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PRACTICE-ORIENTED PAPER

Feasibility of using rubber waste fibers as reinforcements for sandy soils

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Abstract In this study, an alternative and environmentally friendly method for the reinforcement of dune sand is proposed. This technique consists of using randomly distributed rubber fibers to improve the engineering properties of sand. Rubber fibers are added to the sand with different percentages: 0.25, 0.5, 0.75, 1, 1.25, 1.5, 1.75 and 2% of dry weight of sand. The experimental program carried out consists of investigating the effect of rubber fibers on the shear strength properties of sand. Reinforced and unreinforced samples are tested in the dense as well as loose state. The results obtained showed that the inclusion of rubber fibers in dune sand will improve the engineering properties of various civil engineering applications such as shallow foundations and slope. Therefore, incorporation of rubber fibers can enhance the shear strength characteristics, peak and residual strengths, and introduce more ductility to the mechanical behavior of sand. In addition to the technical effect, this paper emphasizes another environmentally attractive option, which is the use of rubber fibers as reinforcements for granular soils as this helps to remove some parts of these wastes and protect the environment.

Keywords Rubber waste · Fibers · Reinforcement · Dune sand · Shear strength · Valorization

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Introduction

One of the main activities of civil engineers is to improve the mechanical properties of soils and/or to limit the deformations under existing structures. Several techniques are used to stabilize many geotechnical applications such as retaining walls and embankments to subgrade stabilization beneath footings and pavements. Soils are commonly stabilized by adding cementitious materials such as cement, lime, steel slag and/or by incorporating reinforcements such as strips, sheets, grids, bars, or fibers [6, 19].

Reinforcing soils can be principally realized using previously oriented continuous geosynthetic or steel elements [16], or using aleatorily oriented discrete fibers. In the first technique, the shear tensile strength in soils surrounding the reinforcement increases, which promotes the appearance of shear plans at the inclusions and affects both local and global stability of earth-based structures, especially when several layers of continuous reinforcements exist. However, in the second case, randomly distributed fibers reduce the formation of weak planes, which could increase the long-term stability of reinforced earth-based structures [3]. Reinforcing soils with short fibers has been increasingly investigated by researchers both in theory and in practice due to its advantages. Tang et al. [20] have reported that using randomly distributed fiber as reinforcements exhibits several advantages in comparison with planar geosynthetics including: discrete fibers can be simply added and mixed with soil, in much the same way as cement, lime and other additives; randomly distributed fibers can limit the potential planes of weakness that can develop parallel to conventional oriented reinforcement, and provide isotropic increase in the strength of the soil composite. Randomly distributed fibers can be distinguished by its material; in fact, many types of fibers are

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used by researchers for reinforcing both granular and cohesive soils, such as polypropylene fibers [8, 20], vegetal fibers [12], polyethylene terephthalate fibers [3], linen fibers [10] and glass fibers [1].

The important increase in the number of vehicles in last decades is accompanied by rapid growing amounts of rubber tire wastes. The United States has about 275 million scrap tires stockpiled across the country. Rubber wastes are considered as one of the major waste problems for all countries due to their direct effect on environment and human health, contaminating soils, water and air. Therefore, rubber wastes are not bio-degradable and can form a favorable environment for breeding rats, mice, vermin and mosquitoes [14, 15, 17]. Furthermore, the storage of this type of wastes in landfills in high volumes could be a serious problem in case of eventual fire, due to their potential to generate toxic fumes. Although, the management of this type of solid wastes in civil engineering applications constitutes an ecological and economical challenges due to their major impact on environment. This may help preserving natural resources and producing an eco-friendly material. On the other hand, geotechnical applications need high volume of soils which helps consuming a large quantity of wastes [15]. Balunaini et al. [2] reported that rubber waste can be used in several civil engineering applications such as embankment fill material, drainage material, vibration dampening material underneath railways, thermal insulation layer and asphalt rubber paving layer. In addition, rubber wastes were used as fine and coarse aggregates in concrete material as reported in several investigations [7, 9, 13, 18, 21].

The potentialities of using shredded rubber waste as back fill material for geotechnical applications, such as highway embankments and retaining walls, were investigated by many studies [4, 11, 23]. In these works, authors have analyzed the effects of the inclusion of shreds rubber on the engineering properties of soils such as shear strength. However, there is no available information on the behavior of sandy soils containing rubber waste as fibers.

The main objective of this work is to investigate the possibility of reinforcing dune sand by randomly distributed rubber fibers. The fibers were incorporated in sand with rates of 0.25, 0.5, 0.75, 1, 1.25, 1.75 and 2% dry weight of sand. A series of standard shear tests are carried out to study the effect of confining pressure, relative density and rubber fibers content on the shear strength properties of dune sand.

Materials and procedures

The soil used in this study is dune sand taken from Boussaâda Region in Algeria. Previous geotechnical study carried out by Meddah [13] indicated that foundations soils of this region are composed mainly of a large layer of dune sand with several meters of depth. The physical properties of this sand, usually used in Algeria for construction and transportation field, are shown in Table 1, while its particle size distribution and granulometric characteristics are shown in Fig. 1. According to the Laboratory of Roads and bridges classifications (French classification), this sand is considered as poorly graded sand. Rubber fibers were provided from Algerian company of Elastomeric Materials in Algiers. The specific gravity of fibers is 0.88. Its length is varied from 3 to 16 mm and its diameter is ranged between 0.2 and 0.5 mm. The aspect of rubber fibers used is shown in Fig. 2.

Ibraim et al. [8] have indicated that several different techniques can be used for the preparation of samples of granular reinforced soils in the laboratory. In fact, the soil may be dry, moist or saturated; it may be placed by pluviation through air, spooning or pouring, and may be densified by tamping, tapping or vibration. In the present study, test specimens are prepared by the dry pluviation of reinforced and unreinforced sands in the shear box. This technique is chosen as the dune sand is generally deposited in the arid zones by Aeolian processes. Soil and fibers are previously mixed in a container for a homogenous distribution of fibers and to reduce the variability of samples. The desired density is obtained by measuring the height of specimens and using a wooden hammer for compaction. As the sandy soils behavior is related to the density, the behavior of the tested sands is studied at loose state as well as dense state, with and then without fibers. Despite the limitation of direct shear test, it is always the common procedure used in laboratories for evaluating strength characteristics of soils due to its simplicity compared to the triaxial test. Therefore, both reinforced and unreinforced sand specimens are sheared in automatic standard shear box, at rate of 0.9 mm/min.

Results and discussion

Shear stress curves

The effect of incorporation of randomly distributed rubber fibers on the mechanical properties of sandy soils is investigated by conducting direct shear tests. To quantify this effect, rubber fibers content is incrementally increased from 0 to 2% with rate of 0.25% dry weight of sand. Moreover, it is well known in geotechnics that the mechanical properties of granular soils are mainly related to their density. Therefore, two series of shear tests are carried out in this investigation, according to the level of densification achieved. In fact, test samples are tested at loose state in which reinforced sand is placed simply in

Table 1 Properties of the sand used

Parameter	Symbol	Range of variation	Average
Specific weight	γs (g/cm^3)	2.65–2.68	2.67
Sand equivalent	ES (%)	82.35–85.86	84.12
Maximum dry density	$\gamma dmax$ (g/cm^3)	1.71–1.72	1.72
Minimum dry density	$\gamma dmin$ (g/cm^3)	1.48–1.5	1.5

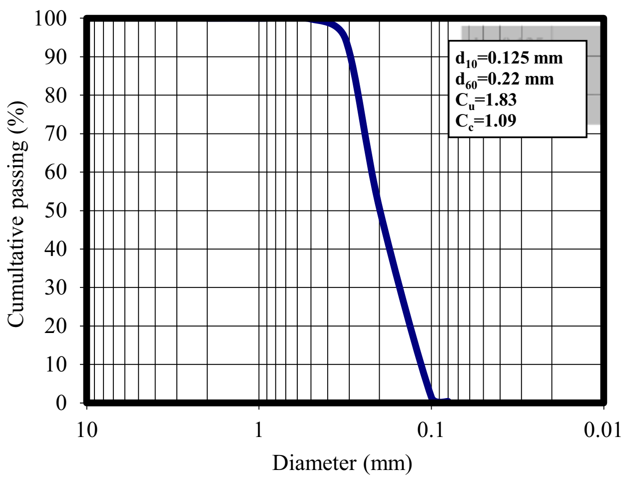

Fig. 1 Granulometric size distribution

Fig. 2 Rubber fibers used

shear box without any compaction effort and at dense state in which reinforced and unreinforced sand specimens are compacted for achieving the desired density by controlling its height in the shear box. As the shear strength behavior of sandy soils is dependent on the applied confining pressure, both reinforced and unreinforced sand samples are subjected to three normal stresses (100, 200 and 400 kPa).

The relationships between the shear stress and the horizontal displacements, for the loose reinforced sand, are shown in Figs. 3, 4, 5 while for the dense reinforced sand are shown in Figs. 6, 7, and 8. It can be seen from the results that the stress–displacement responses, for both reinforced and unreinforced sand, are affected simultaneously by rubber fibers content, level of densification achieved, and by normal stress intensity applied during shearing.

From the obtained results, it can be seen that the trends of behavior curves for both reinforced and unreinforced sand confirm typical responses of granular soils under shearing conditions. Therefore, for loose reinforced sand the deformations are developed gradually towards asymptotic values at high displacements beyond which there are no increases in shear stresses. However, unlike loose reinforced sand, for dense reinforced sand there are marked peaks, at relatively low displacements, followed by reductions in shear stresses towards residual strengths (post failure strengths) at high deformations. On the other hand, it can be observed that the shear strength increased alongside of normal stresses applied during shearing. For a best analysis of shear test results, both loose and dense reinforced sand states are separately discussed.

For loose reinforced sand, it is clearly noted that the kinetics of development of shear stresses decreased with the increase of rubber fibers content, which means that the deformations developed slowly in the presence of rubber fibers. Moreover, displacements that corresponded to ultimate strengths are decreased with the increase of rubber fibers content. Accordingly, the use of rubber fibers in granular soils as stabilizers helps to introduce more ductility to the sand which is suitable for geotechnical applications such as retaining walls and slope. Moreover, the obtained results show that there is no effect of initial

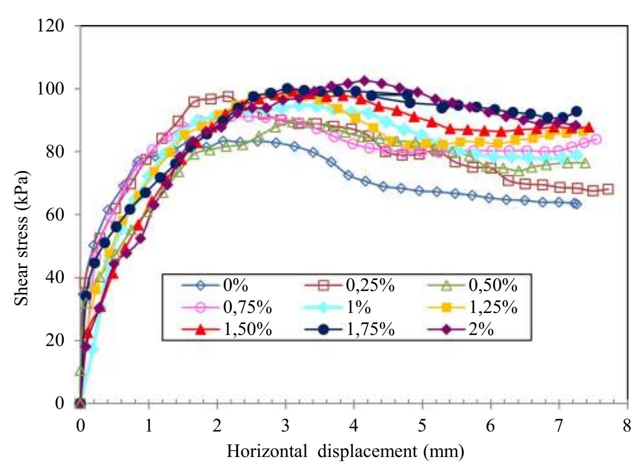

Fig. 3 Effect of rubber fibers on shear stress (loose state, $\sigma_n = 100$ kPa)

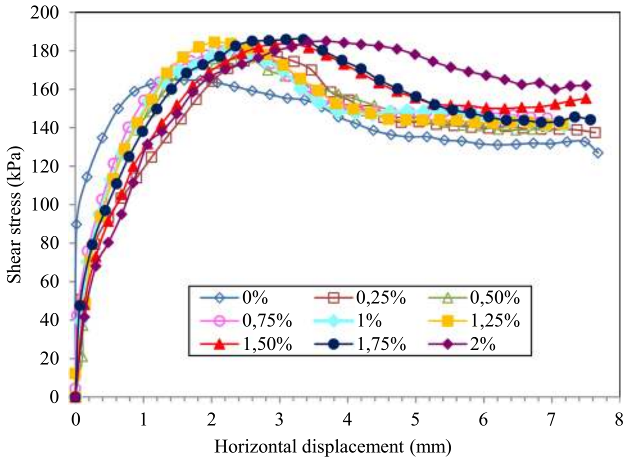

Fig. 4 Effect of rubber fibers on shear stress (loose state, $\sigma_n = 200$ kPa)

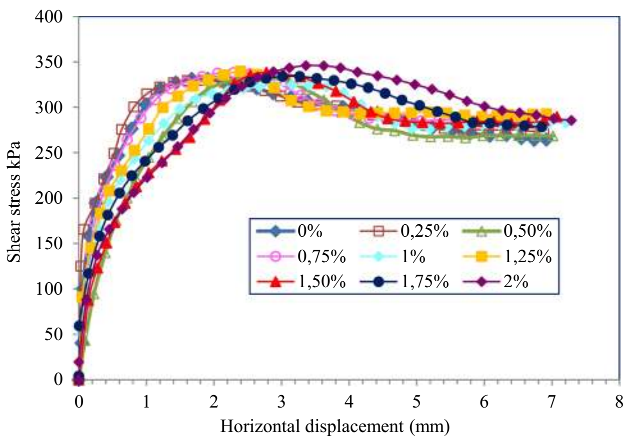

Fig. 5 Effect of rubber fibers on shear stress (loose state, $\sigma_n = 400$ kPa)

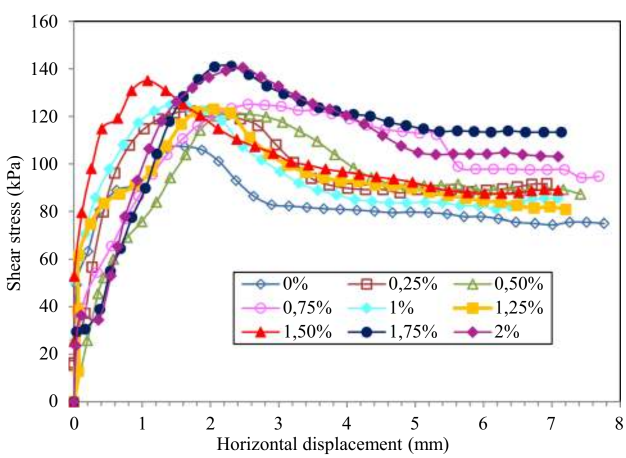

Fig. 6 Effect of rubber fibers on shear stress (dense state, $\sigma_n = 100$ kPa)

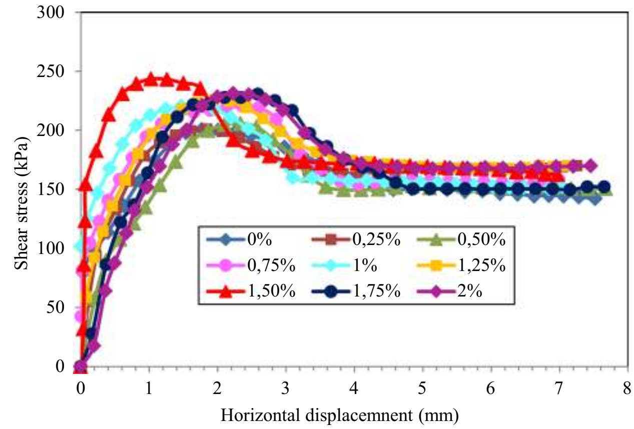

Fig. 7 Effect of rubber fibers on shear stress (dense state, $\sigma_n = 200$ kPa)

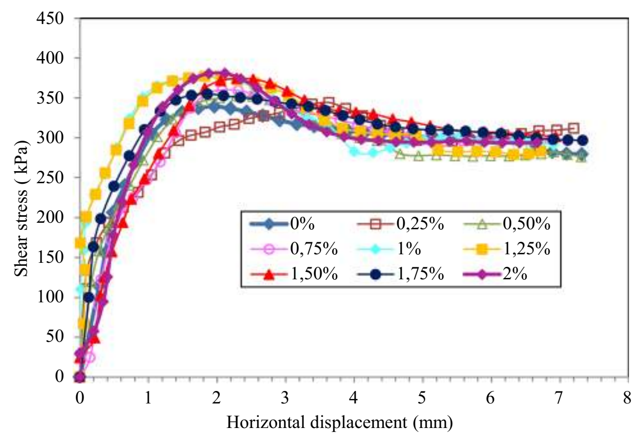

Fig. 8 Effect of rubber fibers on shear stress (dense state, $\sigma_n = 400$ kPa)

behavior (small strains) due to the inclusion of rubber fibers. This finding results are in agreement with that obtained in previous investigation [22]. They have reported that the incorporation of polypropylene fibers in sand has no effect on initial stiffness. At high displacements, as shown in Figs. 3, 4, and 5; both ultimate and residual shear strength of sand have been increased by incorporation of rubber fibers, which means that the reinforced sand exhibits greater strength. But it should be noted that the effect of rubber fibers, at high displacements, decreases with the increase in the vertical pressure.

For dense reinforced sand, like loose state, the inclusion of rubber fibers enhances the engineering properties of sand, such as peak, post peak strength, and ductility, but it should be noted that the effect of rubber fibers is more remarkable in comparison with loose state (Figs. 6, 7, 8). This behavior can be explained by the fact the rubber fibers favorite a denser granular skeleton so that its effect is more effective. The improvement of local behavior of reinforced sand, based on the interaction between the grains of sand and fibers during shear phases, may be explained by the fact that stresses transform from granular skeleton to fibers which put them in tension and consequently increases the tensile strength of reinforced sand. Therefore, this interaction mechanism is more efficient if the sand is denser. In addition, existence of fibers in the sand prevents the relative displacements between the grains of sand, which creates supplementary contact forces and improves the global behavior of reinforced structures founded on such type of soil.

Ultimate state

Figures 9 and 10 show the effect of the incorporation of rubber fibers in sand on the normalized ultimate strength. This parameter is defined as the ratio of the ultimate strength (τ_{ult}) to normal stress (σ_n) applied on the sand during shearing [5]. From these results, it is clearly seen that the normalized ultimate strength is ameliorated by an increasing rubber content. For example, the normalized ultimate strength for the sample contained 2% of rubber fibers and sheared under normal stress of 100 kPa is improved by 23–31%, according to the density of the sand. Moreover, the normalized ultimate strength for reinforced sand is more sensitive to the variation of normal stress in the dense state than the loose one. This finding can be explained by the fact that the existence of rubber fibbers in the sand generates a supplementary resistance. These obtained results are consistent with the previous investigation [5] carried out on reinforced sand with polypropylene fibers. They have indicated that the incorporation of polypropylene fibers in dry sand with the rate of 1% can improve the normalized peak strength by about 25–30%.

Table 2 summarizes the shear strength values and the displacements at peaks. It can be noted that the effect of the

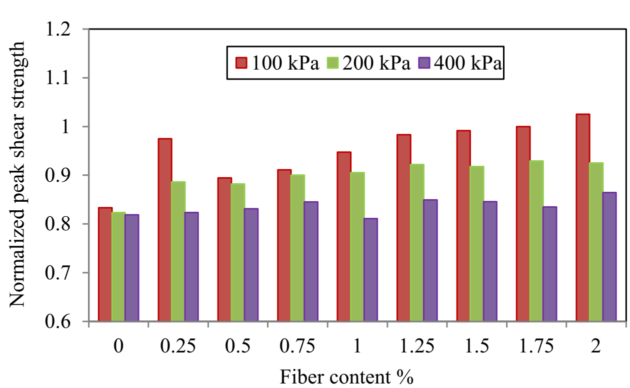

Fig. 9 Effect of rubber fibers on normalized peak strength (loose state)

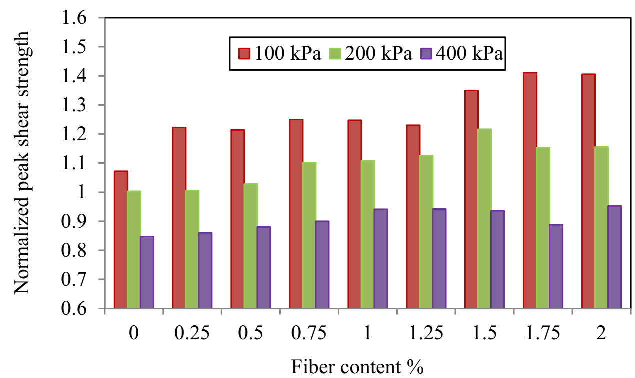

Fig. 10 Effect of rubber fibers on normalized peak strength (dense state)

rubber fibers is more remarkable for the vertical pressure of 100 kPa than the others normal stresses (200 and 400 kPa). This is agreement with the results obtained by Shao et al. [19]. Therefore, the authors have reported that fiber reinforcement is more practical for soils at low confining pressure. They have indicated also that fiber reinforcing procedures are suggested to be used to improve the mechanical properties of shallow foundations, retaining walls and slope.

Dune sand strength is based only on friction angle because the cohesion remains negligible. Figure 11 shows the variation of frictional angle at peak with the increase of rubber fibers content. It can be clearly seen that this parameter is significantly improved by incorporating rubber fibers. In comparison with unreinforced sand, frictional angle of the sample contained 2% of rubber fibers, ameliorated by 2.3° if the specimens are tested at loose state, while it improved by 4.7° if the sand is denser. Rubber fibers participate in strength by supporting some part of surcharges, which make it in tension and preventing the relative displacements between sand grains. The interaction between fibers and soil particles improves the mobilized friction, which helps to generate a supplementary strength. This finding is consistent with other investigations carried out on reinforced sand by polypropylene fibers. Furthermore, other researchers [19] have discussed that the fiber reinforced sand exhibits some ''apparent cohesion'' due to the inclusion of rubber. However, from a practical view, it may be more effective to neglect this cohesion during the design of rubber fibers of dune sand-based structures, because sand will always be cohesionless even after incorporating rubber fibers.

Residual state

In steady state, the obtained results confirm the essential knowledge of previous investigations about the behavior of granular soils, containing natural plant fibers or

Table 2 Peak strength characteristics

Rubber fibers content (%)	Normal stress (kPa)	Loose state		Dense state	
		Peak shear strength (kPa)	Displacement at peak (mm)	Peak shear strength (kPa)	Displacement at peak (mm)
0	100	83.33	2.089	107.22	1.625
	200	164.72	1.599	200.55	1.773
	400	327.5	2.184	339.16	1.946
0.25	100	97.5	2.161	122.22	2.055
	200	177.22	2.72	201.11	1.845
	400	329.44	2.062	344.16	3.634
0.5	100	89.44	3.287	121.38	2.337
	200	176.38	2.766	205.55	2.334
	400	332.5	2.84	351.94	2.278
0.75	100	91.11	3.287	125	2.552
	200	180	2.843	220.27	2.366
	400	338.05	2.295	360	2.075
1	100	94.72	2.495	124.72	1.413
	200	181.11	2.456	221.66	1.711
	400	324.44	3.159	376.38	1.824
1.25	100	98.33	3.407	123.05	2.05
	200	184.44	2.201	225	1.948
	400	339.72	2.39	376.94	1.82
1.5	100	99.16	2.959	135	1.081
	200	183.61	3.177	243.33	1.028
	400	338.33	2.779	374.44	2.445
1.75	100	100	3.028	141.11	2.31
	200	185.83	3.35	230.55	2.589
	400	333.88	3.235	355	1.862
2	100	102.5	4.154	140.55	2.477
	200	185	3.687	231.11	2.228
	400	345.83	3.466	380.83	2.468

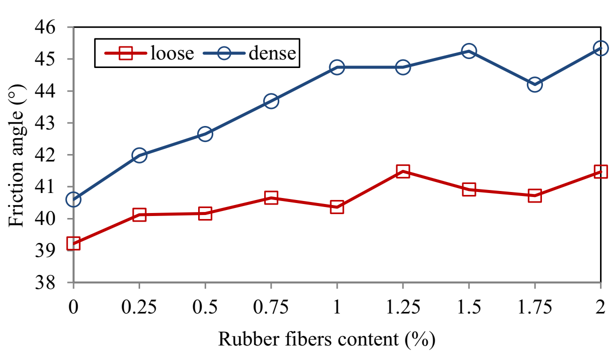

Fig. 11 Variations of friction angle with rubber fibers content

polypropylene fibers [19, 20, 22]. To understand the effects of the rubber fibers on the residual shear strength, shear residual strength ratio (RSR) is calculated and defined as:

$$\mathrm{RSR} = \frac{\tau_r^r}{\tau_r}$$

where τ_r is the shear residual strength of the unreinforced sand and τ_r^r is the residual shear strength of the reinforced sand. Figures 12 and 13 show the effects of rubber fibers on residual strength ratio for loose and dense states, respectively. It can be clearly noted from the results that the residual strength ratio increases with the increase in the rubber fibers content. In addition, it can be observed for both loose and dense states that there is more sensibility to rubber fibers for low confining pressure (100 kPa) than higher pressures (200 and 400 kPa).

The variations of residual friction angle according to the rubber content are shown in Table 3 and Fig. 14. It should be noted that the friction angle has been slightly increased

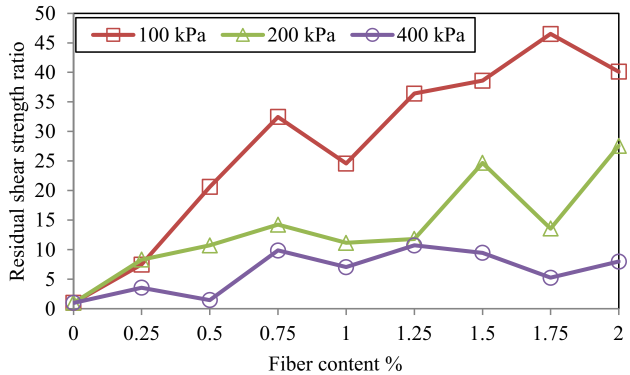

Fig. 12 Relationships between residual shear strength ratio and rubber fibers content (loose state)

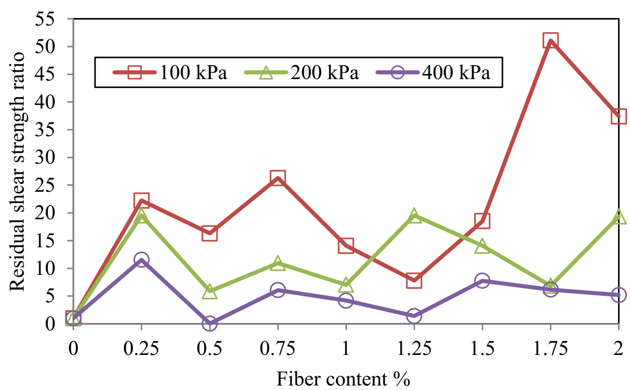

Fig. 13 Relationships between residual shear strength ratio and rubber fibers content (dense state)

Table 3 Effect of rubber fibers on residual friction angle

Rubber fiber content (%)	Residual friction angle (°)	
	Loose state	Dense state
0	35.1	33.2
0.25	35.1	33.2
0.5	35.4	34.3
0.75	37.2	36.2
1	36.5	35.4
1.25	36.5	36.3
1.5	37.6	36.6
1.75	37.3	35.4
2	37.6	36.5

with the increase of rubber fibers content. As compared with the unreinforced sand, it is improved by 2.5°–3.3° according to the density of the sand.

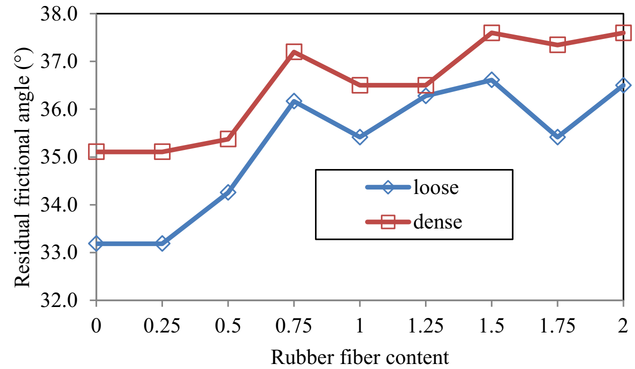

Fig. 14 Variations of residual friction angle with rubber fibers content

Conclusion

The feasibility of reinforcing sandy soils by rubber fibers waste is experimentally investigated in this paper. Dune sand is mixed within randomly distributed short rubber fibers with various concentrations. The obtained results show that adding rubber fibers waste to dune sand confirms common knowledge about the behavior of sandy soils containing polypropylene or vegetal fibers. Specifically:

- The mechanical properties of the sand, peak and residual strengths are improved due to the incorporation of rubber fibers.
- Incorporating rubber fibers in granular soils reduces the displacement rate which helps to introduce more ductility behavior to the sand.

In addition to the technical benefits of the approach proposed in this paper; improving the engineering properties of granular soils, using of rubber fibers in geotechnical applications as reinforcements help making geo-environmentally material, and at same time reducing some parts of rubber waste.

Based on the obtained results, rubber reinforced sand can be used to improve the soil properties for some civil engineering applications, such as shallow foundations, retaining walls and slope.

Finally, to fully quantify the effects of rubber fibers on the performance of dune sand-based structures, it is recommended to study other parameters not investigated in this paper such as aspect ratio and length of rubber fibers. In addition, it may be effective to characterize rubber fibers reinforced sand behaviors with triaxial test with the limitations of direct shear test.

References

1. Ateş A (2016) Mechanical properties of sandy soils reinforced with cement and randomly distributed glass fibers (GRC). Compos Part B: Eng 96:295–304. Available at: http://linkinghub.elsevier.com/retrieve/pii/S1359836816304437. Accessed 13 June 2016
2. Balunaini U et al (2014) Pullout response of uniaxial geogrid in tire shred-sand mixtures. Geotech Geol Eng 32(2):505–523
3. Botero E et al (2015) Stress–strain behaviour of a silty soil reinforced with polyethylene terephthalate (PET). Geotext Geomembr 43(4):363–369. doi:10.1016/j.geotexmem.2015.04.003
4. Cecich V et al (1996) Use of shredded tires as lightweight backfill. Waste Manag Res 14:433–451
5. Eldesouky HM, Morsy MM, Mansour MF (2014) Fiber-reinforced sand strength and dilation characteristics. Ain Shams Eng J. doi:10.1016/j.asej.2015.06.003
6. Gray DH, Ohashi H (1983) Mechanics of fiber reinforcement in sand. 109(3):335–353
7. Güneyisi E, Gesoğlu M, Özturan T (2004) Properties of rubberized concretes containing silica fume. Cem Concr Res 34(12):2309–2317
8. Ibraim E et al (2012) Assessment of laboratory sample preparation for fibre reinforced sands. Geotext Geomemb 34:69–79. doi:10.1016/j.geotexmem.2012.03.002
9. Jingfu K, Chuncui H, Zhenli Z (2008) Strength and shrinkage behaviours of roller-compacted concrete with rubber additives. Mater Struct 42(8):1117–1124
10. Krishna Rao SV, Nasr AMA (2012) Laboratory study on the relative performance of silty-sand soils reinforced with linen fiber. Geotech Geol Eng 30(1):63–74
11. Kyser D, Ravichandran N (2016) Properties of chipped rubber roofing membrane and sand mixtures for civil engineering applications. J Build Eng 7:103–113. Available at: http://linkinghub.elsevier.com/retrieve/pii/S2352710216300547. Accessed 13 June 2016
12. Maity J, Chattopadhyay BC, Mukherjee SP (2012) Behaviour of different types of sand randomly mixing with various natural fibers. J Inst Eng (India) Ser A 93(2):97–104. doi:10.1007/s40030-012-0014-7
13. Meddah A (2015) Characterization or roller compacted concrete containing rubber-tire wastes. National Polytechnic School of Algiers, Algiers
14. Meddah A, Beddar M, Bali A (2014a) Experimental study of compaction quality for roller compacted concrete pavement containing rubber tire wastes. In: Sustainability, eco-efficiency, and conservation in transportation infrastructure asset management. CRC Press, New York, pp 273–278
15. Meddah A, Beddar M, Bali A (2014b) Use of shredded rubber tire aggregates for roller compacted concrete pavement. J Clean Product 72:187–192. Available at: http://www.sciencedirect.com/science/article/pii/S095965261400198X. Accessed 13 Sept 2014
16. Meddah A, Sahli M, Safer S (2015) Etude de l'effet de la rugosité des renforcements sur le comportement des massifs en terre armée. Journées d'étude de Génie Civil. M'sila University, Algeria, pp 54–59
17. Naik BTR, Singh SS (1991) Utilization of discarded tires as transportation facilities. Report N. CBU-1991-02
18. Onuaguluchi O, Panesar DK (2014) Hardened properties of concrete mixtures containing pre-coated crumb rubber and silica fume. J Clean Product 82:125–131. Available at: http://www.sciencedirect.com/science/article/pii/S0959652614006568. Accessed 13 Sept 2014
19. Shao W et al (2014) Experimental investigation of mechanical properties of sands reinforced with discrete randomly distributed fiber. Geotech Geol Eng 32:901–910
20. Tang C-S, Shi B, Zhao L-Z (2010) Interfacial shear strength of fiber reinforced soil. Geotext Geomemb 28(1):54–62. doi:10.1016/j.geotexmem.2009.10.001
21. Thomas BS, Gupta RC (2015) Long term behaviour of cement concrete containing discarded tire rubber. J Clean Product 102:78–87
22. Yetimoglu T, Salbas O (2003) A study on shear strength of sands reinforced with randomly distributed discrete fibers. Geotext Geomemb 21(2):103–110
23. Yoon S et al (2006) Construction of a test embankment using a sand-tire shred mixture as fill material. Waste Manag 26(9):1033–1044