soil sample were determined according to ASTM D4253 (ASTM, 2006a) and ASTM D4254 (ASTM, 2006b) standards. The grain size distribution curve of the sand was obtained based on the ASTM D422-63 (ASTM, 2002) standard, the curve is presented in Figure 1. According to the unified soil classification system (USCS), the soil is classified as poorly graded sand (SP). The basic properties of sand are summarized in Table 1.

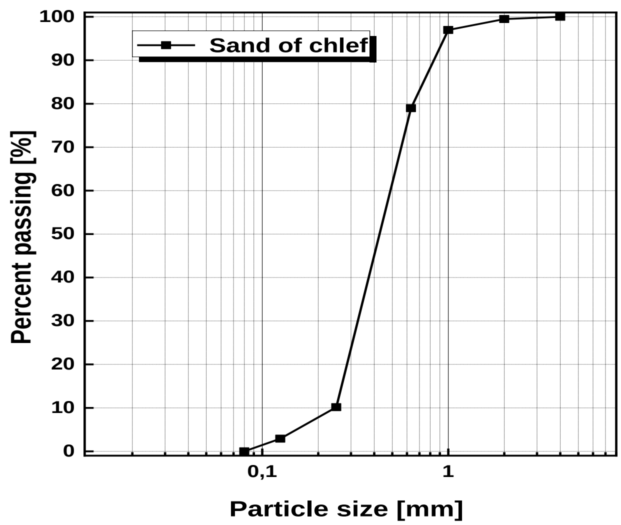


Figure1. Grain size distribution curve of the tested material.

Table 1. Physical properties of sand.

	Properties of sand	Values
a	Specific density, G_S (g/cm^3)	2.67
b	Medium size, D_{50} (mm)	0.427
c	Uniformity coefficient, C_U	1.98
d	Coefficient of curvature, C_C	2.70
e	Minimum void ratio, e_{min}	0.60
f	Maximum void ratio, e_{max}	0.87

2.1.2. Fibers

Two different types of natural fibers were used in this study, namely Alfa fiber and sisal fiber. Alfa fiber is obtained from the esparto plant (Stipa tenacissima), which is used by artisans in traditional industries. Where it randomly resides in the Mediterranean basin (Algeria, Libya, Tunisia, Morocco). Then it was sorted and chopped into pieces of lengths 12 mm. figure 2 illustrate mixture of Alfa fiber and sand.

Figure 2. Mixture of alfa fiber and sand.

Sisal is a leaf fiber with high strength and good toughness and is one of the most multifunctional and commercial natural fibers. Nowadays, is uses in the geotechnical engineering. In this study, the commercial product sisal fiber was provided and chopped into 12 mm length pieces. Figure 3 shows the image of a mixture sisal fiber-sand. The mechanical properties of the fibers are presented in Table 2.

Figure 3. Mixture of Sisal fiber and sand.

Table 2. The mechanical properties of the fibers.

Properties of Fiber	ALFA	Sisal
Specific density, G_S (g/cm^3)	1,52 (Dallel, 2012)	1.3 (Saheb & Jog, 1999)
Tensile strength, MPa	75 – 154 (Dallel, 2012)	510 (Saheb & Jog, 1999)
Young’s modulus (GPa)	12,7 (Dallel, 2012)	28 (Saheb & Jog, 1999)

2.2. *Experimental samples preparation and tests*

To study the effect of adding two types of natural fiber randomly distributed in sandy soil on the shear strength. A series of 36 direct shear tests were carried out on Reinforced and unreinforced sand. Alfa Fiber-reinforced sand mixtures and sisal fiber sand mixtures were prepared with proportions (1, 2, 3, 4%) and (0.1, 0.3, 0.5, 0.7%) respectively. specimens were prepared using the dry method, thus, the calculated mass (by equation 01) of fibers was mixed in small increments by hand to achieve a uniform mixture. For ensure sample homogeneity both in relative density and in fiber arrangement, each sample was prepared into three parts. The samples were placed in three layers in a rectangular shear box with dimensions of 60 mm × 60 mm × 25 mm. Each layer is compacted to a desired density by measuring the height of the layer during the compaction process in order to obtain an average sample density of Dr = 75% or Dr = 40% . After that, was started the shear test of the sample.

Table3. The Parameters of the experimental program

Type of Samples		Vertical stress (kPa)	fiber contents %	Relative density (%)	Number of tests
Unreinforced Sand		50	/	75, 40	2
		100	/	75, 40	2
		200	/	75, 40	2
Fiber reinforced Sand	Alfa fiber	50	1, 2, 3,4	75 (or 40 for 0,75 % of fiber content)	5
		100	1, 2, 3,4		5
		200	1, 2, 3,4		5
	Sisal fiber	50	0.1, 0.3, 0.5, 0.7	75 (or 40 for 3% of fiber content)	5
		100	0.1, 0.3, 0.5, 0.7		5
		200	0.1, 0.3, 0.5, 0.7		5
Total					36

These tests were carried out on all samples using an automatic direct shear-testing machine (UTS-2060.SMPR). The horizontal shearing was performed at a constant displacement rate of 1.00 mm/min. Horizontal load, horizontal and vertical displacements were acquired automatically via load unit of apparatus with the (USOFT-2060) software. Tests was performed at three different vertical normal stresses of 50, 100 and 200 kPa in order to define the shear strength parameters for both unreinforced and fiber-reinforced sand. Table 3 shows all parameters considered in the experimental program.

$$Fc = \frac{Mf}{Ms} * 100\% \quad (1)$$

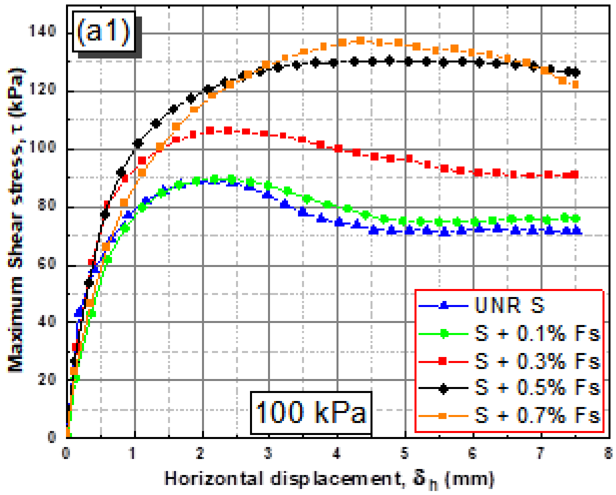
3. Experimental results and discussion

The direct shear tests were carried in this study in order to evaluate the shear behavior response and mechanical characteristics of reinforced sand incorporated with two natural fiber types.

3.1. Shear behavior of unreinforced and reinforced sand

Figures 4 a and b show the shear strength versus horizontal displacement of sandy soil mixed with the sisal and Alfa fiber respectively at different percentages and under normal stress equal to 100 kPa and 50 kPa with a relative density of 75%. It was shown by these curves that with the increase of horizontal displacement, the shear stress increases when the horizontal displacement is less than about 1 mm, then the shear stress gradually increases by smaller degrees until a peak strength is attained. After which, the resistance decreases followed by a residual resistance at the end of shearing process. Figure 4a showed that the increase in sisal fiber content increased the shear strength.

However, Figure 4b showed that increasing Alfa fiber content up to 3% increases shear strength. At 4% Alfa fiber content, a small decrease in shear strength was observed. Other authors also was observed similar results for fiber-reinforced soil (Benziane, Della, Denine, Sert, & Nouri, 2019; Meddah & Merzoug, 2017). Moreover, the result shows that the inclusion of sisal fibers greatly enhances the residual shear stress and limit the post-peak strength of reinforced sand. Figure 5 a and b illustrate the variation of the vertical displacement versus the horizontal displacement of unreinforced and reinforced sand with sisal and Alfa fibers, respectively; At varying ratio of soil-fiber mixtures, for applied normal stress equal to 100 kPa. Overall, the shape of these curves showed an initially limited contraction followed by dilation.



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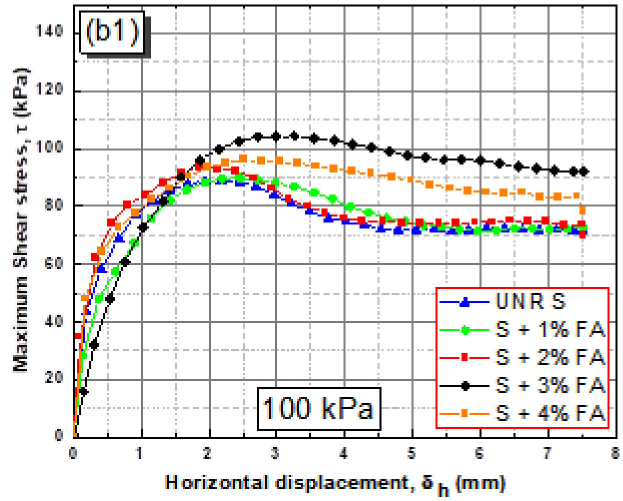

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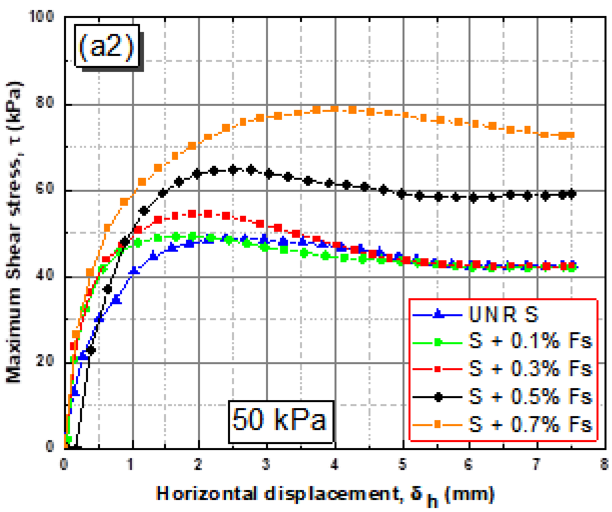

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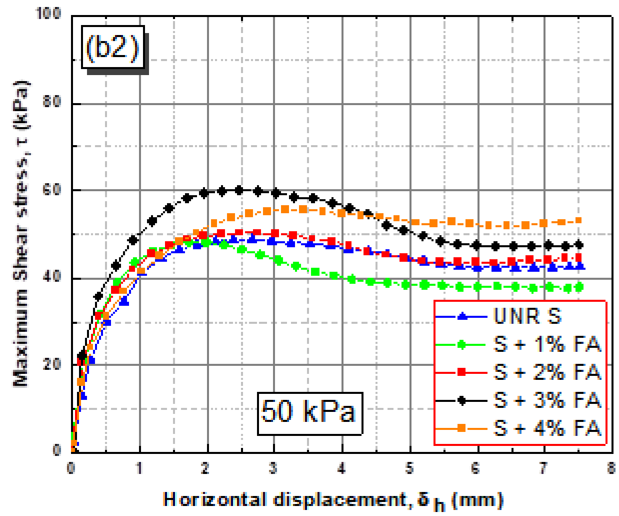
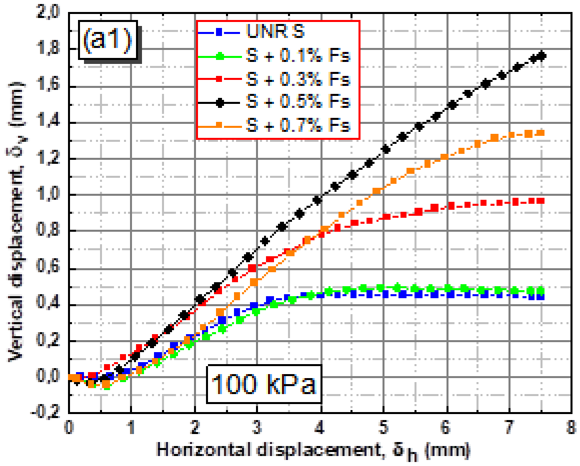


b)

Figure 4. Shear behavior of fiber reinforced sand, shear stress as a function of horizontal displacement, (**σ**N=50 kPa and **σ**N=100 kPa); Dr=75%: (a) Sisal fiber (Fs), (b) Alfa fiber (FA).



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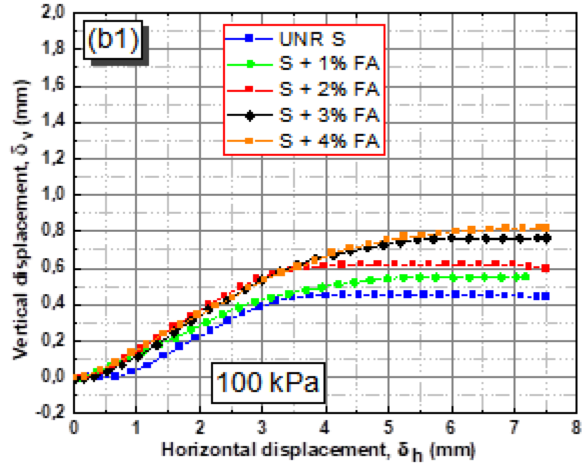

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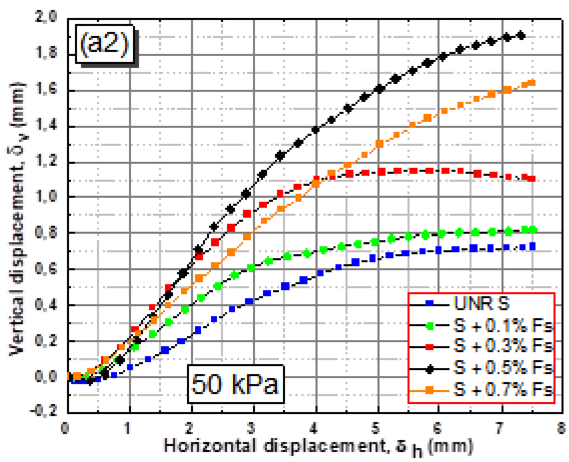

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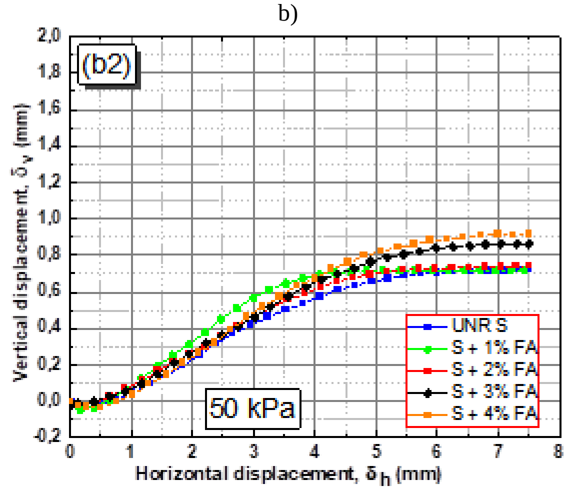

b)

Figure 5. Shear behavior of fiber reinforced sand: Vertical displacement as a function of horizontal displacement, (**σ**N=100 kPa, Dr=75%): (a) Sisal fiber (Fs), (b) Alfa fiber (FA).

Figure 5 (a1) shows that adding of sisal fiber increases the dilation tendency in the sand and significantly for higher fiber contents, where the final vertical displacement of unreinforced sand increased from 0.45 mm to 1.77 mm when adding 0.7% of sisal fibers while adding the Alfa fiber until 3%. Figure 5 b1 demonstrates that the increasing in amount of Alfa fiber increases the dilation of sand, where the final vertical displacement increases to 0.82 mm. In addition, it can note that the addition of sisal fiber increases the dilation behavior of sand more than addition of Alfa fiber. Benziane. M. M et al. (2019) reported a similar observation for sandy soil reinforced with polypropylene fiber.

3.2. Influence of relative density

Figures 6 show the shear strength versus horizontal displacement of sandy soil mixed with the sisal and Alfa fiber by 0,75 % and 3% of fiber content respectively, under normal stress equal to 50 kPa with tow relative densitys of 75% and 40 % .The results show that the strength of sand reinforced with sisal and alpha fibers increases with the increase of the relative density. This finding coincides with those of Benziane. M. M et al. (2019).

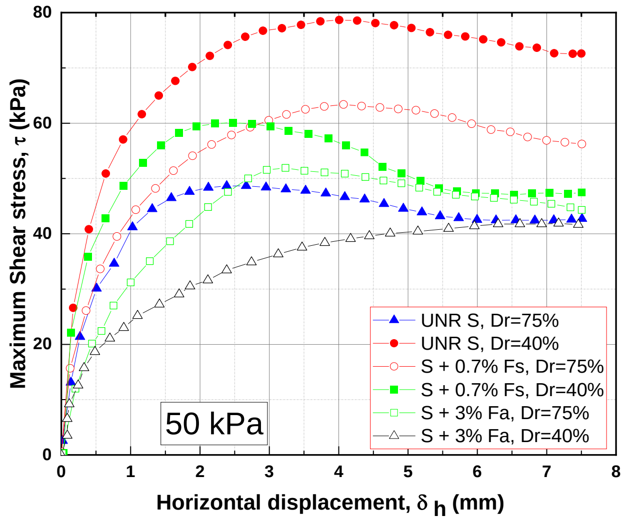

Figure 6. Shear behavior of fiber reinforced sand, shear stress as a function of horizontal displacement, (**σ**N=50 kPa); Dr=75%: and Dr=40%.

3.3. *Influence of fiber content on maximum shear strength and strength ratio*

Figure 7 shows the evolution of the maximum shear strength as function of fiber content for three applied normal stresses 50, 100 and 200 kPa. Results show that increasing normal stress increases the maximum shear strength considerably. Figure 7a presents the effect of sisal fiber content on the maximum shear strength, it can be seen that the maximum shear strength of the reinforced sand by sisal fiber increases with an increase of fiber content according to a quasi-linear growth. Where the value of unreinforced sand obtained were 46.6, 88.9 and 182.1 kPa under normal stresses 50, 100 and 200 kPa, respectively, which was increased to 78.7, 137.4 and 223.2 kPa when adding 0.7% sisal fiber content. The effect of Alfa fiber content on maximum shear strength is illustrated in Figure 7b. The result indicates that the augmentation in fiber content until 3% increases the maximum shear strength under normal stresses. However, the maximum shear strength tends to decrease after reaching the optimum fiber content under all applied normal stresses. S. K. Patel and B. Singh. (2019) reported the optimum ratio of glass fiber to improve the strength of sandy soil at 3%.

Table 4 summarizes the results of shear strength ratios (SsR) of reinforced sand with various fiber contents of sisal and Alfa fibers, under three normal stresses 50, 100 and 200 kPa. It is noted from the results that the strength ratio is increased as fiber content increases. However, regarding alfa fiber reinforced samples; it is observed that the strength ratio decreased after reaching a fiber content of 4%. The highest strength ratio value was obtained for reinforced sand samples with 0,7% of sisal fiber. In addition, these results indicate that the augmentation of normal stress reduces the strength ratio of fiber-reinforced sand.

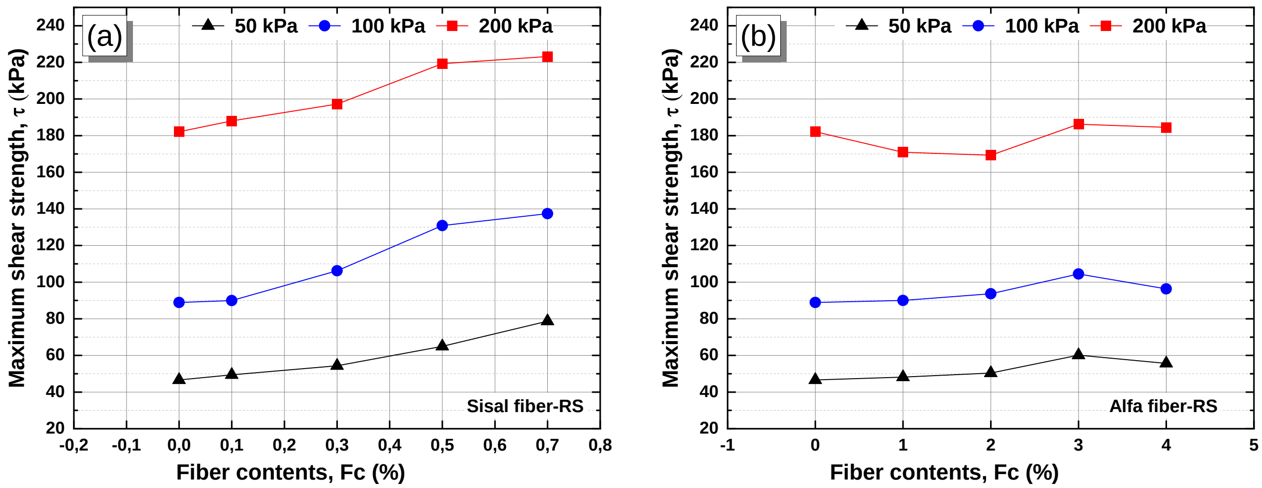

Figure 7. Effect of fiber content on maximum shear strength: (a) Sisal fiber (Fs), (b) Alfa fiber (FA).

Table 4. Strength ratio values.

Samples	Fc (%)	τ_{max} (kPa)			S_s R (-)		
		σ_n=50 kPa	σ_n=100 kPa	σ_n=200 kPa	σ_n=50 kPa	σ_n=100 kPa	σ_n=200 kPa
Pure Sand	0	46.6	88.9	182.1	-	-	-
Sand _Sisal Fiber (Fs)	0.1	49.4	90	188.1	1.06	1.01	1.03
	0.3	54.3	106.2	197.3	1.17	1.19	1.08
	0.5	65	130.9	219.3	1.39	1.47	1.2
	0.7	78.7	137.4	223.2	1.69	1.55	1.23
Sand _Alfa Fiber (FA)	1	48.2	90	170.9	1.03	1.01	0.94
	2	50.4	93.7	169.3	1.08	1.05	0.93
	3	60.2	104.5	186.2	1.29	1.17	1.02
	4	55.7	96.3	184.5	1.19	1.08	1.01

3.4. Effect the fiber reinforcement on the mechanical characteristics of sand

Figures 8a and 8b show the Mohr-Coulomb failure line that represents the relationship between the maximum shear stress and the normal stress of unreinforced and reinforced sand by sisal and Alfa fiber, it was noted that maximum shear strength increases with an increase in normal stresses. From these figures, the mechanical characteristics (cohesion and friction angle) were evaluated according to :

$$\tau = Tng(\phi) * \sigma_N + C \quad (2)$$

Table 5 summarizes cohesion and angle friction values. It can be seen these mechanical characteristics vary according to the type and amount of added fiber in the soil. It should be noted that the cohesion has been greatly increased with the increase of sisal fibers content. Whereas, for alfa reinforced sand, it has observed an increase in cohesion with an increase in fiber content to a maximum of 3 %. Compared with unreinforced (cohesionless) sand, the cohesion improves to 35.84 and 20.49 kPa when added of 0.7% sisal fiber and 3% Alfa fiber, respectively. Moreover, the friction angle was found to increase by adding more content of sisal fiber where it was insignificant for sand reinforced with Alfa fiber.

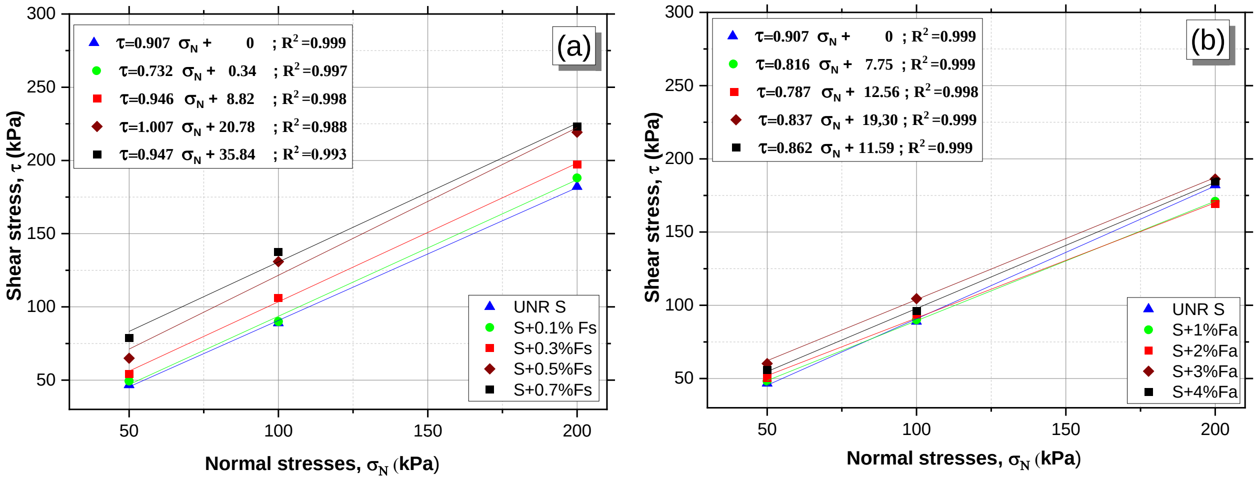

Figure 8. Mohr–Coulomb intrinsic curves of reinforced sand: (a) sisal fiber (Fs), (b) alfa fiber (FA)

Table 5. Mechanical characteristics of sand_ fiber mixtures.

Samples	Fc (%)	C (kPa)	ϕ (°)
Pure Sand	0	0	42.20
Sand _Sisal Fiber (Fs)	0.1	0.34	42.98
	0.3	8.82	43.41
	0.5	20.78	45.20
	0.7	35.84	43.44
Sand _Alfa Fiber (FA)	1	7.75	39.21
	2	12.56	38.20
	3	19.30	39.95
	4	11.59	40.76

4. Conclusions and comments

In this study, a series of direct shear tests were carried on unreinforced sand and reinforced with two types of randomly distributed fibers as Sisal and Alfa fibers with fibers inclusion on the mechanical properties of sand. Based on these results the following conclusions were obtained:

1. The addition of 0.7% sisal fibers and 3% Alfa fibers in the sand increases the maximum shear strength by 1.69 and 1.29 times, respectively, compared to the unreinforced sand under the normal pressure of 200 kPa. Moreover, the inclusion of sisal and alfa fibers enhances the residual shear stress and limits the post-peak strength of sand.
2. Fiber inclusion increases the dilation tendency of sandy soil. It was observed that this dilative behavior is more pronounced at higher fiber percentages.
3. Inclusion of sisal and alpha fibers in sand improves cohesion by 35% and 20% compared to unreinforced sand. Moreover, it was found sisal fibers slightly increase the friction angle of soil.
4. The improvement in shear strength is greater for samples with high relative density, i.e. in dense soils
5. Sisal and Alfa fibers are considered sustainable alternatives to soil strengthening.

Nomenclature

F_s Sisal fiber
F_a Alfa fiber
F_c Fiber content, (%)

M_f	Mass of fibers, (g)
M_s	Mass of dry sand, (g)
S_sR	Strength ratio, (-)
τ_{max}	Maximum shear strength, (kPa)
τ	Shear strength, (kPa)
σ_N	Normal stress, (kPa)
δ_h	Horizontal displacement, (mm)
δ_v	Vertical displacement, (mm)
C	Intercept cohesion, (kPa)
ϕ	Friction angle, (°)

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References

Adda Berkane, H., Della, N., Benziane, M. M., Denine, S., Elroul, A. B., & Feknous, H. (2022). Laboratory investigation on the effect of a combination of xanthan gum and clay on the behavior of sandy soil. Innovative Infrastructure Solutions, 7(4), 269. doi: 10.1007/s41062-022-00867-z

ASTM. (2002). ASTM D422-63, Standard test method for particle-size analysis of soils: ASTM international: West Conshohocken, PA, USA.

ASTM. (2006a). ASTM D4253-00, Standard test methods for maximum index density and unit weight of soils using a vibratory table: ASTM international: West Conshohocken, PA, USA.

ASTM. (2006b). ASTM D4254-00, Standard test methods for minimum index density and unit weight of soils and calculation of relative density: ASTM international: West Conshohocken, PA, USA.

Ayhan, V., & Edinçliler, A. (2010). Influence of tire fiber inclusions on shear strength of sand. Geosynthetics International - GEOSYNTH INT, 17, 183-192. doi: 10.1680/gein.2010.17.4.183

Aziz, M. (2020). Engineering properties of expansive soil treated with polypropylene fibers. Geomechanics and Engineering, 22, 227-236. doi: 10.12989/gae.2020.22.3.227

Benziane, M. M., Della, N., Denine, S., Sert, S., & Nouri, S. (2019). Effect of randomly distributed polypropylene fiber reinforcement on the shear behavior of sandy soil. Studia Geotechnica et Mechanica, 41(3), 151-159. doi: doi:10.2478/sgem-2019-0014

Benziane, M. M., Della, N., Sert, S., Denine, S., Nouri, S., Bol, E., & Elroul, A. B. (2022). Shear behaviour of sandy soil from Chlef river reinforced with different types of fibres. Marine Georesources & Geotechnology, 40(10), 1232-1241. doi: 10.1080/1064119x.2021.1984619

Bouri, D. E., Krim, A., Brahimi, A., & Arab, A. (2019). Shear strength of compacted Chlef sand: effect of water content, fines content and others parameters. Studia Geotechnica et Mechanica, 42, 18–35. doi: 10.2478/sgem-2019-0027

Cerdà, A. (1997). The effect of patchy distribution ofStipa tenacissimaL. on runoff and erosion. Journal of Arid Environments, 36(1), 37-51. doi: https://doi.org/10.1006/jare.1995.0198

Dallel, M. (2012). Evaluation of textile potential of Alfa (Stipa Tenacissima L.) fibers : Physico-chemical characterization from fiber to yarn. Haute Alsace - Mulhouse university. Retrieved from https://tel.archives-ouvertes.fr/tel-00844129

Dasaka, S. M., & Sumesh, K. S. (2011). Effect of Coir Fiber on the Stress–Strain Behavior of a Reconstituted Fine-Grained Soil. Journal of Natural Fibers, 8(3), 189-204. doi: 10.1080/15440478.2011.601597

Della, N., Muhammed, R. D., Canou, J., & Dupla, J.-C. (2016). Influence of Initial Conditions on Liquefaction Resistance of Sandy Soil from Chlef region in Northern Algeria. Geotechnical and Geological Engineering, 34. doi: 10.1007/s10706-016-0077-8

Denine, S., Della, N., Muhammed, R. D., Feia, S., Canou, J., & Dupla, J.-C. (2021). Triaxial behaviour of geotextile reinforced sand. Geomechanics and Geoengineering. doi: 10.1080/17486025.2021.1986235

Diambra, A., Ibraim, E., Muir Wood, D., & Russell, A. R. (2010). Fibre reinforced sands: Experiments and modelling. Geotextiles and Geomembranes, 28(3), 238-250. doi: https://doi.org/10.1016/j.geotexmem.2009.09.010

Gray, D., & Alrefeai, T. (1986). Behavior of Fabric-Versus Fiber-Reinforced Sand. Journal of Geotechnical Engineering, 112. doi: 10.1061/(asce)0733-9410(1986)112:8(804)

Gray, D. H., & Ohashi, H. (1983). Mechanics of Fiber Reinforcement in Sand. Journal of Geotechnical Engineering, 109(3), 335-353. doi: doi:10.1061/(ASCE)0733-9410(1983)109:3(335)

Maher, M., & Woods, R. (1990). Dynamic Response of Sand Reinforced with Randomly Distributed Fibers. Journal of Geotechnical Engineering, 116. doi: 10.1061/(asce)0733-9410(1990)116:7(1116)

Maity, J., Chattopadhyay, B. C., & Mukherjee, S. P. (2012). Behaviour of Different Types of Sand Randomly Mixing with Various Natural Fibers. Journal of The Institution of Engineers (India): Series A, 93(2), 97-104. doi: 10.1007/s40030-012-0014-7

Mavinkere Rangappa, S., Puttegowda, M., Parameswaranpillai, J., Siengchin, S., Ozbakkaloglu, T., & Wang, H. (2022). Chapter 1 - Introduction to plant fibers and their composites. In S. Mavinkere Rangappa, J. Parameswaranpillai, S. Siengchin, T. Ozbakkaloglu & H. Wang (Eds.), Plant Fibers, their Composites, and Applications (pp. 1-24): Woodhead Publishing.

Meddah, A., & Merzoug, K. (2017). Feasibility of using rubber waste fibers as reinforcements for sandy soils. Innovative Infrastructure Solutions, 2(1), 5. doi: 10.1007/s41062-017-0053-z

Noorzad, R., & Zarinkolaei, S. (2015). Comparison of Mechanical Properties of Fiber-Reinforced Sand under Triaxial Compression and Direct Shear. Open Geosciences, 7. doi: 10.1515/geo-2015-0041

Patel, S. K., & Singh, B. (2018). Experimental Study on Shear Strength Behavior of Glass Fiber-Reinforced Sand. Enhancements in Applied Geomechanics, Mining, and Excavation Simulation and Analysis.

Prabakar, J., & Ramachandran, S. S. (2002). Effect of random inclusion of sisal fibre on strength behaviour of soil. Construction and Building Materials, 16, 123-131. doi: 10.1016/s0950-0618(02)00008-9

Rajagopal, S. (2017). A Review on performance of coir fiber reinforced sand. International Journal of Engineering and Technology, 9, 249-256. doi: 10.21817/ijet/2017/v9i1/170901428

Rhanem, M. (2009). L'alfa (Stipa tenacissima L.) dans la plaine de Midelt (haut bassin versant de la Moulouya, Maroc) – Éléments de climatologie. Physio-Géo. doi: 10.4000/physio-geo.696

Saheb, D. N., & Jog, J. P. (1999). Natural fiber polymer composites: A review. Advances in Polymer Technology, 18(4), 351-363. doi: https://doi.org/10.1002/(SICI)1098-2329(199924)18:4<351::AID-ADV6>3.0.CO;2-X

Wiam, K., Della, N., Denine, S., Canou, J., & Dupla, J.-C. (2018). Undrained behaviour of polypropylene fibre reinforced sandy soil under monotonic loading. Geomechanics and Geoengineering, 14, 1-11. doi: 10.1080/17486025.2018.1508855

Yetimoglu, T., & Salbas, O. (2003). A study on shear strength of sands reinforced with randomly distributed discrete fibers. Geotextiles and Geomembranes - GEOTEXT GEOMEMBRANE, 21, 103-110. doi: 10.1016/s0266-1144(03)00003-7