EFFECT OF SAND PAPER GRADING ON THE SHEAR BEHAVIOURS OF FINE-GRAINED SAND

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ABSTRACT: This paper presents the results of direct shear test on sand paper reinforced and un-reinforced poorly graded fine-grained sand obtained from natural costal sand deposits of western shore of Cyprus Island. Mining of sand from natural deposits, including beaches, yields an inexpensive source of sand for construction or industrial uses. Samples prepared in identical densities with and without addition of different grading of discrete sand papers have been tested in order to assess the effect of sand paper grading on the shear strength parameters of soil. Laboratory testing program consisting 41 specimens were performed in circular shear box with 63 mm in diameter which were prepared regarding BS 1377-7. Tests are conducted with four vertical confining pressures: 100, 200, 300 and 400 kPa. The test results reveal that the sand paper grading play important role in the shear strength parameters of the soil. It was observed that the choose of grading close to the major percentage of sand particle size results to achieve increase in shear strength at all confining pressures which also results in increase of cohesion and friction angle.

Keywords: *(Shear, Sand, Compaction, Vibration, Friction, Reinforcement.)*

1 INTRODUCTION

Reinforcing soil with fibres has the attention of many geotechnical researchers. Such inclusion of materials into the soil were found to increase the shear strength which, in return, increases the bearing capacity of the soil and reduces settlement and lateral displacement. In this study direct shear tests have been carried out to determine the influence of different percentages, arrangement (one-sided, two-sided) and surface grading of fibres on variety of soil types, along with characterisation tests such as sieve analysis and specific gravity.

In the 1930s, the modern concept of soil reinforcing was proposed by Casagrande who idealised the problem in the form of a weak soil reinforced by high-strength membranes laid horizontally in layers. However, it was Vidal, in the 1960s, who investigated this field in detail. Vidal's concept was to lay flat reinforcing strips horizontally in a frictional soil, as this enabled the interaction between the soil and the reinforcement to create a friction force to hold the soil in place (Colin 1996). Reinforcing soils with tensile elements is still a common practice in many developing countries where soil and straws are mixed to be used as a construction material. Later, as stated by Gray et al. (1983), other types of reinforcement attracted more attention and were found to be more effective in soil reinforcement. McGrown et al. (1988) introduced alternatives such as fabrics with lower stiffness, where such realisation results in categorising reinforcement fibres as: inextensible inclusions such as metal strips, and extensible inclusions such as polypropylene fibres. In this study, sand paper which are used for sanding concrete, steel, paint etc. will be used, belonging to the second category.

Gray et al. 1983 reported that extensible reinforcements contribute more to the strength and results in a smaller reduction on the post peak strength, when compared to that of the unreinforced sand and/or sand reinforced with steel strip s.

Several researches have been conducted on sand that is reinforced with fibres. Eldesoukey et al. (2016) reported that increases in the fibre content up to 1,1 % improves the normalized peak shear strength of dry sand by up to 50 %, on the other hand, increasing the relative density from 25 % to 90 % improves the normalized peak shear strength of dry unreinforced sand by about 28 % such results show the effectiveness of fibre reinforcement. Mali & Singh (2013) have also reported that as the fibre content increases, the contribution of the interfacial friction becomes larger, in other words, increasing the cohesion of soil which results in an increase of the bearing capacity of the soil.

Infante et al. (2016) conducted similar studies on a direct shear equipment. These authors reported that for the reinforced loose sand, shear strength increases gradually to the maximum value at a certain strain value, while for reinforced dense sand, the stress increase to a peak with increasing shear strain from zero to a certain magnitude, then gradually decreases to the residual shear strength with the increase in strain. Authors concluded that relative density of the sand affect the contribution of fibres to the shear strength parameters.

Eldesouky et al. (2016) investigated polypropylene reinforced poorly graded siliceous sand under similar testing conditions. Authors reported that soil moisture content affect the contribution of the fibres on the shear stress. Studies revealed that the increase in moisture content of the soil, reduces the fibres effect on the peak and post peak shear strength as it reduces the friction between soil grains and fibres. Additionally, authors concluded that dry loose 0.5 % reinforced sand achieves the same peak shear strength of moist very dense unreinforced sand, at more than double the horizontal displacement.

In this study, a fine poorly graded sand, obtained from a natural costal sand deposits on the western shore of the island of Cyprus has been used. On a similar study of costal sands, Skuodis et al. (2013) reported that the air-dried sand of the Baltic Sea coastal area was used to perform the experiments for determining the shear strength parameters. The average density (ρs) of the particles is 2.66 Mg/m^3, ranging from 2.65 -2.67 Mg/m^3 (Skuodis et al. 2013). Vertical stresses of 100, 200 and 300 kPa were applied where specimens were tested under a constant horizontal displacement speed of 0.5 mm / min until reaching the 9 mm limit for horizontal deformation. The shear test performance is considered in two different situations. First, when constant vertical stress (q = const.) is applied and second, when constant sample volume (h = const.) is applied. Initially, in the case of loose sand and constant q, there is no significant particle coming from its predecessor and the shear stress observed gradually increases to a final value, without peaking and reducing in volume. In the work they did, when the value of h was constant, the shear force showed a sudden increase and decrease and then remained stable. Under the applied loads (100,200 and 300 kPa), the vertical stress remained constant throughout the entire test period.

Vieira et al. (2013) performed direct shear tests to determine the behaviour of siliceous sand reinforced with high strength geotextile. Studied sand has mean diameter of 0.45 mm, uniformity coefficient of 1.9 and coefficient of curvature equal to 0.9. The tests were carried out under normal stresses (50, 100, 150 kPa) with a constant displacement speed of 1 mm / min. The shear stress-shear displacement curves show a well-defined peak shear strength, which was recorded for shear displacements that increased with the confining pressure. As expected, initially, the sand exhibited a contraction followed by a dilating phase. After reaching the interface interruption peak, the vertical displacement progression during slip for higher pressure achieved the same observations for lower high pressure.

Consoli and Casagrande (2006) investigated the polypropylene reinforced Osorio Sand which was sampled from the region of Osorio near Porto Alegre, Brazil. Authors classified the soil as non-plastic fine sand and determined the specific weight of this soil to be 2.63. Polypropylene fibre used in this study has 12mm length, 0.023 mm thickness and 1.4 mm width. Specific gravity of the fibres are 0.91 Mg/m^3, tensile strength is 120 MPa and elastic modulus is 3 GPa. Authors observed that there was a significant increase in the shear strength of fibre reinforcement compared to unreinforced sand. Fibre reinforcement was found to increase the sand stress by about 50 kPa under 200 kPa confinement. At the end of the tests authors removed the fibres from the cut-off area of the tested samples and found that the fibres were both stretched and broken, which means that the fibres were subjected to a major plastic deformation before breaking.

2 MATERIALS

The sand which was used in this study is named as Akdeniz sand which is located at the western cost of the Cyprus island. Physical properties and the grain size distribution curve are shown in Figure 2 where sieve analysis and specific gravity tests were conducted to obtain the parameters. It can be seen that sand used can be classified as poorly graded fine sand and nearly 90% of the particles are within 0.12 to 0.3 mm diameter.

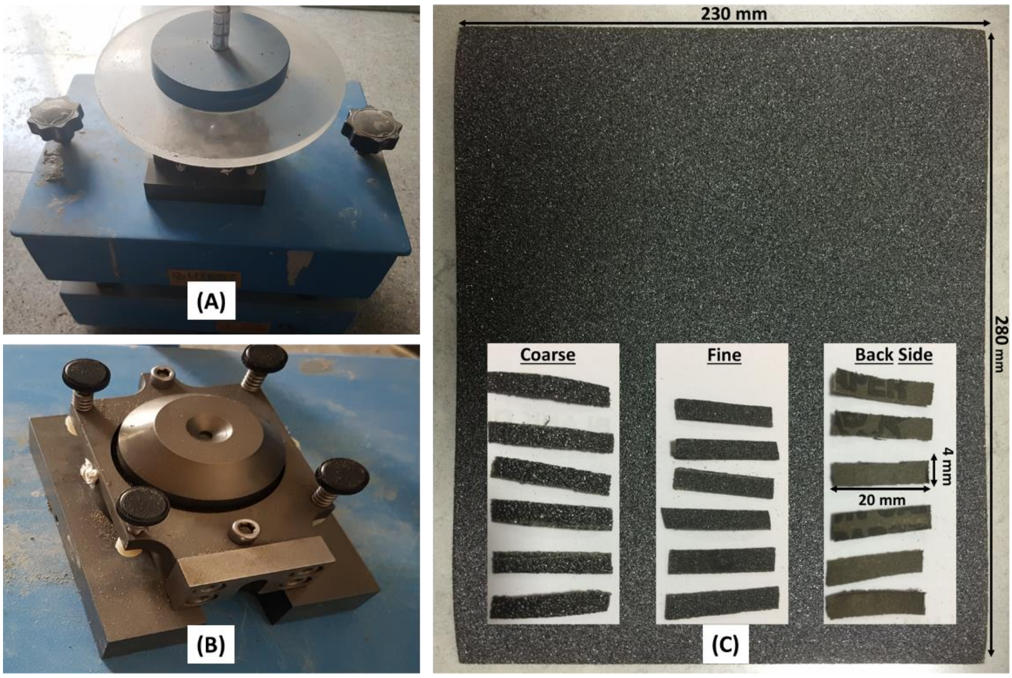
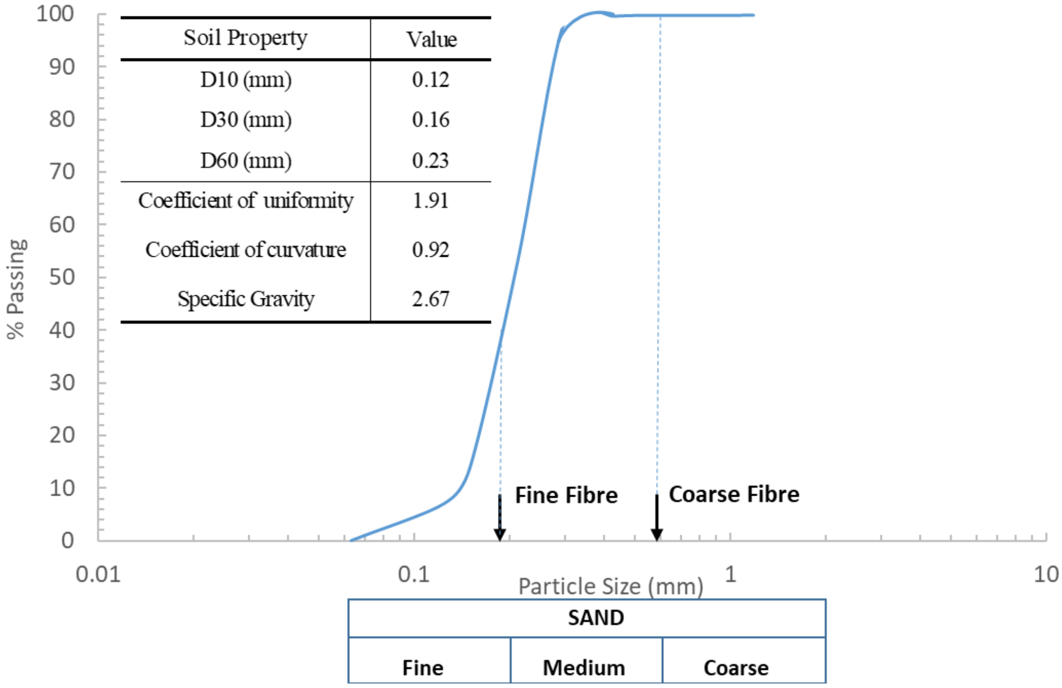


Figure 1: (a) Shaking table, (b) Shear Box, (c) Fibres, used in this study.

The fibres used were cut from fine sand paper with the number 180 (size of grains on top of paper is 0.18mm) and specific gravity of 3.5, and coarse sand paper with the number 60 (0.6mm grain size) and specific gravity of 3.8. Selected sand papers are used for metal sanding and can be used in a wet environment and will not absorb any water. The fine sand paper was chosen as the particle size is similar to the sand particles and the coarse size chosen to be above the grain size of sand.



Soil Property	Value
D10 (mm)	0.12
D30 (mm)	0.16
D60 (mm)	0.23
Coefficient of uniformity	1.91
Coefficient of curvature	0.92
Specific Gravity	2.67

Figure 2: Particle size distribution of Akdeniz sand.

3 PREPARATION AND TESTING PROCEDURE

Specimens have been prepared according to BS 1377-7:1990. Fibres were cut from the sand papers into dimensions that have been found to be optimum according to previous researches in fibre reinforced soils (4mm in width and 20mm in length). Fibres were hand mixed into the sand in the dry state and an adequate time was spent to ensure the homogeneity of the mix. Prepared specimens were poured directly into the assembled shearbox (35 mm in height and 60 mm in diameter) from a quantity of known mass. Finally, specimens were vibrated, on a small shaking table (Figure 1b), with top cap and porous stone assembled to avoid spilling. Such procedure has been carried out in order to keep the specimen densities constant by archiving the same volume after vibration.

During this study, unreinforced, fine graded and coarse graded fibres, single sided, double sided and double sided mixed fibres have been tested. The properties of each tests can be seen on Table 1. At first, fiber content was taken as 2% of dry weight of sand, however, as the mass of fine and coarse fibres were different and the contribution of the fibres are via friction surfaces, a decision was taken to vary the fibre content based on the surface area of fibres.

A set of 41 direct shear test were conducted under four normal stress of 100 kPa, 200 kPa, 300 kPa, 400 kPa, in order to determine the effect of fibre inclusion combinations on the mechanical behaviour of sand. A constant shear rate of 1mm/min and a maximum displacement of 8 mm were used.

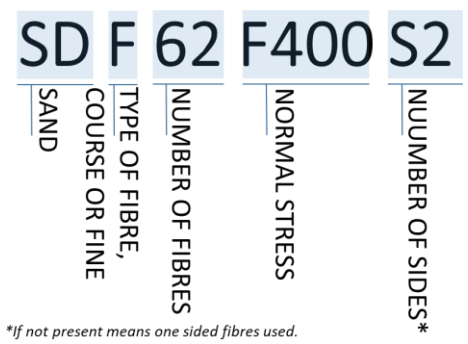


Figure 3: Notation used for short names of the tests.

The notation in Figure 3 is divided in sections: first section indicates the type of soil, second section is indicating the type of fibre (coarse or fine) third section is showing number of fibres inside the specimen, fourth section is applied normal stress and if present, the last section is configuration of fibres (one sided, two sided etc.).

Table 1. Physical properties of soil samples.

Short Name	***Fiber Type***	***Consolidation Pressure (kPa)***	***Sample Mass (g)***	***Number of Fibres***	***Fiber Mass (g)***	***Fiber Area (mm^2)***	***Height (mm)***	***Diameter (mm)***	***Sample Volume (mm^2)***	***Dry Unit Weight (kN/m^3)***
SDNF100	No	100.00	149.04	0.00	0.00	0.00	29.36	63.35	92542.06	15.79
SDNF200	No	200.00	149.08	0.00	0.00	0.00	29.14	63.35	91848.63	15.92
SDNF300	No	300.00	149.59	0.00	0.00	0.00	29.02	63.35	91470.39	16.04
SDNF400	No	400.00	149.26	0.00	0.00	0.00	29.22	63.35	92088.18	15.89
SDF102F100	Fine	100.00	149.21	102.00	3.00	8160.00	29.64	63.35	93412.01	15.54
SDF102F200	Fine	200.00	149.03	102.00	3.00	8160.00	29.76	63.35	93809.16	15.46
SDF102F300	Fine	300.00	149.04	102.00	3.00	8160.00	30.31	63.35	95542.74	15.18
SDF102F400	Fine	400.00	151.70	102.00	3.00	8160.00	29.36	63.35	92545.21	15.95
SDC62F100	Coarse	100.00	149.05	62.00	3.00	4960.00	29.78	63.35	93865.89	15.48
SDC62F200	Coarse	200.00	149.04	62.00	3.00	4960.00	29.75	63.35	93771.33	15.49
SDC62F300	Coarse	300.00	149.80	62.00	3.00	4960.00	29.32	63.35	92415.98	15.80
SDC102F100	Coarse	100.00	149.69	102.00	4.70	8160.00	29.93	63.35	94326.08	15.41
SDC102F200v2	Coarse	200.00	149.18	102.00	4.83	8160.00	30.42	63.35	95870.55	15.11
SDC102F300	Coarse	300.00	149.07	102.00	4.73	8160.00	30.33	63.35	95599.48	15.15

SDC102F400	Coarse	400.00	153.84	102.00	4.80	8160.00	30.20	63.35	95177.12	15.70
SDF62F100	Fine	100.00	149.04	62.00	1.83	4960.00	30.02	63.35	94609.76	15.38
SDF62F200	Fine	200.00	149.19	62.00	1.85	4960.00	30.13	63.35	94969.08	15.33
SDF62F300	Fine	300.00	149.08	62.00	1.93	4960.00	29.94	63.35	94363.90	15.42
SDF62F400	Fine	400.00	151.53	62.00	1.93	4960.00	29.94	63.35	94363.90	15.67
SDC62F100S2	Coarse	100.00	149.08	62.00	6.68	9920.00	31.32	63.35	98730.97	14.62
SDC62F200S2	Coarse	200.00	149.28	62.00	6.31	9920.00	31.32	63.35	98707.33	14.65
SDC62F300S2	Coarse	300.00	149.19	62.00	7.13	9920.00	30.68	63.35	96702.67	14.92
SDC62F200S2v2	Coarse	300.00	149.05	62.00	6.31	9920.00	30.38	63.35	95744.47	15.07
SDF62F100s2	Fine	100.00	149.04	62.00	5.48	9920.00	29.78	63.35	93865.89	15.35
SDF62F200s2	Fine	200.00	149.06	62.00	5.52	9920.00	30.25	63.35	95334.71	15.12
SDF62F300s2v2	Fine	300.00	149.23	62.00	5.30	9920.00	30.68	63.35	96715.28	14.93
SDF62F400s2	Fine	400.00	153.50	62.00	5.30	9920.00	30.68	63.35	96715.28	15.36
SDF51C51F100	Mix	100.00	149.21	102.00	3.80	8160.00	29.83	63.35	94010.88	15.43
SDF51C51F200	Mix	200.00	149.56	102.00	3.66	8160.00	30.09	63.35	94830.40	15.34
SDF51C51F300	Mix	300.00	149.20	102.00	3.66	8160.00	29.42	63.35	92718.57	15.64
SDF51C51F400	Mix	400.00	152.86	102.00	3.87	8160.00	30.05	63.35	94701.17	15.69
SDF102F400s2	Fine	400.00	156.00	102.00	3.66	8160.00	29.42	63.35	92718.57	16.36

4 RESULTS AND DISCUSSION

The results have been evaluated in the light of shear stress against horizontal displacement, vertical against horizontal displacement and failure envelope plots.

4.1. Shear behaviour

Consolidated drained direct shear tests were performed to determine the shear strengths and vertical or volumetric strain characteristics of the sandy soil alone and sandpaper (both fine, coarse, two sided and mix of both) mixtures under different normal pressures. The shear stress versus horizontal displacement curves for different normal stresses are shown in Figure 4. As seen in the figure, almost all the samples showed pronounced peaks where afterwards a residual stress was developed. Only the samples reinforced with coarse fibres, tested at 100 kPa normal stress show a strain-hardening behaviour throughout the test, in other words, there were no clear drops on the stress or pronounced peaks (failure points) on the slopes of the curves.

A noticeable increase in the peak and residual shear stress was observed in all reinforced samples under all normal stresses. By saying that, it is clearly visible that the two sided fibres contribute the most in both fine and coarse fibres. Out of those, the fine graded fibres are showing higher shear strength than all specimens, in all normal stresses. It has also been confirmed that the sand paper grading is playing an important role on the shear behaviour of the sample; in this case it was observed that the reinforcement grading chosen, similar to the average sand particle size, yields the highest shear stresses.

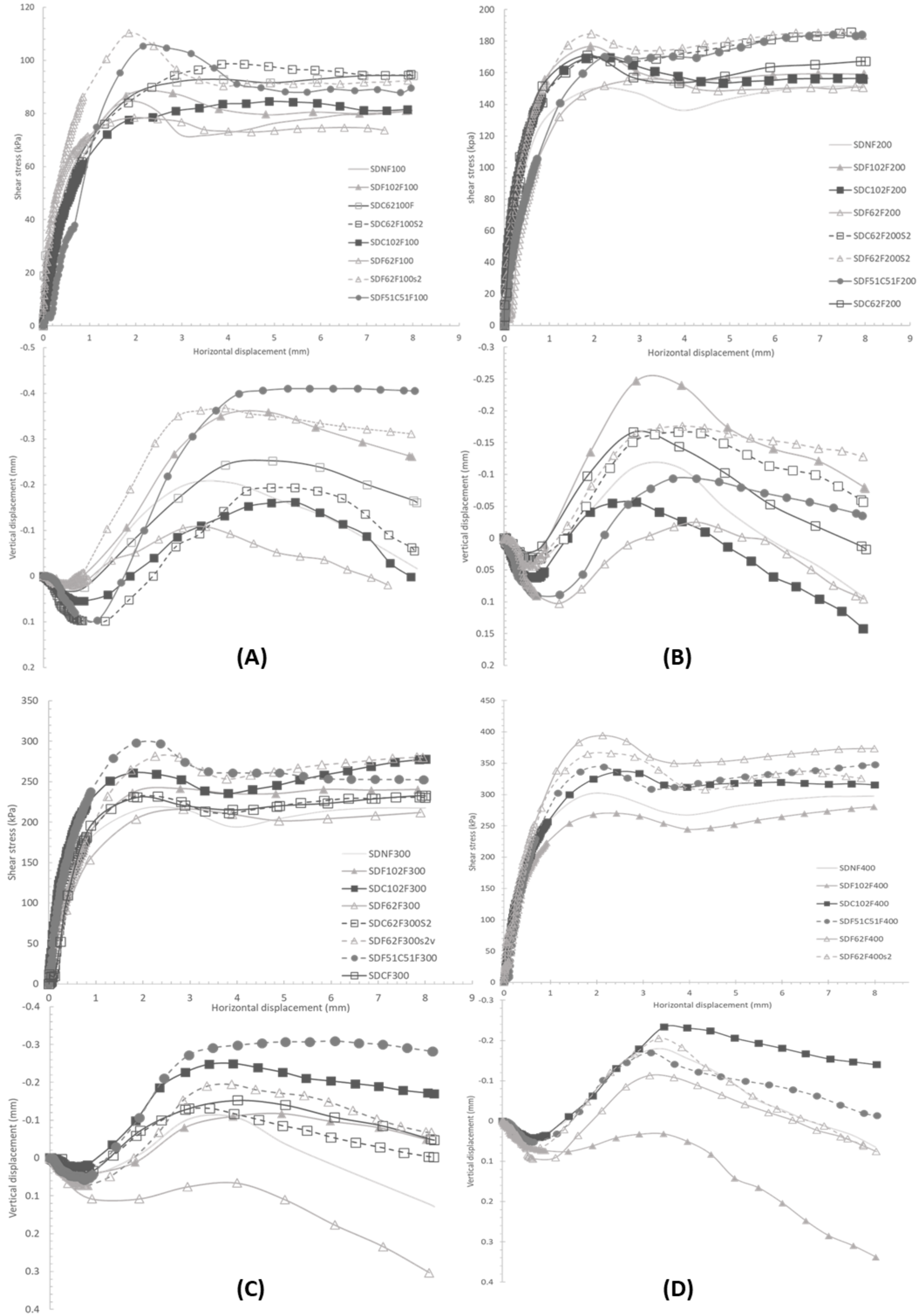


Figure 4: Shear behaviour for normal stress of (a) 100 kPa, (b) 200 kPa, (c) 300 kPa and (d) 400 kPa with and without reinforced soil.

4.2. *Volumetric Behaviour*

Figure 4 also show the volumetric (vertical) strain versus horizontal shear strain characteristics. The vertical strain values, under the selected normal pressures, for the sandy soil alone, are all positive or dilation is taking place. This is consistent with typical sandy soils (Figure 4). It was observed that regardless of the grain type (coarse or fine) double sided fibres are exhibiting considerably low dilation with respect to one sided fibres. It is another fact that the increase in fibre amount within the soil matrix results in higher dilation. In general, the increase of both fine and coarse fibres seems to increase vertical strains specially under higher normal pressures. It was also observed that there is no regular pattern between the volumetric behaviours of coarse and fine reinforced specimens.

4.3. Shear parameters and failure envelopes

The failure envelopes for all reinforced samples plot above the failure envelopes of the unreinforced and the samples that contain 102 fibres. Specimens that contain 102 fibres were the specimens seen to show the highest dilation, followed by contraction. It was also observed that shear stresses and cohesion parameters are higher in the two-sided fibres, specifically the fine one. Also, the peak friction angles for coarse graded fibres are lower than the peak friction angles for fine graded, the biggest difference between values of peak friction angle for the two types of fibres is 7°. In addition to peak friction angles, residual friction angles were slightly lower for the fine fibres. The maximum difference between values of peak and residual friction angle was 1°. As shown in Table 2, the values of apparent cohesion for peak shear stress are greater in reinforced specimens, the maximum difference in the apparent cohesion between the unreinforced and reinforced was 30 kPa, and this value was reached at SDF62V2, reinforced with two-sided fine fibre. Shear strength improvement (Figure 5) shows a maximum difference of 115 kPa at high normal stress (400kPa) which reduces to 22 kPa at the lower normal stresses (100 kPa).

Table 2. Shear stress parameters for tests conducted.

Short Name	*C (kPa)*	*φ Max (°)*	*φ Residue (°)*
SDNF	11.4	33.3	34.1
SDF102F	35.8	37.4	38.5
SDC62F	27.3	34.8	34.8
SDC102F	12.5	39.7	38.2
SDF62F	9.37	34.5	34.5
SDC62S2	32.6	33.9	34.3
SDF62S2	20.5	40.4	39.2

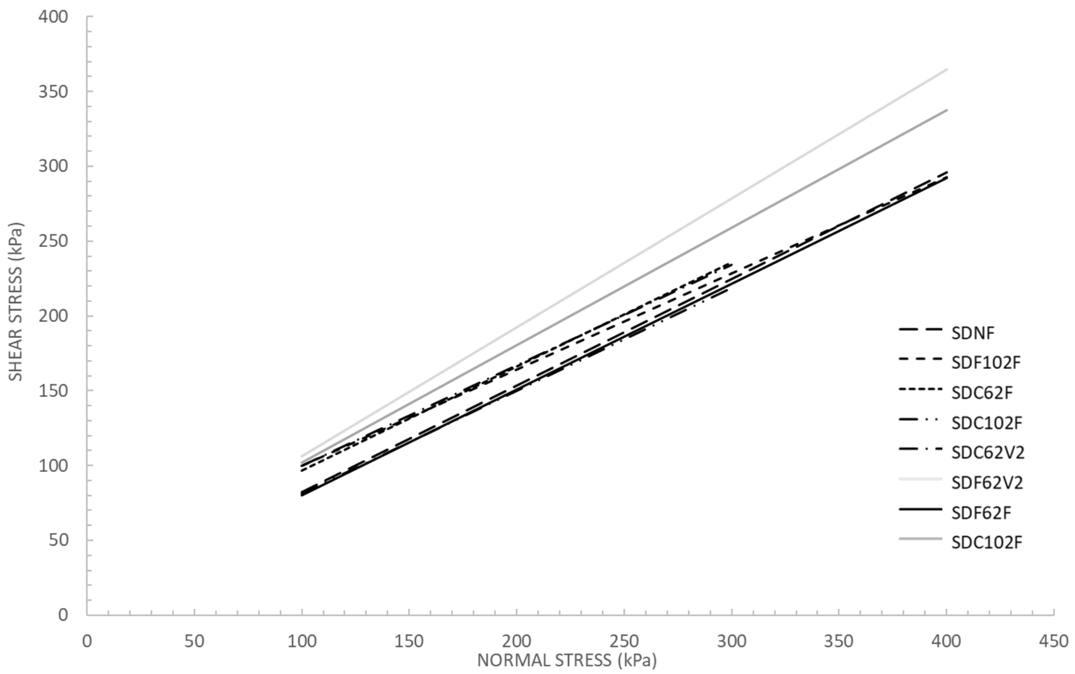


Figure 5: Failure envelopes for maximum shear values.

5 CONCLUSION

This paper presents direct shear test results for different variations of fibre reinforced dense sand and the effects of these fibres on the cohesion and friction angle of the soil. The following are the conclusions that can be drown from this study:

- Almost all the samples showed a pronounced peak where a residual stress is reached afterwards.
- A noticeable increase in the peak and residual shear stress is observed in all reinforced samples, particularly fine graded fibres, under all normal stresses other than the coarse fibred samples under 100 kPa normal stress as these exhibit a strain-hardening behaviour throughout the shearing.
- Coarse and fine two sided fibres have shown the highest increase in strength, with fine graded fibres showing the highest shear strength at all normal stresses.
- The sand paper grading is playing an important role on the shear behaviour of the sample. The grading similar to the average sand particle size is showing the highest shear stresses.
- Regardless of grain type (coarse or fine) double sided fibres are exhibiting considerably low dilation in respect to one sided fibres.
- In general, the increase of both fine and coarse fibres seems to increase vertical strains specially under higher normal pressures. It was also observed that there is no regular pattern between the volumetric behaviours of coarse and fine reinforced specimens.
- Finally, the peak friction angles of coarse graded fibres were found to be lower than the peak friction angles of the fine graded fibres.

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