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Full Length Research Paper

The effect of waste polypropylene fibre inclusion on the mechanical behaviour of sand generated from the aggregate industry

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During the last decades, the rising demand for land reclamation and the utilization of soft or unstable soils led to a great advance in the ground amelioration techniques as a major part of civil engineering around the world. Within this framework, this paper presents the results of an experimental program based mainly on direct shear tests on sand generated from aggregate industry, with and without waste polypropylene (PP) fibre reinforcement, in order to assess the effect of randomly distributed PP fibre on the stress displacement behaviour and shearing strength of this type of sand. The effects of the variation of PP fibre content (limited to 1.5% of the weight of sand) and length (0.5, 1 and 1.5 cm) are investigated. The obtained test results indicate that PP fibre reinforcement increases the maximum shear constraint and changes the sands brittle mechanical behaviour into a more ductile one. These results pave the way to an effective valorisation of such a traditionally useless kind of sand.

Key words: Polypropylene fibres, fibre-reinforced sand, shearing strength, mechanical behaviour.

INTRODUCTION

The recourse to inclusions to reinforce materials of construction is a very old technique; the ancient Egyptians used the straw in mud-based bricks and residuals of linen fibres and hairs in gypsum mortars for plastering. The Basilica Saint-Marc in Venice is constructed, like many other buildings situated on the edge of the lagoon, on wooden pillars in order to improve the bearing capacity of soil. Since the sixties, the spectacular development of the use and performance of composite materials, notably the ones containing fibres, has been favored by the the application of the same idea of reinforcement by inclusions at a very small scale (Magnan et al., 1983). Investigations began with the study of the cause of slope failure in deforested areas of Canada and USA. These early works suggested that the fibrous root material enhanced the mechanical properties of the soil (Gudhus, 1981). The study then developed the look at the addition of natural plant fibres to soil to improve their shear strength characteristics. The study done by Maher and Gray (1990) showed that the addition of natural Palmyra and reed fibres increases strength properties of soil and lowers the post-peak strength reduction. In addition, the study carried out on sand reinforcement techniques show that the inclusion of fibers has a significant effect in increasing effective friction angle (Chen, 2006).

The reinforcement of soils incorporates a variety of techniques consisting of improving the initial resistance of soil by the inclusion of resistant materials, notably metallic, textiles, fibreglass and plastic fibres, in order to form a composite material (Schlosser et al., 1981). Such elements of reinforcement are generally classified according to their geometrical form: linear, bidimensional or tridimensional. The mechanical and hydraulic phenomena that intervene by the system of reinforcement are the improvement of the shearing resistance of soil, the increase of its bearing capacity, and the reduction of the water infiltration following the diminution of the soil permeability (Benson et al., 1994; Dhouib et al., 2004). Previous research (Gregory et al.,

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Table 1. Characterization of the inclusion material.

Properties	Value
Type of fibre	Waste polypropylene
Fibre width	0.2 mm
Fibre length	0.5 ; 1 ; 1.5 cm
Fibre density	1070 $kg.m^{-3}$
Electrical conductivity	Low
Thermal conductivity	Low
Resistance to acid and salt	High
Young Modulus	3,60 $kN.mm^{-2}$
Tensile strength	400 $N.mm^{-2}$

1998; Kumar et al., 1999; Nataraj et al., 1997) has shown that inclusion of fibres increased both the cohesion intercept and angle of internal friction values as compare to values for non reinforced soil.

In this paper, we are mainly interested in evaluating the effect of the use of randomly dispersed waste polypropylene (PP) fibre on the stress displacement behaviour and shearing strength of sand generated from the aggregate industry.

MATERIALS AND EXPERIMENTAL PROGRAM

The experiment consisted of firstly carrying out a physical and mechanical characterization of the sand generated by aggregate industry. Waste PP fibre was then added to this sand in order to study the resulting mechanical behavioural changes.

Sampling

In the present work, we used a manual sample tube for extracting cylindrical samples (diameter = 4 cm) of sand in the open air according to the French Standard X 31-210. The sand that was used for the tests was taken from the aggregate industrial plant of El Fayedh in Tunisia. Representative samples were taken during our visit to the sand stockpile of the plant in October 2007. This sand is traditionally considered as an unsalable waste product of the plant.

The material that was included in the sand consists of segments of waste polypropylene obtained from a plastic industry plant in Sfax, Tunisia, cut into short slight (linear) fibres. Three dimensions of fibre were selected to be added to sand, namely, 0.5, 1 and 1.5 cm.

Characterization

Before the inclusion, sand samples underwent the following identification tests:

i. Water content
ii. Particle size distribution
iii. Particle density
iv. Direct shear test

The direct shear tests were applied to sand samples with and without waste PP fibre reinforcement. Table 1 specifies the characterization of the used inclusion material.

Testing program

Shear tests on dry sand were carried out on specimen size 60 × 60 × 25 mm according to the French Standard P94-071-1 at a maximum deformation rate of 1 mm min^{-1}. Both shear stress and vertical displacement were recorded as a function of horizontal displacements until failure occurs or up to a total displacement of 5 mm. Tests were run at different vertical stresses namely 50, 100, and 200 kPa in order to define the shear strength of reinforced and unreinforced sands over the confining stresses.

A motorized shear box apparatus was used to determine the shear strength parameters (cohesion 'C' and angle of shearing strength 'Φ') of the sand with and without inclusion.

The test program of this study consisted of an initial shear test on samples of non-reinforced sand that served as a starting reference test. Different tests on three sets of samples of reinforced sand were then carried out at varied PP fibre lengths (0.5, 1 and 1.5 cm). The discrete randomly distributed PP fibre in each set was mixed with the sand contents of 0.5, 1 and 1.5%.

RESULTS

Characterization results of non-reinforced sand

The results of the characterization tests of non-reinforced sand are determined in Table 2. According to the Central Laboratory of Bridges and Pavements (LCPC) classification of the granular soils (AFNOR 1999) and with reference to the curve of particle size distribution and to the results summarized in Table 2, we observe:

(i) A rate of 90.5% of elements superior to 80 µm having a diameter smaller than 2 mm.
(ii) A rate of 9.1% of elements lower than 80 µm.

These observations affirm that the studied sand which is a by-product generated from the aggregate industry is slightly slimy granular with a weak cohesion value and a

Table 2. Physical and mechanical characterization of non-reinforced sand.

Water content (%)	Density	Particle size analysis	Direct shear test
5.76	Max dry density : γ = 1.56 g.cm^{-3}	Uniformity coefficient (C_U); $C_U = D_{60}/D_{10}$= 11.25	C = 5.58 kPa
	Min dry density: γ = 1.83 g.cm^{-3}	Curvature coefficient (C_C) ; $C_C = (D_{30})^2/(D_{10}*D_{60})$ = 1.01	Φ = 31.15 °

Effective diameter (mm): D_{10} = 0.08; D_{30} (mm) = 0.27; main diameter (mm): D_{50} = 0.8; D_{60} (mm) = 0.9; particle size range (mm): 0.08 to 4.

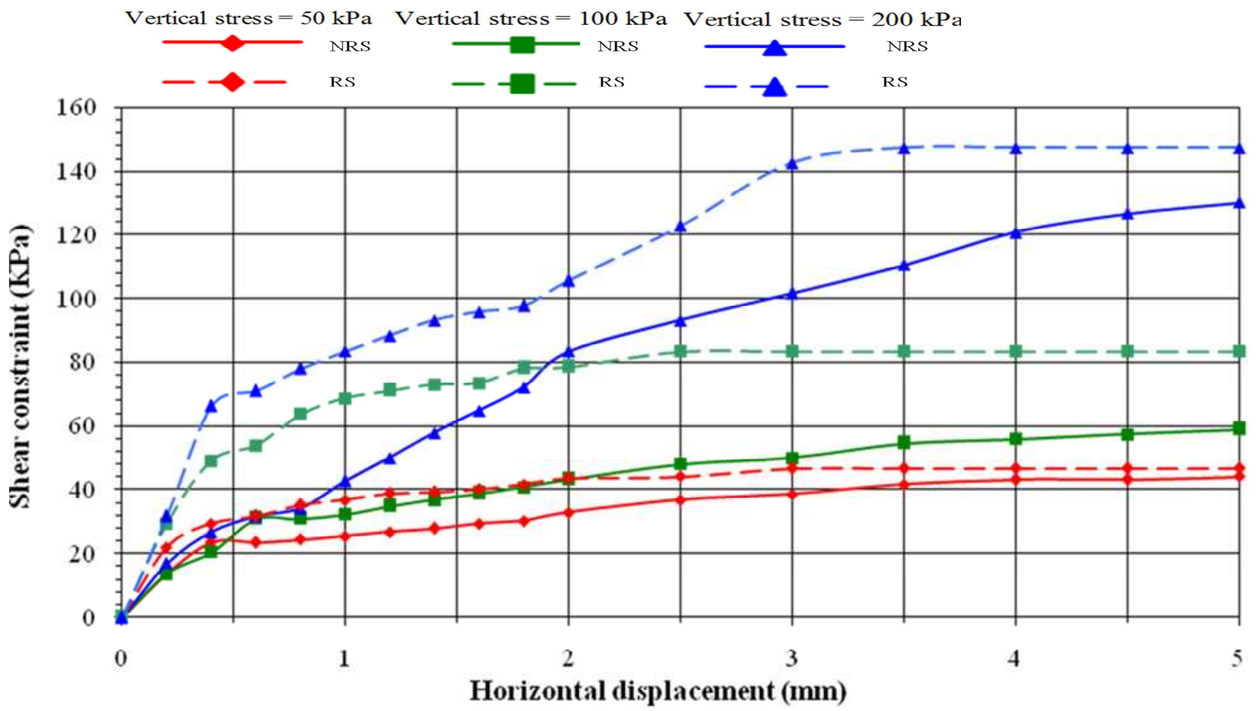

Figure 1. Constraint/deformation curves of the sand under different normal efforts (with or without fibre inclusion at 0.5% of the sand weight, FL= 0.5 cm).

satisfactory friction angle.

Shear test results after PP fibre inclusion

The mechanical characterization results of shear tests carried out on non-reinforced and reinforced sand at well defined lengths and contents as indicated in “testing program” are presented in Figures 1, 2, 3, 4, 5, 6, 7, 8 and 9.

The shear tests results offered by the shear box apparatus clearly demonstrate the influence of the inclusion of PP fibre on the mechanical features of the sand. Indeed, we observe a considerable increase of the maximum shear constraint of the sand according to the length of the included fibres and the inclusion rate as well. In fact, we notice:

(i) An average increase of about 16% of maximum shear constraint when the included fibre length is 0.5 cm.
(ii) An average increase of about 30% when the included fibre length is 1 cm.
(iii) An average increase of about 37% when the included fibre length is 1.5 cm.

This increase is more or less sustained according to different inclusion rates (0.5, 1 and 1.5%). The direct shear test results also show that there is an improvement of the angle of shearing strength (Figure 10) as well as the cohesion value (Figure 11) of the sand according to the rate and length of the included PP fibre. We notice:

(i) An improvement of 13% of the angle of shearing strength when the included fibre length is 0.5 cm and the inclusion rate is 1.5%.
(ii) An improvement of 18% when the included fibre length is 1 cm and the inclusion rate is 1.5%.
(iii) An improvement of 28% when the included fibre length

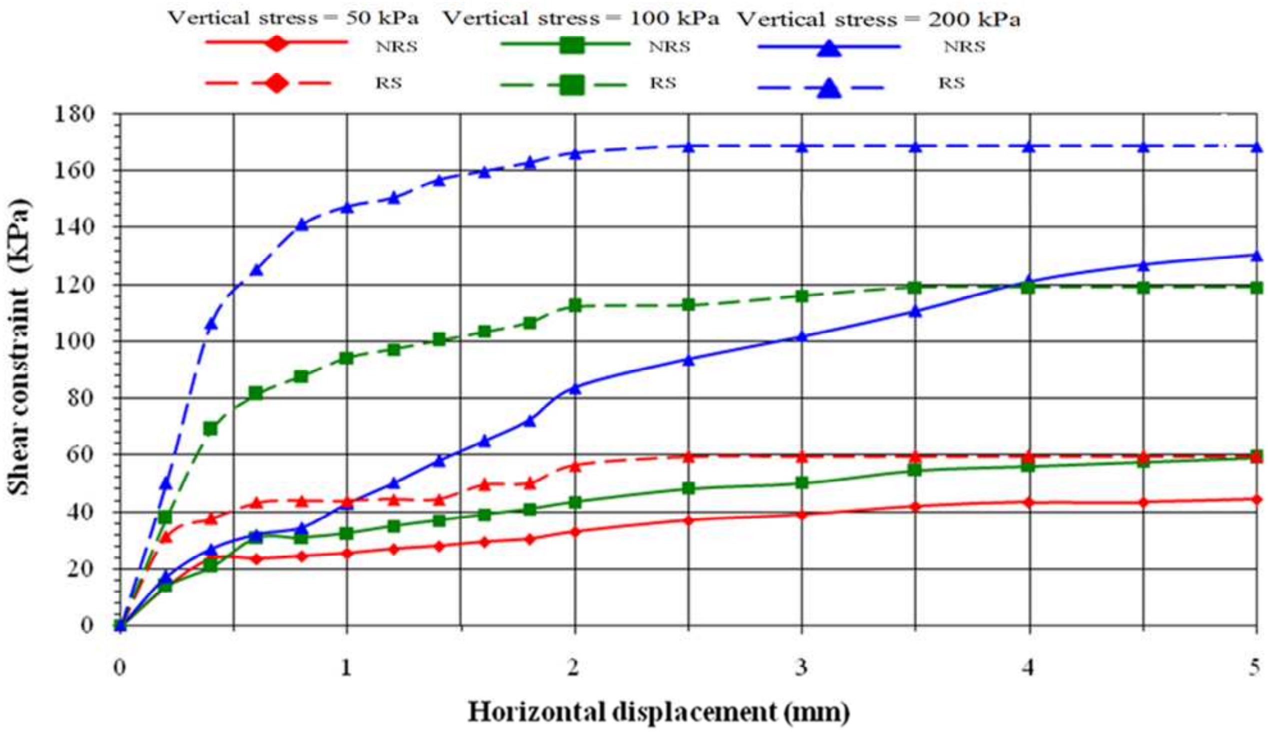

Figure 2. Constraint/deformation curves of the sand under different normal efforts (with or without fibre inclusion at 0.5% of the sand weight, FL=1 cm).

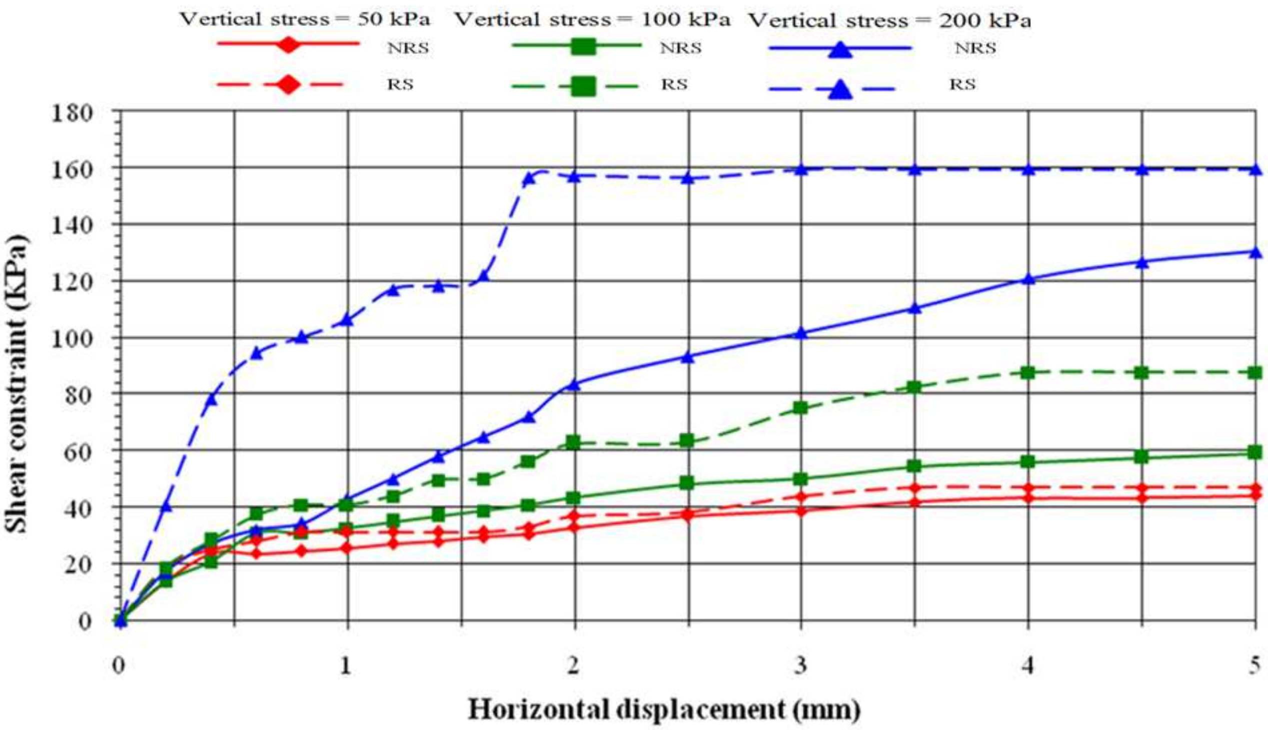

Figure 3. Constraint/deformation curves of the sand under different normal efforts (with or without fibre inclusion at 0.5% of the sand weight, FL=1.5 cm).

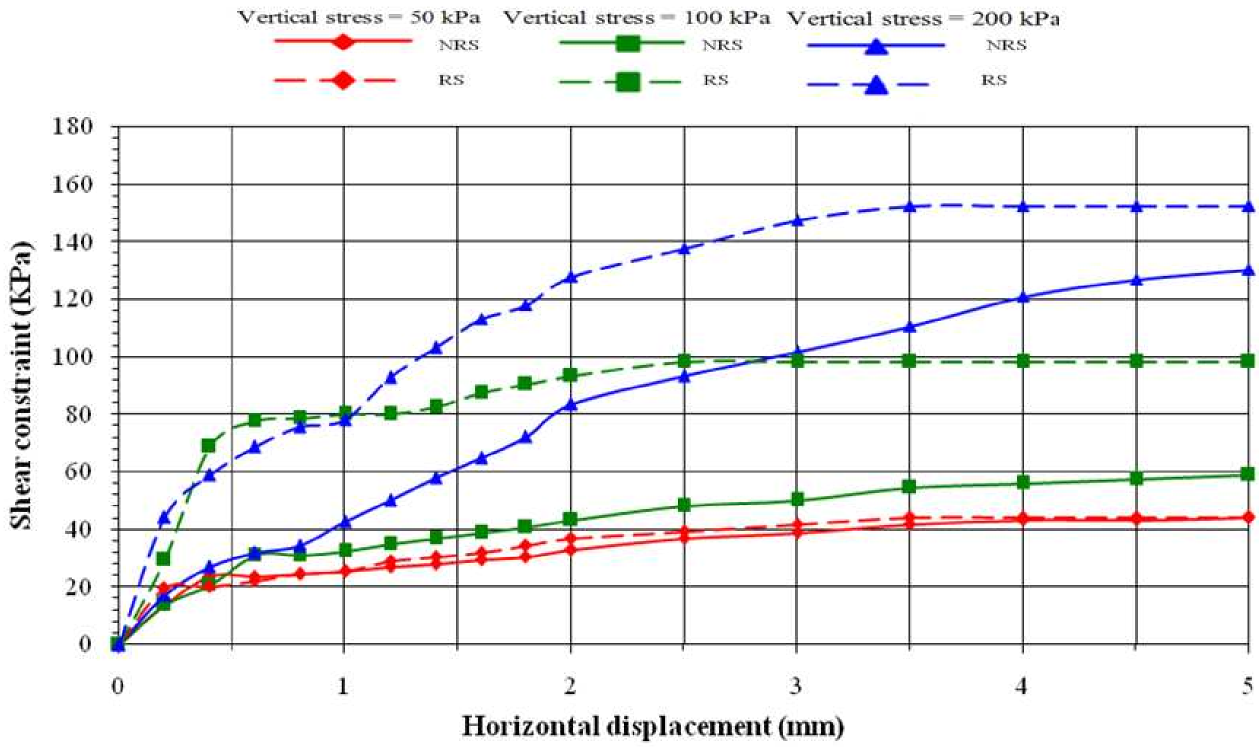

Figure 4. Constraint/deformation curves of the sand under different normal efforts (with or without fibre inclusion at 1% of the sand weight, FL=0.5 cm).

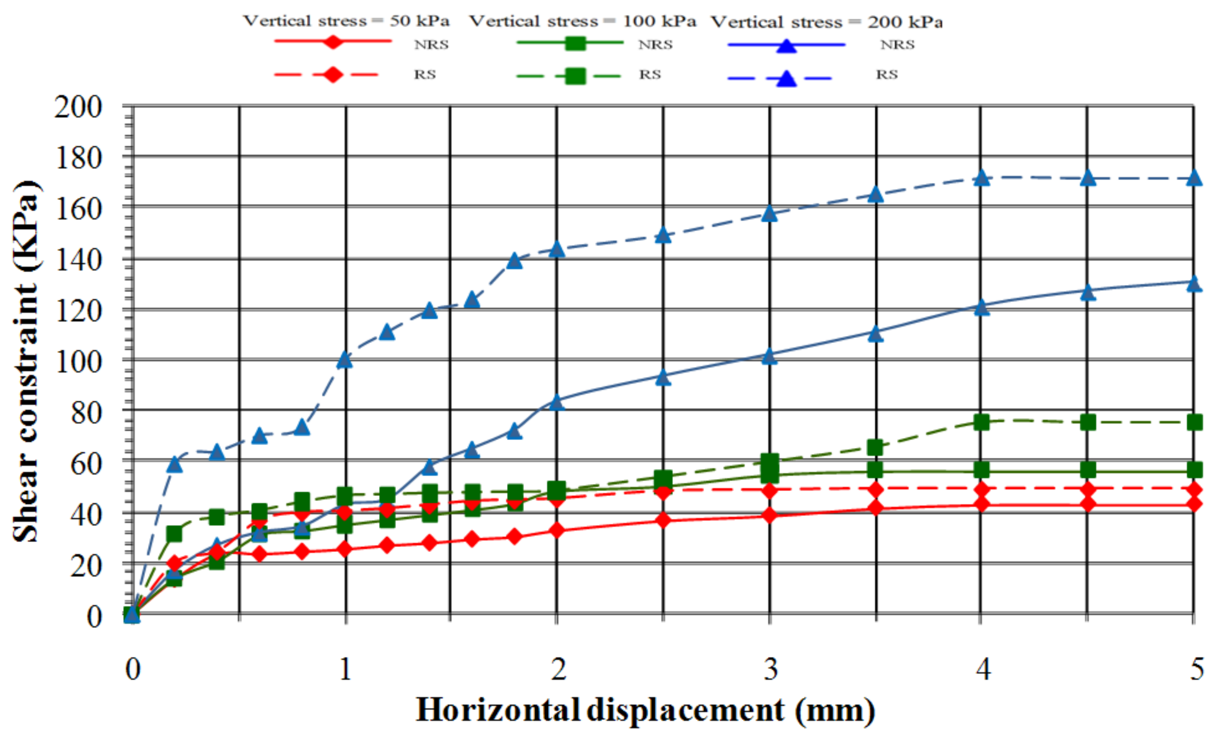

Figure 5. Constraint/deformation curves of the sand under different normal efforts (with or without fibre inclusion at 1% of the sand weight, FL=1 cm).

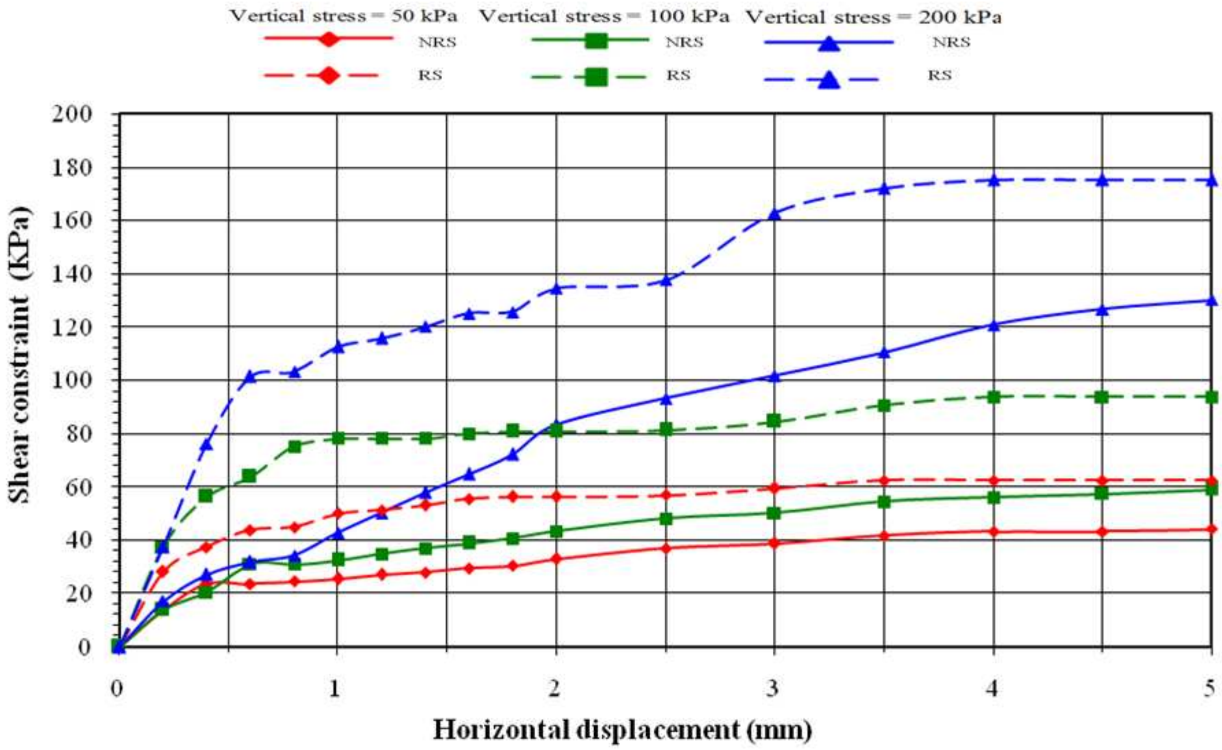

Figure 6. Constraint/deformation curves of the sand under different normal efforts (with or without fibre inclusion at 1% of the sand weight, FL=1.5 cm).

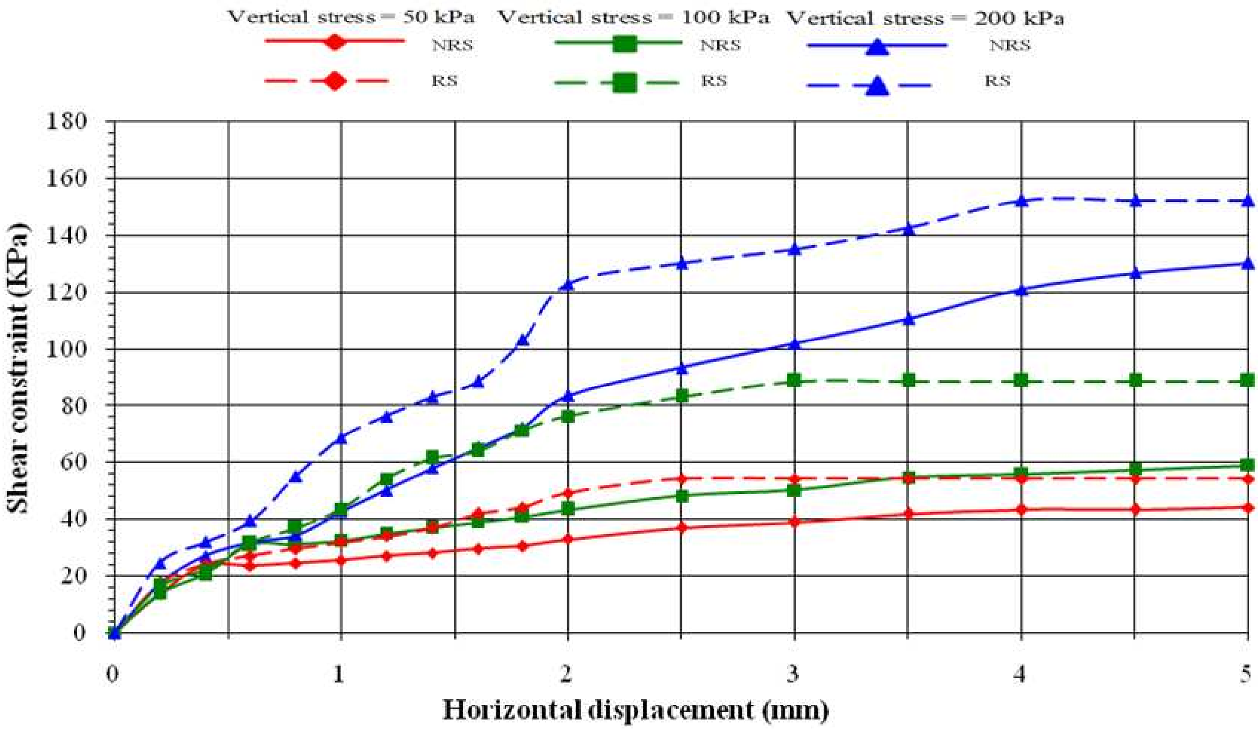

Figure 7. Constraint/deformation curves of the sand under different normal efforts (with or without fibre inclusion at 1.5% of the sand weight, FL=0.5 cm).

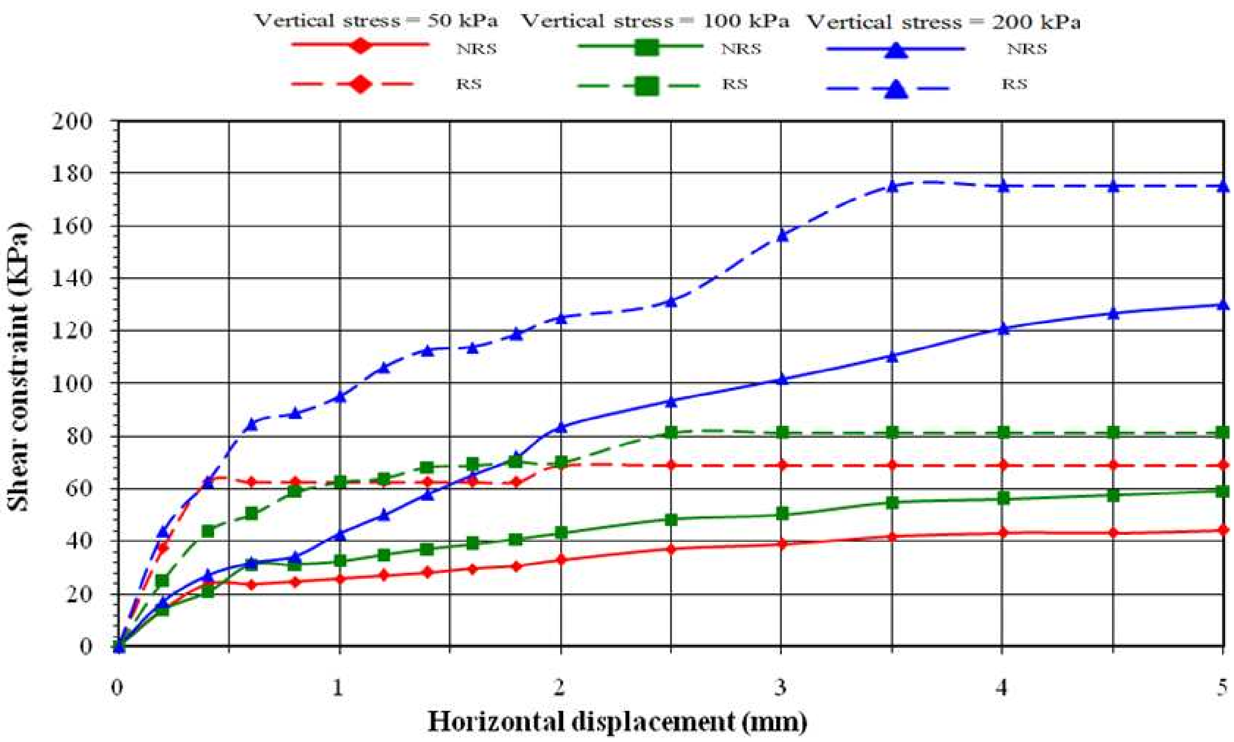

Figure 8. Constraint/deformation curves of the sand under different normal efforts (with or without fibre inclusion at 1.5% of the sand weight, FL=1 cm).

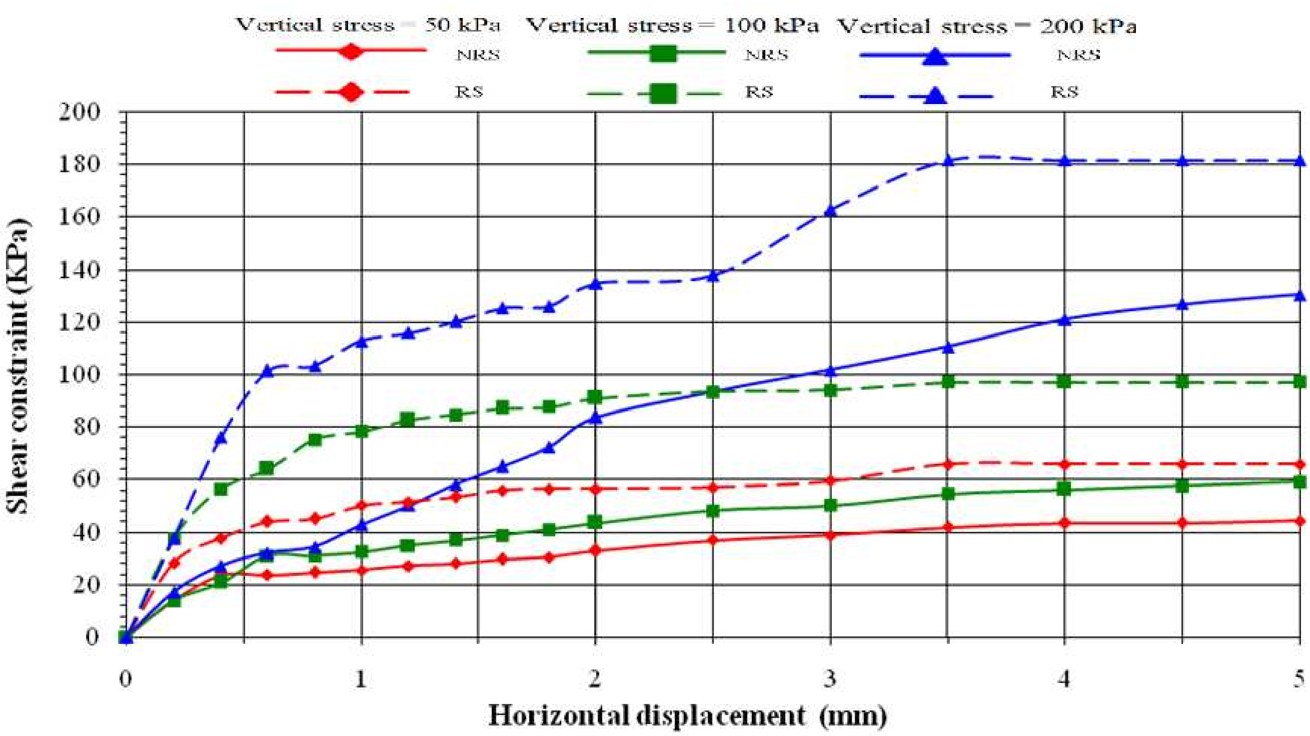

Figure 9. Constraint/deformation curves of the sand under different normal efforts (with or without fibre inclusion at 1.5% of the sand weight, FL=1.5 cm).

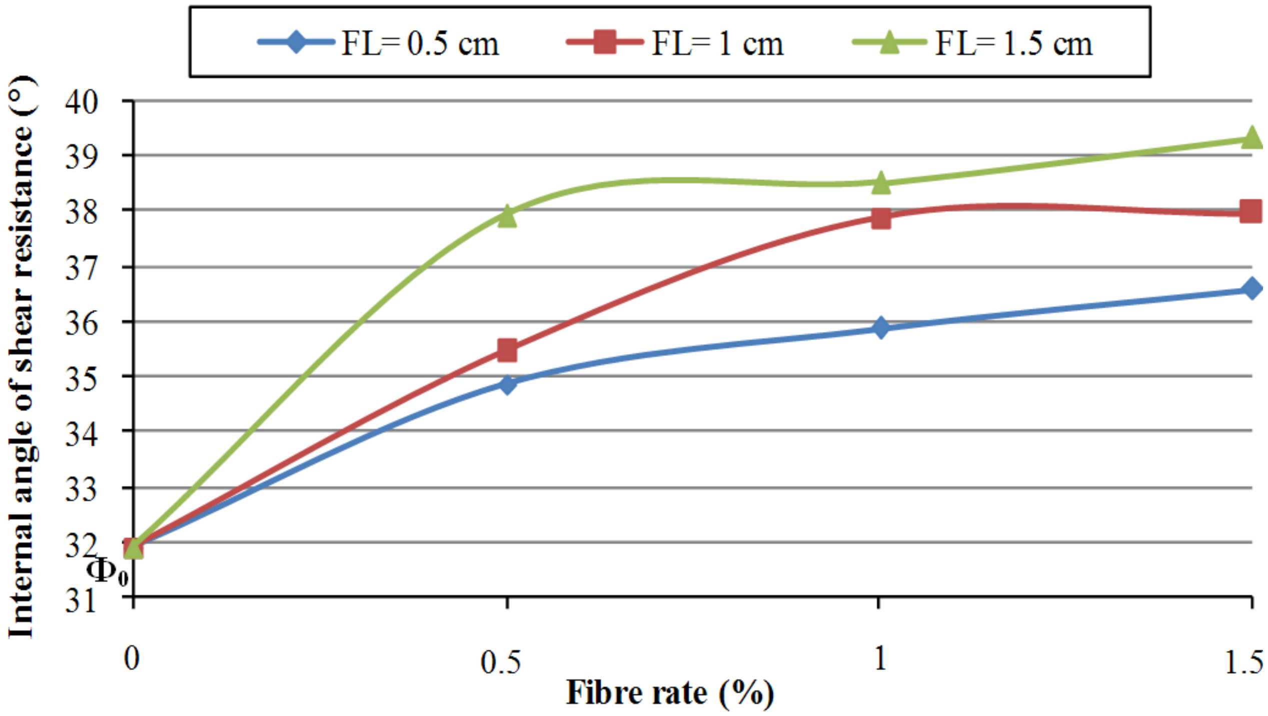

Figure 10. Variation of shearing strength angle of sand according to the rates of included PP fibre different lengths. Φ_0: Friction angle of non-reinforced sand (°); FL: fibre length (cm) .

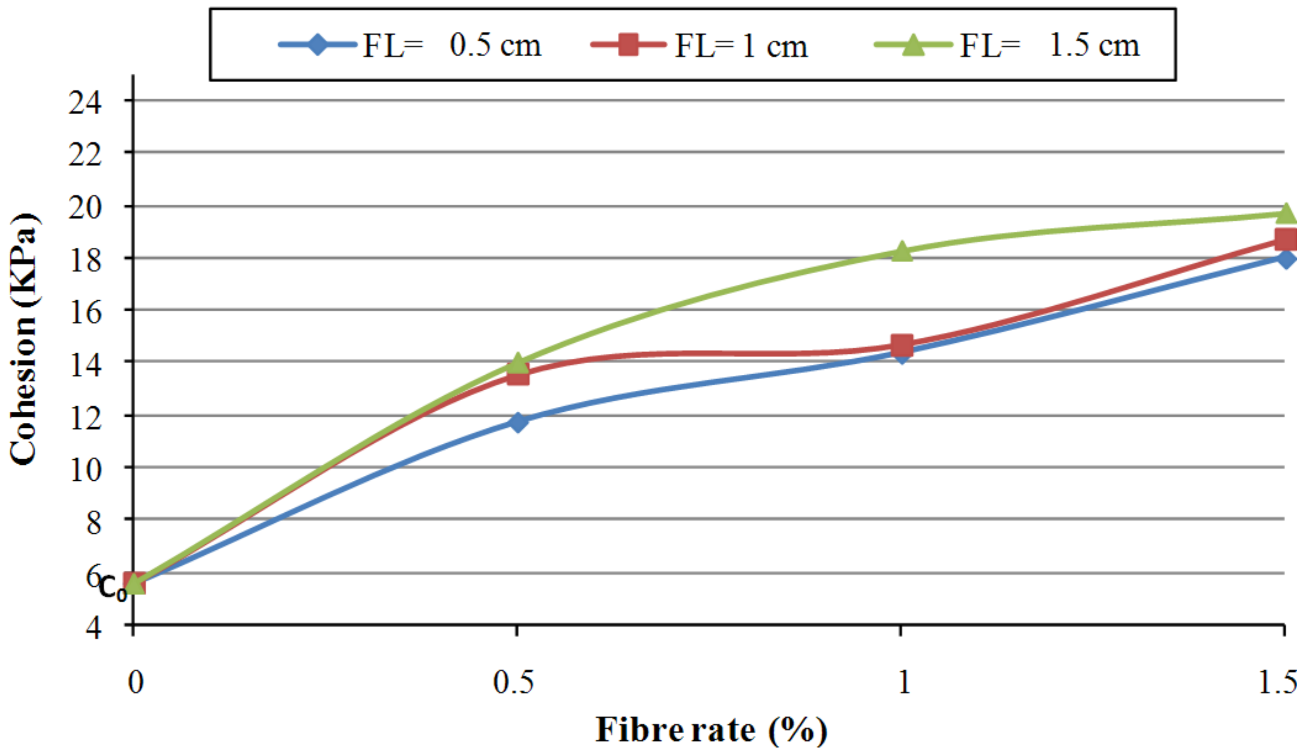

Figure 11. Variation of the cohesion of sand according to the rate of included fibre. C_0: cohesion of aggregate sand without fibre inclusion (KPa); FL: fibre length (cm).

is 1.5 cm and inclusion rate is 1.5%.
- A remarkable improvement of the cohesion value reaching a maximum rate of 300 % when the included PP fibre rate is 1.5% at the three used fibre lengths.

DISCUSSION

The mechanical characterization results of shear tests carried out on sand generated from the aggregate industry before and after including PP fibre at well defined lengths and rates proved that such an inclusion is beneficial as far as the angle of shearing strength and the cohesion value are concerned. This claim has also been confirmed in the works made by Mostapha et al. (2004).
The shear test results of the non-reinforced sand show that the shear constraint increases according to displacement to attain a steady stage at a displacement of about 3 to 4 mm. This phenomenon is almost the same for the vertical stresses namely 50, 100, and 200 kPa. As for the reinforced sand, the same test's results show that the shear constraint increases according to displacement and represent a particular evolution: We firstly notice a shear constraint increase according to displacement to attain a first steady stage at a weak displacement of about 2 to 3 mm; and then, the constraint grows again and reaches a second steady stage clearly observed at the highest vertical stresses.

At a weak displacement within the lower vertical stresses, the included fibre interacts with the sand grains, which is translated into an evolution of the shear constraint. This evolution is mainly due to the friction between the fibre and the sand. As soon as a definite level of vertical stress is exceeded, the second steady stage is reached because of an intensification of the friction; which leads to an improvement of the mechanical behaviour represented by a more ductile behaviour of the reinforced sand as a response to the effect of the included fibre at a high vertical constraint namely 200 kPa. This improvement is embodied in the increase of the angle of shearing strength and the cohesion value of sand at the different inclusion rates and fibre lengths.

It is still worth noting that up to a limit of 0.5% of inclusion rate, the shearing strength angle increases considerably at 12% with the fibre length equal to 0.5 cm, 14 % at 1 cm and 21% at 1.5 cm. Beyond this rate, the shearing strength angle keeps almost the same at different fibre lengths. The behaviour of fibre-reinforced sand is in fact dictated by this rate of inclusion. Any addition above this rate has no substantial effect on the mechanical behaviour of the reinforced sand.

Although the studied sand presents an initial weak cohesion value, the fibre inclusion led to a substantial improvement up to 14 kPa at a 0.5% rate of inclusion. Beyond this limit, the improvement of the cohesion value is less noticeable. Nonetheless, the variation of the fibre's length has no significant effect.

Conclusion

According to the obtained results of the shear tests that were done on sand generated from the aggregate industry before and after waste polypropylene fibre inclusion, the mechanical behaviour of this sand witnesses a considerable improvement after inclusion. It is clear that PP fibre reinforcement increases the maximum shear constraint of the sand and changes its brittle mechanical behaviour into a more ductile one. The addition of PP fibres to the studied sand beyond the limit of 0.5% of its weight does not have a great effect on the improvement of its mechanical characteristics.
Furthermore, using waste polypropylene fibres to reinforce such sand which is in turn initially a useless by-product is in fact a cost-effective way to realise a valorisation of a traditionally useless kind of sand without any risk of affecting the environment in the field of geotechniques; especially that the used fibres are biodegradable at a long term and proven to be inert when interacting with different types of soil.

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