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Polymers additives for improving resistance of sandy soil

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ABSTRACT: Many researchers concentrate on increasing the resistance of soil through densification this soil. The principle for densification methods is to reduce the volume of voids between soil particles, thus reducing the void ratio and changing the stress state of the deposit. This will improve soil in its bearing, its shear strength and its resistance to liquefaction. Using Polymer additives have developed as one of the modern and effective additives for improving the soil properties, especially sandy soil. Polymers could improve the shear strength, and decrease the permeability of soil without negative impacts on the environment. Therefore, this research studies the effect of using two types of polymers: polypropylene fibers (PPF) and polypropylene granules (PPG) on improving the soil properties and comparing both types. All results showed positive trends in sandy soil

1 INTRODUCTION

It is well known that increase the shear stregnth and density of the soil mitigates the liquification by allowing rapid pore water pressure dissipation and particle rearrangement, preventing the loss of effective stress that causes liquefaction. So many reserchers tried to study the effect of polymer additives fibers and granules on the density and shear strength. (Sadek & Najjar, 2010) apply comprehensive direct shear test program on both type of sand (fine and medium) and using fiber additives in percentage from 0% to 1.5%. The aim of research was to study the effect of fiber on shear strength of sand. They found that the additives have increased the shear strength of soil. And the length of fiber affect positively on the shear strength. (Lovisa et al. 2010), have studied the effect of water content on the behavior of reinforced sandy soil with fiber. Glass fiber was used and the results show the increasing in internal friction angle in wet situation less 3 degree than the angle in dry situation. (Anagnostopoulos et al, 2013) studied the effect of polypopelene fiber in reiforcing the soil. Fiber addtivies was used in range 0.1% to 0.5%. results show that additives increase obviouly the shear strength which relate strongly on the finenes of sand and the percentage of fiber. (Poweth, et. Al. 2014) concentrate on shear strength, CBR, permeability and Proctor test for samples of sand soil using additives of plastic granules (0.25, 0.5, 0.75) percentage of the weight of soil. They conclude that 0.25 of plastic granules that mixed with soil give the best results. (Eldesouky et. Al., 2015) studied the possibility of using randomly distributed fibers to increase the shear strength of soil. The research was done on 108 samples to verify the effect of fiber content, relative density, normal stress and moisture content on shear strength and volume change of sandy soil. The results indicate that the addition of fibers significantly improved the shear strength and expansion of sandy soil. (Darvishi and Erken, 2018) investigated the shear strength of sandy soils improved by polypropylene fiber. The fiber percentage from 0% up to 1%. The results show that fiber affect on increasing internal friction angle values. (Al-Saray et. Al., 2021) have collected samples of sandy soil from Najaf Governorate. The study included conducting a set of tests such as permeability, direct shear and CBR on samples of sandy soil improved with polypropylene fibers and unimproved, where the percentage of added fibers (polypropylene) ranged from (0.1-0.3-0.6-1) of the soil weight. The tests were conducted according to ASTM. It is clear the increase in the angle of internal friction and the shear strength of sandy soil with increasing polypropylene fiber (PPF).. On the other hand, the effect of PPF on the permeability coefficient (k) where the later decrease at 0.1% and 0.3% PPF and above 0.3% soil permeability increase with increasing PPF. Therefore when their concentration in the soil exceeds the optimal ratio, it will produce the opposite result by increasing permeability due the ease with which water slides off their surface. (Benziane et al. 2022) evaluate the effect of two types of fiber-glass fibers and polypropylene fibers with percentage from 0% up to

1% of dry weight. The fibers was distributed randomly. It improved the shear strength (friction angle).

The aim of this research is to study the effect of both types of polypropylene additives: Fiber (PPF) and Granules (PPG) on the density and shear strength of the same soil.

2 MATERIALS AND METHODS

2.1 Soil

The soil used in this research is sandy soil collected from Damascus Governorate, southwest syria, the engineering characteristics of sandy soil were found through several laboratory tests in the civil engineering laboratories of Damascus University such as sieve analysis, specific gravity, relative density, direct shear test, as shown in the Table1.

Table 1.Mechanical Properties of sand soil

Mechanical Properties	Value
Sand	94.29%
Gravel	0.73%
Fine grain	4.98%
Coefficient of uniformity Cu	2.33
Coefficient of curvature Cc	0.94
Classification (UCS)	SP
Water content ,Wc	1%
Specific gravity ,Gs	2.67
Minimum void ratio e_{min}	0.58
D_{30}	0.178
D_{60}	0.28
D_{10}	0.12
Minimum density	1.51
Maximum density	1.69

2.2 Fiber

In this research, one of the most available type of fibers is used, which is polypropylene fiber (PPF) with a length of 12 mm and a diameter 0.032 mm Figure 1, different PPF contents (0.1, 0.3, 0.6 and 1%) were used to investigate its effect on the behavior of reinforced sandy soil by a series of direct shear test. The physical properties of PPF are summarized in Table 2.

Figure 2. Polypropylene Granule (PPG)

Table 2. Properties of Fibers

Mechanical Properties	Value
color	Transparent fibers
Specific gravity	0.91gm / cm3
Length	12 mm ±1
Diameter	0.032 mm
Shape	Straight
Tensile strength	600 -700 MPa
Elastic modulus	3000 -3500 MPa
Elongation	20-25 %
Chemical base	100 % polypropylene fiber
Melt point	160º C
Ignition point	365º C
Absorption,	No absorption

Figure 1. Polypropylene Fiber (PPF)

2.3 Granules

Second type of additives is polypropylene granules (PPG) Figure 2. Different percentages of PPG granules (0.25%, 0.5%, 0.75%, and 1%) were used to study their effect on the behavior of reinforced sandy soil through a series of direct shear tests. Table 3 summarizes the physical properties of the polypropylene granules.

Table 3. Properties of Granules

Property	value	unit
Density	0.90 – 0.91	g/cm^3
Melt Flow Rate (MFR)	1.5 – 25.0	g/10 min
Pellet Size / Shape	3.0 /(Lentil)	mm
Tensile Strength @ Yield	25 – 35	MPa
Flexural Modulus	25 – 36	MPa
Rockwell Hardness	25 – 37	MPa
Vicat Softening Point	25 – 38	MPa
Melting Temperature	25 – 39	Mpa

Haze (Transparency)	25 – 40	Mpa

3 LABORATORY TESTS

3.1 Direct Shear Test

The direct shear test for soil is determined according to ASTM D3080. The shear strength of a soil mass is the internal resistance per unit area that the soil mass can offer to resist failure and sliding along any plane inside. In the direct shear test a square prism of soil is laterally restrained and sheared along a mechanically induced horizontal plane while subjected to a normal pressure applied to that plane. Laboratory specimens are prepared with relative density (Dr) values of 35% in order to investigate the behaviors of loose dense. Direct shear tests were carried out at rate (0.5 mm/min) under normal stresses of 54.5, 109, and 218 kPa

3.1.1 Test description

The experimental study was conducted by performing a series of direct shear tests, using a shear box with dimensions 60 mm by 60 mm in plan, and 25 mm in depth. The tests were performed at the vertical normal stresses of 54.5, 109, and 218 kPa in order to completely define the shear strength parameters (i.e. cohesion and angle of internal friction) for both the unreinforced and reinforced. Shear stresses were recorded along with horizontal displacement up to the displacements that allowed an adequate description of ultimate strength. In order to describe the behavior of fibre-reinforced sand and granul-reinforced sand, direct shear tests were conducted at varying additives percentage for each of type of additives. Fiber was added with percentage 0.1, 0.3, 0.6, and 1% as shown in table 4 which present the value of friction angle for each test at each percentage of additives.

Table 4. Internal friction angle for sandy soil reinforced with fiber

Diplacement Rate (mm/min)	Additives %	ϕ(°)
0.5	0	19.93
	0.1	21.44
	0.3	23.00
	0.6	24.4
	1.0	27.2

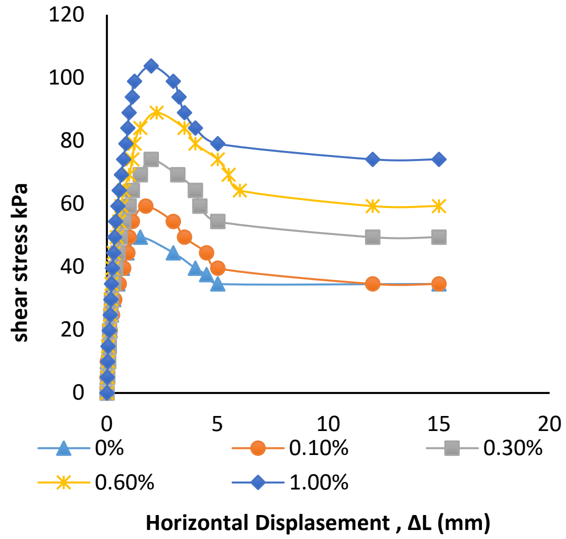


Figure 3. shear stress vs. displacement for reinforced soil with (PPF) for 2kg load

Figure 3, Figure 4, Figure 5 show the shear stress versus horizontal displacement for soil with PPF additives 0%, 0.1%, 0.3%, 0.6% and 1% at all loads 2kg, 4kg and 8kg. it is so obvious that the trend is increasing in the strength as the percentage of additives increased. Where Granules was added with percentage 0.25, 0.50, 0.75 and 1% as shown in Table 5. Figure 6, Figure 7, Figure 8 show the shear stress versus horizontal displacement for soil with PPG additives 0%, 0.25%, 0.5%, 0.75% and 1% at all loads 2kg, 4kg and 8kg.

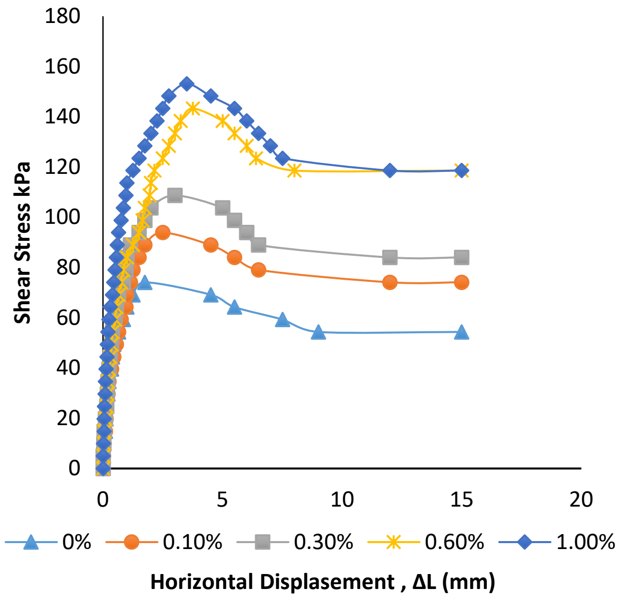


Figure 4. Shear stress vs. displacement for reinforced soil with (PPF) for 4kg load

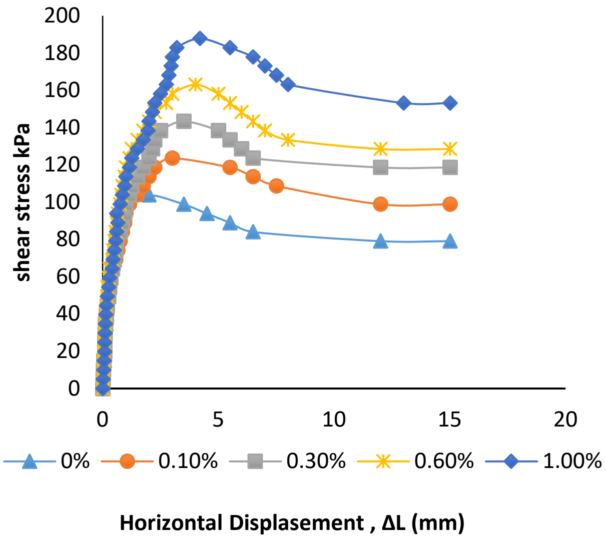


Figure 5. shear stress vs. displacement for reinforced soil with (PPF) for 8kg load

Table 5. Internal friction angle for sandy soil reinforced with Granules

Diplacement Rate (mm/min)	Additives %	ϕ(°)
0.5	0	19.93
	0.25	20
	0.5	21.5
	0.75	23
	1	24.4

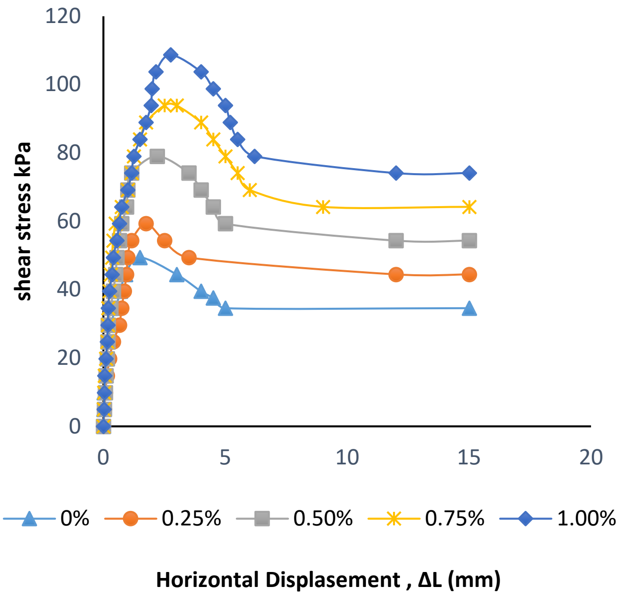


Figure 6. shear stress s. displacement for reinforced soil with (PPG)for 2kg load

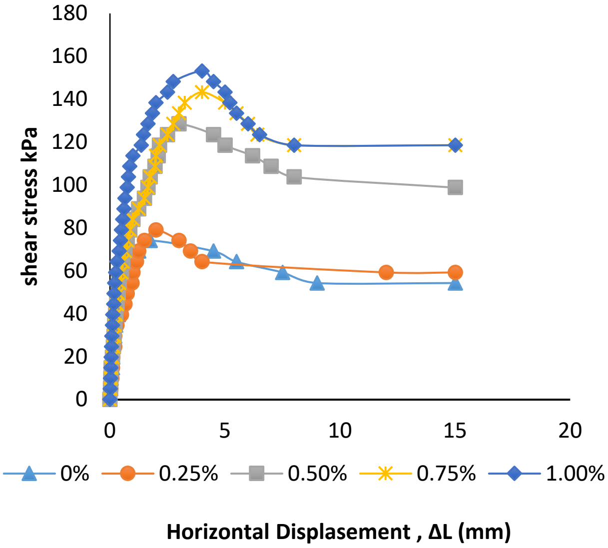


Figure 7. shear stress vs. displacement for reinforced soil with (PPG)for 4kg load

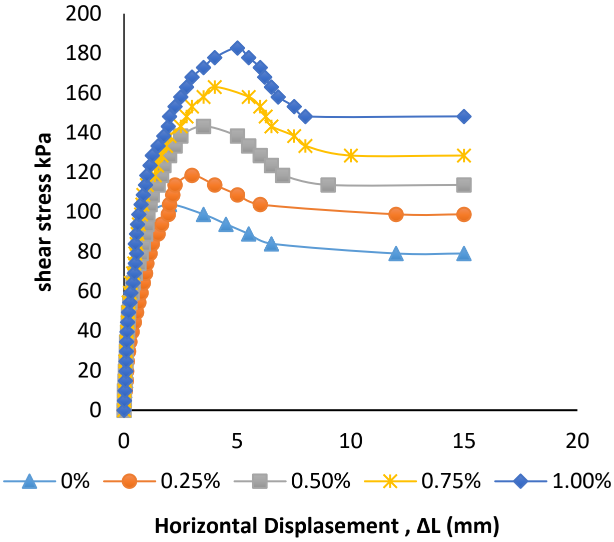


Figure 8. shear stress vs. displacement for reinforced soil with (PPG) for 8kg load

3.2 Proctor Test

The optimum moisture content and the maximum dry density of the soil samples for various percentage of polypropylene fiber (0%,0.1%,0.3%,0.6%and 1%) were determined by performing the Standard Proctor's test, ASTM D698. The dry density was determined and plotted against the the percentage of fibers, as shown in Figure 9. In addition, The dry density was determined and plotted against the the percentage of graules, as shown in Figure 10.

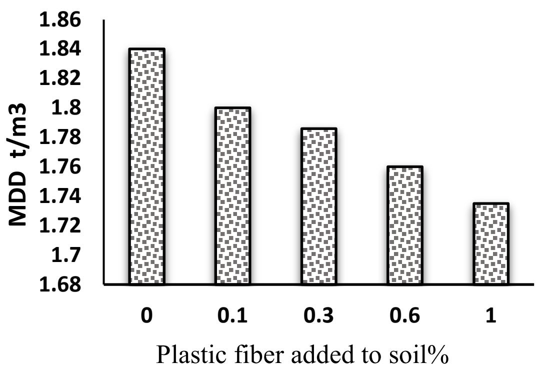


Figure 9. maximum dry density vs. Fiber percentage in soil

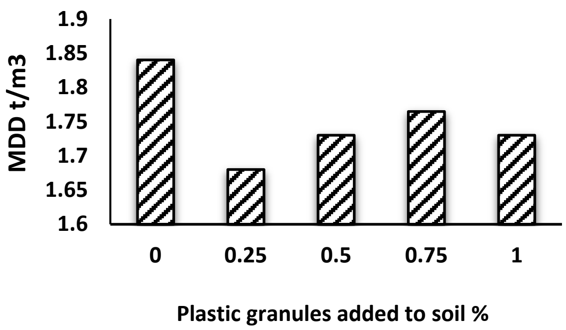


Figure 10. maximum dry density vs. Granules percentage in soil

4 DISCUSSION

4.1 The effect of Fibre additives:

According to the results of Figures 3,4 and 5, we could analysis the behaviour and the effect of additives on the value of shear stress as it is illustrated in Figure 11 where we relate the maximum shear stress for each load with rate of additives.

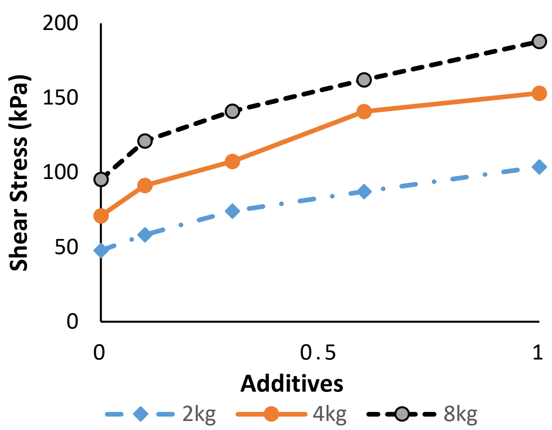
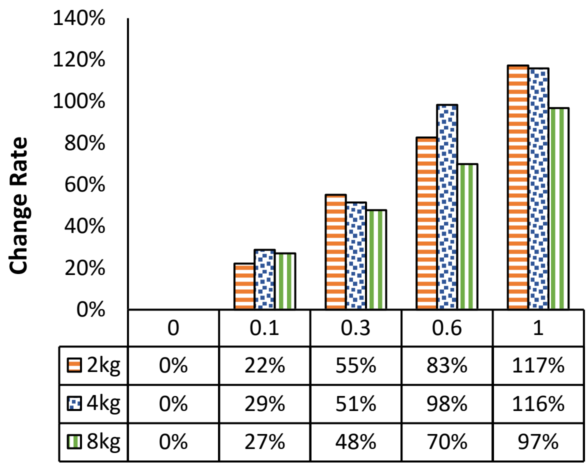


Figure 11. PPF additives vs. maximum shear stress for all loads

The trend is clear positive for all loads as the additives rate increase as the shear stress increase and for more clarification the Figure 12 show the change rate of shear stress for each load at all additives rate. There is no relation between the load value and the change rate, where it is obvious that at higher value of load the change become smaller. And this because the same sample has first load 2kg then 4kg then 8kg where the changing in the arrangement of soil and fibre will be less.



	0	0.1	0.3	0.6	1
2kg	0%	22%	55%	83%	117%
4kg	0%	29%	51%	98%	116%
8kg	0%	27%	48%	70%	97%

Figure 12. PPF additives vs. change rate in maximum shear stress for all loads

4.2 The effect of Granules additives:

According to the results of Figures 6,7 and 8, we could analysis the behaviour through draw the relation between the maximum shear stress at each load at different rate of additives as shown in Figure 13.

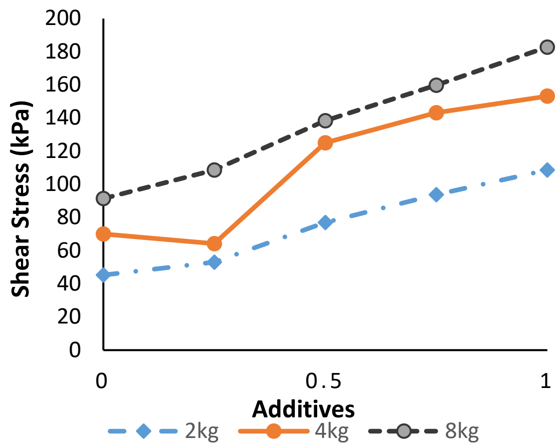
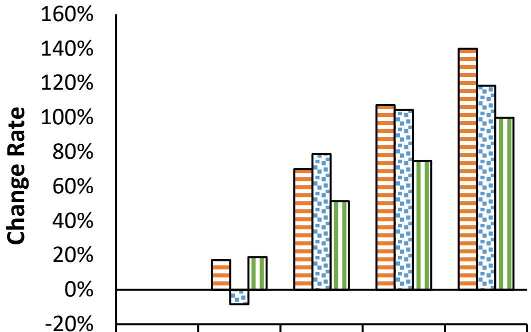


Figure 13. PPG additives vs. maximum shear stress for all loads

The increasing of shear stress at different load as the increasing of additives however in Figure 14 it is obvious that the change rate al the higher load (8kg) will be smaller than the smaller load (2kg) and this logic since the sample will subject to load 2kg then

4kg then 8kg, but to make comparison between the effect of PPF and PPG we arrange the Figure 15 between the maximum shear stress at each load for both samples with PPF and samples with PPG. Approximately the same effect but the effect of PPF is more positives for these type of soils.



	0	0.25	0.5	0.75	1
2kg	0%	17%	70%	107%	140%
4kg	0%	-8%	79%	104%	119%
8kg	0%	19%	51%	75%	100%

Figure 14. PPG additives vs. change rate in maximum shear stress for all loads

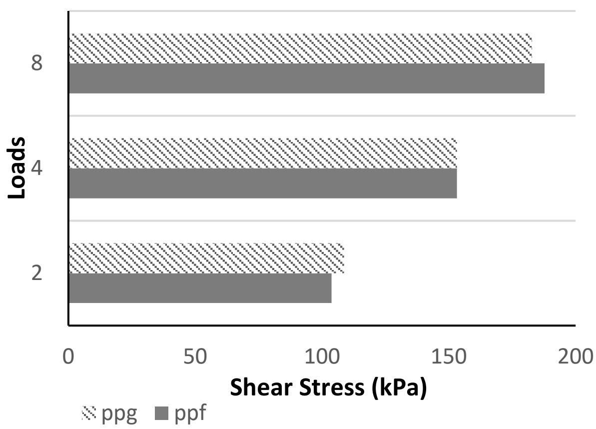


Figure 15. Comparision between PPG additives and PPF effect on strength of soil

5 CONCLUSIONS

PPF&PPG additives improve the shear strength of sandy soil, It is explained by the properties of PPF such as high flexural strength due to their semi-crystalline nature and high shear strength. Therefore, when mixed with sandy soils, they reinforce the soil by creating network and increasing friction at the interface. However, the proctor test show that the density decrease gradually by adding PPF additives to the soil where the decrease was sharply by adding PPG additives to the soil. But, both samples either with PPF or PPG reach to the same density at percentage 1% of each additives. This behavior is explained by the fact that PPF have relatively slippery surface and are difficult to bond to other surfaces, in addition to their relatively low density. Granules act randomly, and when it begins to fill the voids between particles the density return to increase but it still less than the density of virgin sample because the granules (which have less density of soil particles) try to replace the soil particles so the density decrease. Both types will affect positively to increase the resistance of the sand soil against liquefaction.

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REFERENCES:

Al-Saray, N., Shafiqu, Q., Ibrahim, M.A., (2021), *Improvement of strength characteristics for sandy soils by polypropylene fibers (PPF)*

Anagnostopoulos,A.C., Papaliangas,T.T., Konstantinidis, D.F., Patronis, C., (2013), Shear Strength of Sands Reinforced with Polypropylene Fibers, *Geotechnical and Geological Engineering* Volume 31, pages 401–423-

Benziane, M, Della, N., Sert, S., Denine, S., Nouri, S., Bol, E., & Abdelnacer Boukeffoussa, A., (2022), Shear behaviour of sandy soil from Chlef river reinforced with different types of fibres ,*Marine Georesources & Geotechnology*, Volume 40, Issue 10

Darvishi, A., Erken, A., (2018), Istanbul Technical University, Effect of Polypropylene Fiber on Shear Strength Parameters of Sand, *Proceedings of the 3rd World Congress on Civil, Structural, and Environmental Engineering* , Paper No. ICGRE 123

Eldesouky, H.M., Ky, M. M. Morsy, Mansour,M.F., (2016), “Fiber reinforced sand strength and dilation characteristics,” *Ain Shams Engineering Journal*, vol. 7, pp. 517-526.

Lovisa, J., Shukla, S.K., and Sivakugan, N., (2010), *Shear strength of randomly distributed moist fibre reinforced sand*

Poweth, M.J., Haneef, F. M., Jacob, M.T., Remya Krishnan, R., Rajan, S., (2014), *Effect of Plastic Granules on the Properties of Soil*

Sadek,S., Najjar, S.S., (2010), Shear Strength of Fiber-Reinforced Sands, *Journal of Geotechnical and Geoenvironmental Engineering*, Volume 136, Issue 3