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RESEARCH ARTICLE - CIVIL ENGINEERING

Laboratory Study on Shear Strength Behaviour of Reinforced Sandy Soil: Effect of Glass-Fibre Content and Other Parameters

Ismail Benessalah[1] · Ahmed Arab[1] · Pascal Villard[2] · Marwan Sadek[3] · Abdelkader Kadri[1]

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Abstract The areas near Chlef Valley (Algeria) and the Constructions built on show many phenomena during the last earthquake (El Asnam 1980). A significant decrease in shear strength of Chlef sandy soil, especially in the presence of water, has been reported in numerous researches. Several methods and techniques of soil stability and capacity are available. However, including geosynthetic material, the use of fibres as reinforcement showed some efficiency due to friction between the synthetic material and the soil particles, which increases the bonding between the grains. In this paper, the influence of the glass-fibres content for medium and high densities on the shear strength behaviour of Chlef sandy soil was studied, highlighting the percentage of fibre content (0.1, 0.3 and 0.5 % as a fibre volumetric content), and this will be investigated by a series of direct shear tests. The results will be compared with those of unreinforced sand. Before this work, a further set of direct shear tests will be performed to study the effect of water content on shear strength behaviour (water content of 0, 1.5, 2.3 and 3 %). The experimental results show that the mechanical characteristics are improved with the addition of glass-fibres, especially for wet specimens. It has been showed also that 0.3 % of fibre content is a critical value for fibre contribution to improve the mechanical characteristics. The addition of fibres not only improves the shear strength of soil, but also provides diversity in the resistance against the deformations imposed load, which can be established by a decrease in the soil dilatancy observed by a minimization of the vertical displacement. For the dry case, the reinforcement with fibre has a negative effect on the residual strength especially for average dense samples which may explain probably by the low specific weight of geosynthetics materials.

Keywords Glass-fibres · Water content · Confining · Shear stress · Friction angle · Cohesion

✉ Ahmed Arab
ah_arab@yahoo.fr

Ismail Benessalah
i.benessalah@univ-chlef.dz

Pascal Villard
pascal.villard@ujf-grenoble.fr

Marwan Sadek
Marwan.Sadek@polytech-lille.fr

Abdelkader Kadri
kadri.abdelkader19@yahoo.fr

1 LsmE, Laboratory of Materials Sciences and Environment, UHBC Chlef University, Chlef, Algeria

2 3SR, CNRS UMR 5521, BP 53, 38041 Grenoble, Grenoble Alpes University, Grenoble, France

3 LGCgE, Laboratory of Civil Engineering and geo-Environment, University of Lille 1, Lille, France

1 Introduction

The geosynthetics reinforcement is an interesting solution to treat geotechnical problems, its elements can be used in geotechnical engineering as many forms such as layers, cellular or randomly mixed with soil (discrete fibres), and this last one has recently been used for reinforcing soils. Many studies showed that it was economical and effective way to improve the mechanical characteristics of soil and also due to a more satisfactory performance compared with metal reinforcement. Several studies show the benefit of adding fibres to treat its contribution on the mechanical behaviour of soils, for clays (Andersland and Khattak [1]; Maher and Ho [2]; Al Wahab and EL-Kedrah [3]; Zeigler et al. [4]; Feuerharmel et al. [5]; Kumar and Tabor [6]; Casagrande et al. [7]; Maliakal and Thiyyakkandi [8]). Miller and Rifai [9] based on their test results indicated that fibre inclusion increased the crack reduction and hydraulic conductivity of compacted clay soil. The use of a mixing reinforced fibre for certain applications designed to achieve a decrease in shear strength of soil is summarized by: (a) repair local slope failures with a mixture of fibres and compacted soil (Gregory and Froid [10]), (b) construction of embankment with steeper slopes, (c) minimization of expansion–contraction cracks in condensed layers of clay (Zeigler et al. [4]), (d) mechanical stabilization of flexible routes (Choubane et al. [11]) and (e) during base layer of floor airstrip (Webster and Santoni [12]; Tingle et al. [13]). In addition, the construction of fibre reinforced soils is easily achieved by simply mixing soil with fibres and then properly compacting the mixture (Anagnostopoulos et al. [14]). A study of DOS Santos [15], whose experiments reported on a fibre-reinforced cemented sand under pressures up to 40 MPa, reported that the fibre-reinforcement reduced fracture propagation and cracks in cemented sand particles. Improved mechanical properties of soils due to fibre reinforcement cannot be a general rule to destroy and due to contradictory conclusions of the majority of researchers can be explained by the kind and the shape of the fibres used or the physical characteristics of the soil, their relative density and the method of sample's preparation. Recent research interests to study the behaviour of the low-strength soils reinforced with fibre, and their result shows that the addition of fibres to low resistance of soil can improve the mechanical properties in terms of the peak and residual shear strength and also the deformations caused by the imposed loads. These factors influence on the mechanism of fibre/soil interaction. The results of the studies mentioned above are important for practical applications, and they should be given special attention to the design produced. For example, Michalowski [16] stated that the efficiency of the fibre-reinforcing method depends strongly on the ratio of the fibre size (diameter, length) and grains form. Consoli et al. [17] realized triaxial tests on sand reinforced with uniform-end ethylene terephthalate fibres with an effective diameter of 0.16 mm (coefficients of uniformity and curvature of 1.9 and 1.2, respectively, and a relative density of 70 %). These tests showed that the addition of fibres significantly increased the resistance in peak and residual shear strength while not seemed to be affected. Yetimoglu and Salbas [18] showed that the addition of the fibres does not increase the maximum shear strength and therefore does not increase the angle of internal friction, and then, it slightly decreases the shear rigidity and slightly increases the residual strength of the sand.

This paper presents the experimental results on the influence of glass-fibres on the direct shear strength behaviour and the vertical displacement change of Chlef sandy soil. Tests were conducted using different fibre contents, and expressions for obtaining strength parameters, namely cohesion, friction angle and stiffness, are proposed.

The main aim of this research is to study the effect of glass-fibre reinforcement on the strength and stiffness of soil. A series of direct shear tests were carried out to evaluate the influence of glass-fibres on the soil mechanical behaviour.

2 History and Geological Context

Most of the northern Algerian cities lie in earthquake-prone zones. Chlef (formerly known as El Asnam) and other important cities have been affected by damaging earthquakes in the last century. The last earthquake of magnitude 7.3 (wave magnitude of 7.3) occurred on 10 October 1980 at 13:25:23.7 local time (12:25:23.7 GMT). The Earthquake Pliocene of the main shock was located 12 km in the east region of Chlef city (210 km west of Algiers) at latitude 36.143°N and longitude 1.413°E with a focal depth of about 10 km. The approximate duration of the quake was between 35 and 40 s. The event, commonly referred to as the Chlef earthquake, was among the most disastrous earthquakes that have affected the northern region of Algeria. The earthquake devastated the city of Chlef, population estimated at 125,000 and the nearby towns and villages. The large loss of life (reportedly 5000–20,000 casualties) and property was attributed to the collapse of buildings. In several places of the affected area, especially along Chlef river banks, great masses of sandy soils were ejected on to the ground surface level. A major damage to certain civil and hydraulic structures (earth dams, embankments, bridges, slopes and buildings) was caused by this earthquake.

Chlef city lies in a broad alluvial valley flanked to the north and south by ranges of hills that rise to a height of approximately 1000 m. The valley is drained by the Chlef river. Although there was clear evidence of different types of soil failure, some of these failures occurred in a region where engineered structures existed; thus, loss of life and property because of soil failure was important. Settlement of structures may have occurred, particularly in fill areas, and most backfills behind bridge abutments settled. Numerous slope failures were observed in the mountains, some involving the whole side of hills in the region of fault movements. Some major slope failures were observed in the city of Chlef. Soil liquefaction occurred over widespread areas in the flood plain of the Chlef river, particularly in the region of Chlef and surrounding areas. Numerous sand boils were visible. Some of these were 4 m in diameter. Water spouts up to 2 m high were reported in many of the sand boil areas. Partially as a result of liquefaction subsidence, a large earthquake lake formed south-east of the canyon mouth where the Oued Fodda and Oued Chlef rivers join and flow north-westward through the uplands on the up-thrown block of the Oued Fodda fault.

3 Materials and Laboratory Procedure

The experimental programme is a series of direct shear test that was performed on Chlef sandy soil obtained from areas of the river, unreinforced and reinforced with glass-fibres (fibre volumetric content varied from 0.1, 0.3 and 0.5 %), and a confining pressure of 50, 100, 200 and 300 kPa. Another parameter was studied; water content of 0, 1.5, 2.3 and 3 % is problematic. All tests were performed at loading rate of axial strain equal to 1.00 mm/min.

3.1 Materials

The soil used in this study was obtained from Chlef valley (Algeria) in the same area, with fine content (*fc*) equal to 0.5 %. The soil is medium sand with a mean grain size $D_{50} =$ 0.603 mm. The unit weight of the soil particles $\gamma_s = 2.653$ g/cm^3 according to ASTM D854-83 [19]. The silt is no plastic with a plasticity index of 6 %. This sand is used as raw material for the preparation of the specimens. The particles of Chlef sand are with a reduced grain shape and consist mainly of quartz with some carbonate materials (Fig. 3a), and they are generally isometric particles. Grains ranged in size from 0.08 to 2 mm, and the grain size distribution was obtained based on ASTM D422-63 [20]. The basic properties of the sand are given in Table 1, and particle size analysis is represented in Fig. 1. The sand can be classified as poorly graded with little or no fines with the letter symbols SP according to the USCS. All the samples were collected from the bank-liquefied layer of the deposit areas of 6.00 m (Fig. 2). Many tests were carried out on the Chlef sand (Arab [21], [22]; Arab et al. [23]; Krim et al. [24]; Della et al. [25]; Belkhatir et al. [26], [27], [28], Djaafar et al. [29]). Discrete glass-fibre of name EWR800 (E fibreglass woven roving) was used in this study to build the examined sand specimens (Fig. 3b). Their most significant index properties and strength, as given by the manufacturer, are as follows: $D_F = 0.024$ mm of diameter, length L_F variant (used lengths of 10 mm), aspect ratio (length/diameter) ≈ 416 depends on the selected length and specific weight = 800 g/m^2. All the reinforcement properties were determined by testing as per relevant ASTM standards.

Table 1 Properties of the sand and their examined ratings

Composition	Chlef sandy soil
The average size, D_{50} (mm)	0.6033
Uniformity coefficient, Cu (.)	2.53
Coefficient of curvature, Cc (.)	0.9877
USCS classification	SP
Specific weight of solids, γ_s (KN/m^3)	26.5298
Minimum void ratio, e_{min} (.)	0.6325
Maximum void ratio, e_{max} (.)	0.7957
Fine content (%)	0.5
Plasticity index of fine element (%)	6

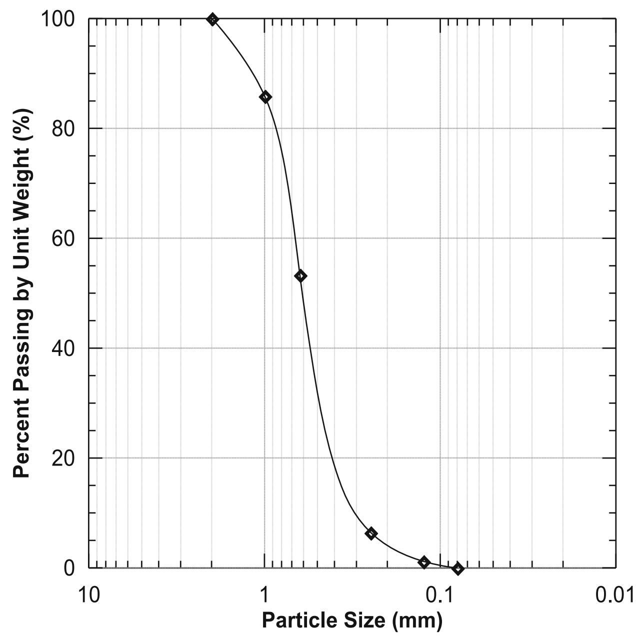

Fig. 1 Grain size distribution curve of Chlef sand

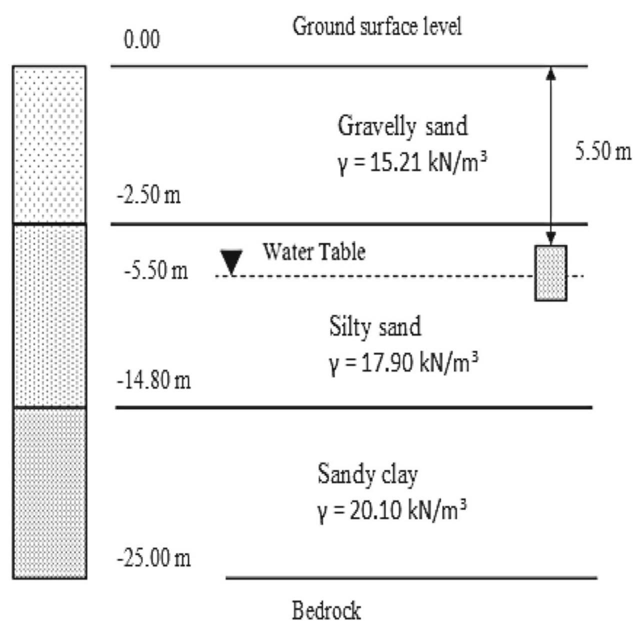

Fig. 2 Geotechnical profile of the soil deposit at the site

An extensive direct shear test programme was conducted to investigate the parameters that affect the shear strength behaviour of the fibre-reinforced sands.

3.2 System and Test Procedures

A total of 128 direct shear tests of samples are reinforced with fibres of different volumetric contents (0, 0.1, 0.3 and 0.5 %). The tests were done under a constant mass represents the vertical stress (50, 100, 200 and 300 kPa). Two categories

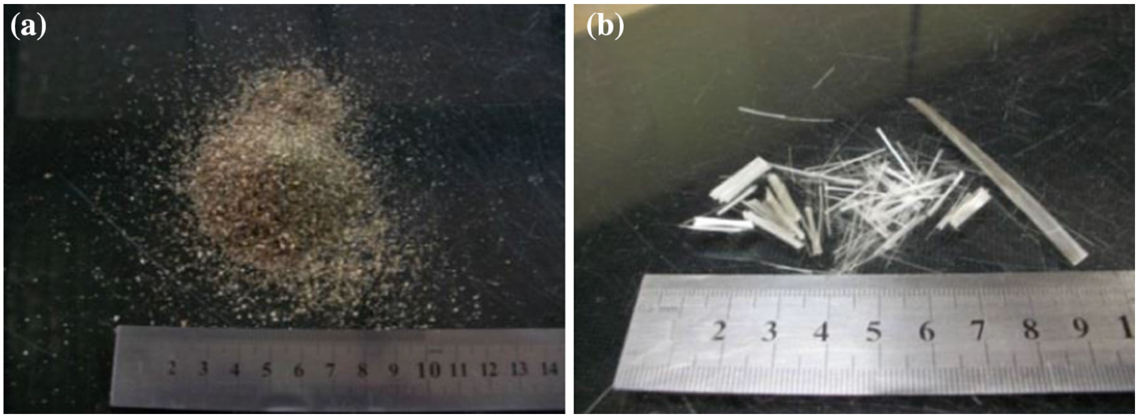

Fig. 3 Materials used in this study: Chlef sand (**a**) glass-fibres (**b**)

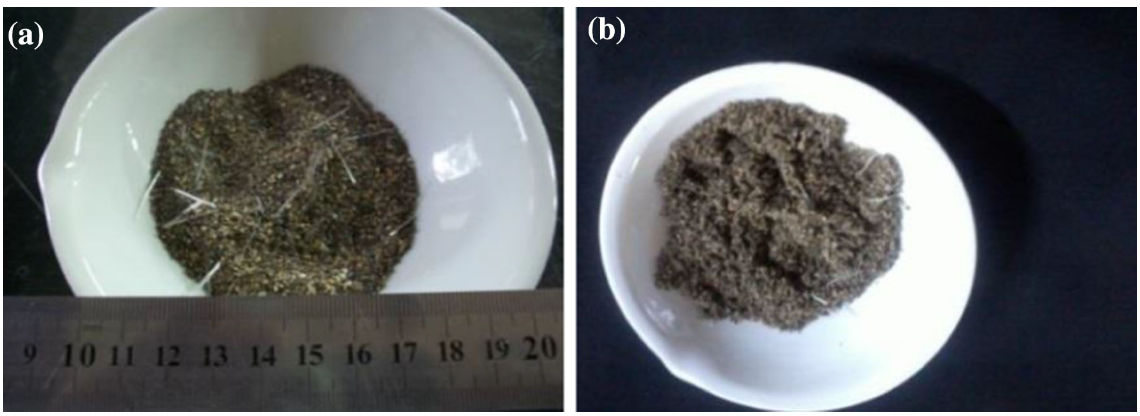

Fig. 4 Samples preparation: **a** dry specimens, **b** wet specimens

of samples preparation have been used (Fig. 4); dry specimens and wet specimens that characterize by water content of (1.5, 2.3 and 3 %). All tests were done on both medium and high relative densities (48 and 87 %). In this study, we have avoided the loose sand case because the majority of soils treated by fibres are generally groomed or compacted. Small direct shear test apparatus with a box specimen of 60 × 60 mm in the plan was used to perform shear tests on fibres reinforced sand. The thickness of all samples was 25 mm.

The calculations of weight and content of sand used to obtain a fibre reinforced with a volume (V) and a void ratio (e_0) equal to those for unreinforced specimen were based on the equations developed for the hypothetical case (Anagnostopoulos et al. [14]). In this case, a particular soil mixture is changed by replacing a portion of a full solid by another component which has a lower density such that the entire solid mass remains unchanged (Ozkul and Gokhan [30]; Michalowski and Zao [31]). The procedure was followed:

1. Using the void ratio (e_0) and the volumetric fibre content (ρ_v), the corresponding percentage of fibres (ρ_f) in weight was calculated as the formulas:

$$\rho_f = \frac{(1+e_0)\cdot\gamma_f\cdot\rho_V}{(1+e_0)\cdot(\gamma_f-\gamma_S)\cdot\rho_V\cdot\gamma_S} \tag{1}$$

where γ_f and γ_s are fibre and solid unit weight, respectively. P_f is defined as the mass of the fibres relative to the mass of dry sand.

2. The mass of dry sand W_S and the mass of fibre W_f required to obtain the test specimen with the total volume of the box V were calculated by the following equations:

$$W_S = \frac{V}{1+e_0}\cdot\frac{(1-\rho_f)\cdot\gamma_S\cdot\gamma_f}{(1-\rho_f)\cdot\gamma_f+\rho_f\cdot\gamma_s} \tag{2}$$

$$W_f = \frac{V}{1+e_0}\cdot\frac{\rho_f\cdot\gamma_S\cdot\gamma_f}{(1-\rho_f)\cdot\gamma_f+\rho_f\cdot\gamma_s} \tag{3}$$

3. During the compaction process, the specimen size (h) within the shear box was carefully measured and recorded to estimate the equivalent volume (V) used (Anagnostopoulos et al. [14]).

4 Results and Discussion

4.1 Water Content Effect

Several studies on the effect of moisture (water content) on the mechanical behaviour of soils have proved a remarkable decrease in the mechanical characteristics measured in terms of studying their behaviour in charges. In this way, we will study the effect of the water content on the mechanical behaviour of Chlef region's sand. In the graphs below, we will set the parameters studied in this work (density, confining pressure) to highlight the effect of the water content on the mechanical behaviour of sand used. The study of the effect will be made by comparing the results obtained from the direct shear tests at different water contents (1.5, 2.3 and 3 %) in unreinforced specimens, and their results will be compared to following results with dry sand.

4.1.1 Medium Dense Samples ($D_r = 48\,\%$)

Figure 5 presents the effect of water content on the mechanical properties of the sand studied under a fixed confining pressure of 200 kPa and an average relative density $D_r = 48\,\%$. A proportional increase in the shear strength with the horizontal displacement has been observed in Fig. 5a, and this relationship will be constantly 2.5 mm of horizontal deformation for the dry specimens than slight decrease in a residual strength of 180 kPa. It is not that the phase of stabilization and residual shear strength has not been found for wet specimens. The shear strength decreases with increasing water content, and it was at the end of test 173, 161 and 150 kPa for water content of 1.5, 2.3 and 3 %, respectively. Figure 5b represents the variation of vertical displacement versus horizontal displacement; the dry samples test has dilatancy behaviour representing by an augmentation of the vertical displacement until a horizontal displacement of 2.5 mm than a contractancy phase until the end of the test. All the wet specimens showed contractancy behaviour established by augmenting the specimen's volume that will be increased with increasing water content. The results of Fig. 5a allowed as to trace the intrinsic curves showed in Fig. 5c of the Mohr–Coulomb, and based on these curves (of equations type of $\tau = \sigma \cdot tg\varphi + c$), we can obtain the mechanical characteristics of studied soil. It is observed that the slope of the dry specimen's line is the higher value 0.819, and in the other way, the slope of wet specimen's line 0.781, 0.775 and 0.762 for a water content of 1.5, 2.3 and 3 %, respectively.

4.1.2 Dense Sample ($D_r = 87\,\%$)

Figure 6 shows the effect of water content on shear strength, vertical displacement and development of the intrinsic curves of a confining pressure of 200 kPa, and a relative high density ($D_r = 87\,\%$). Similar gait graphs have been showed comparing with those for an average relative density. With higher values of shear strength, low dilatancy represented by slight deformation comparing with the average dense samples.

Figure 7 shows the effect of water content on the variation of mechanical characteristics (cohesion C and friction angle ϕ) of the soil used versus the water content in specimens. The cohesion decreases proportionally and with a linear manner with increasing water content for the both sides of relative densities (Fig. 7a). A linear decrease also has observed for the friction angle versus the water content in examined samples (Fig. 7b). This rate curve for the behaviour of cohesion and friction angle can mean that the moisture has negative effect on the shear strength behaviour that was established by a low resistance compared with the dry case and a high dilatancy of the samples and finally decreasing the mechanical characteristics of the soil.

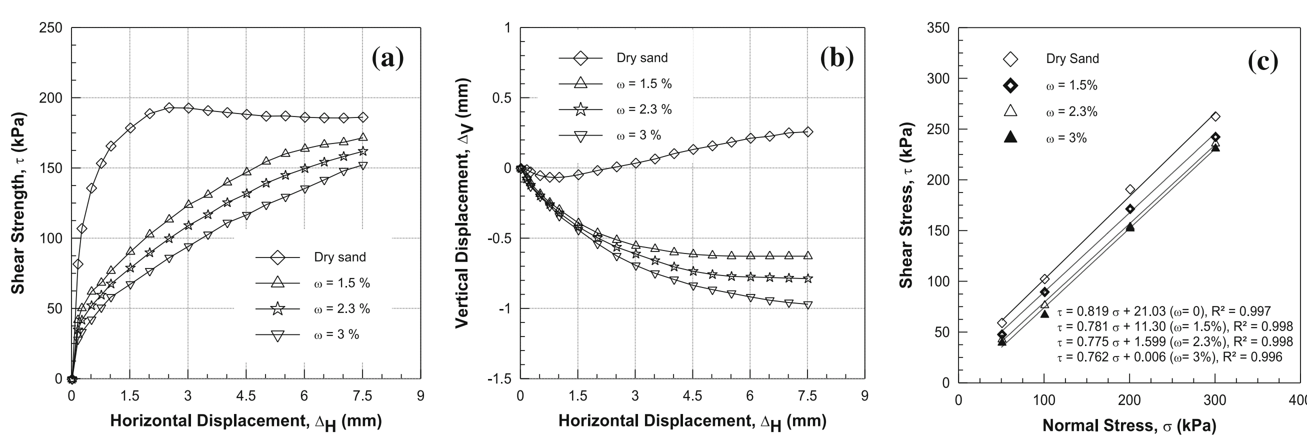

Fig. 5 Effect of moisture on the mechanical behaviour, confining pressure of 200 kPa and an average relative density $D_r = 48\,\%$: **a** variation of the shear strength versus horizontal deformation, **b** variation of vertical displacement versus horizontal deformation, **c** intrinsic curves equation $\tau = \sigma \cdot tg\varphi + c$

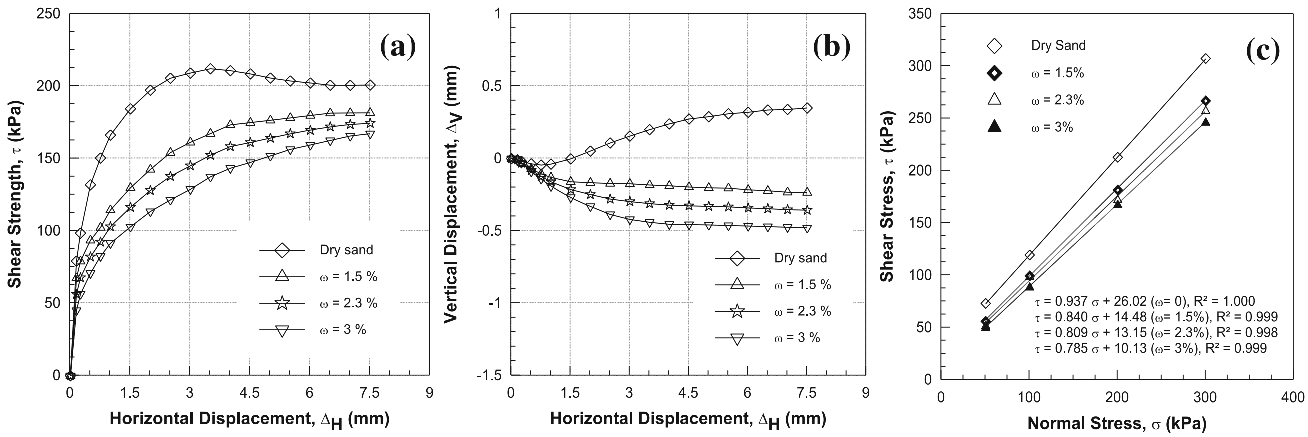

Fig. 6 Effect of moisture on the mechanical behaviour, confinement of 200 kPa and a high relative density $D_r = 87\,\%$: **a** variation of the shear strength as a function of the deformed horizontal, **b** variation of the vertical displacement versus horizontal displacement, **c** intrinsic curves of equation $\tau = \sigma \cdot tg\varphi + c$

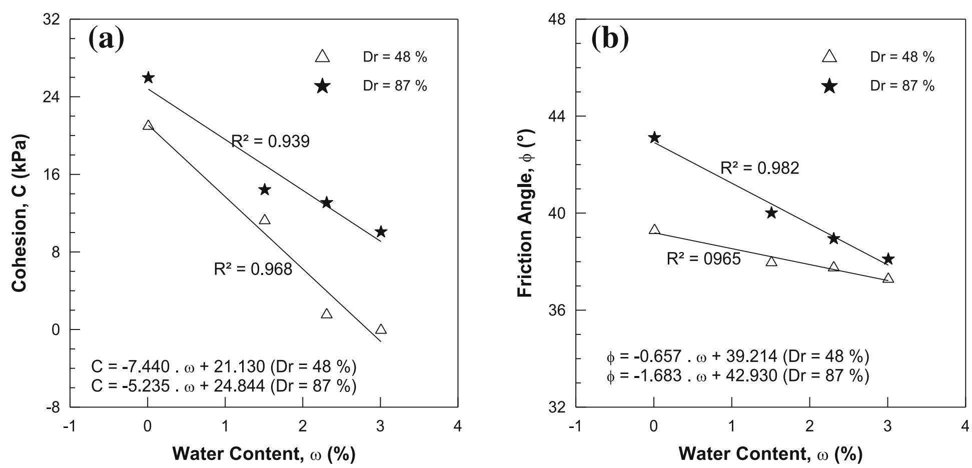

Fig. 7 Effect of water content on the cohesion and the friction angle: **a** variation of the cohesion, **b** variation of the friction angle

4.2 Glass-Fibre Effect on Dry and Wet Sand

4.2.1 Medium dense sample ($D_r = 48\,\%$)

The effect of fibre on the shear strength development and the limits of resistance (intrinsic curves) for an average relative density ($D_r = 48\,\%$) will be stabilized. For the dry samples (Fig. 8a), a proportional increase in the shear strength has been observed during the time of the test until where it will be constant after 2.5 mm of horizontal displacement. It is noticeable that the addition of fibre has improved the time of shear strength development, and it reached the pic strength after 1.5 mm of horizontal displacement for 0.1 and 0.3 % as volumetric content of fibres, and also a low value of residual shear strength observed for samples reinforced by fibres for this case of relative density and specimen preparation (dry samples). Due to the decrease in the mixtures unit weight, Aqeel et al. [32] found at any particular fibre content (Papyrus fibres have been used) an increase in fibre content causes a reduction in dry density. As already explained, this is due to the reduction in average unit weight of the solids in the soil fibre mixture. This result is also in good agreement with that of Parbakar and Sridhar [33].

For the wet samples (Fig. 8b), a significant amelioration has been presented, especially for fibre volumetric content of 0.3 %. The results show that the inclusion of reinforcement increases the shear strength when compared with that of unreinforced soil; the other fibres percentages have a lower value than that of 0.3 %. Similar observations were made by Kumar et al. [6] on fibre-reinforced silty sand and by Maher and Gray [34] on fibre-reinforced sand. All the specimens have shear strength higher than of the unreinforced sand that is established in intrinsic curves (Fig. 8d), where we found that the slope of unreinforced line 0.762, and for the reinforced samples 0.767, 0.772 and 0.632 for fibre volumetric content of 0.1, 0.3 and 0.5 %.

Graphs of Fig. 9 represent the effect of including fibres on vertical deformation of the samples (the volume). In the dry specimens (on the left), the unreinforced samples show a dilatancy phase until a horizontal displacement of 2.3 mm, than a contractancy phase represented by a decrease in the vertical displacement to the value of 0.25 mm at the end of the

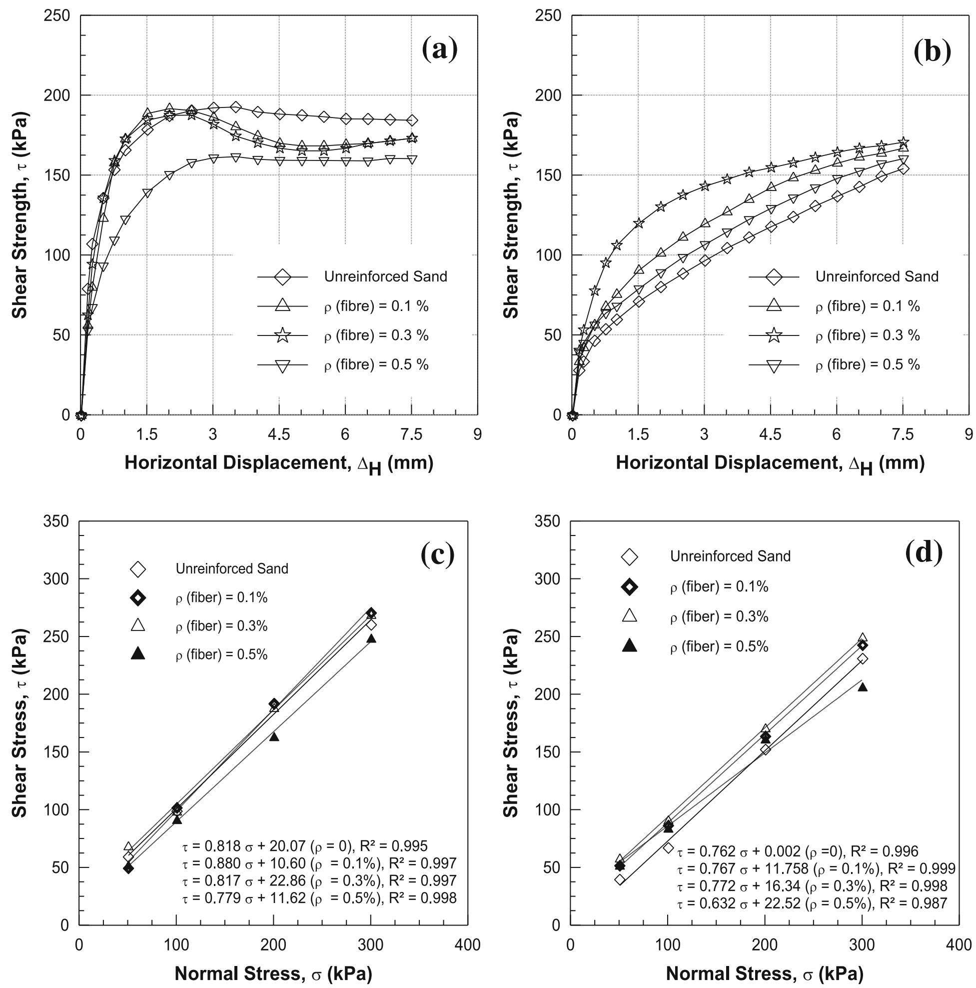

Fig. 8 Effect of fibres content on shear strength, confining pressure of 200 kPa and an average relative density $D_r = 48\,\%$: **a** variation of the shear strength according to the deformed shape of horizontal dry sand, **b** variation of the shear strength as a function of the horizontal deformed with a water content $\omega = 3\,\%$, **c** intrinsic curve of a dry sample, **d** intrinsic curve with a water content $\omega = 3\,\%$

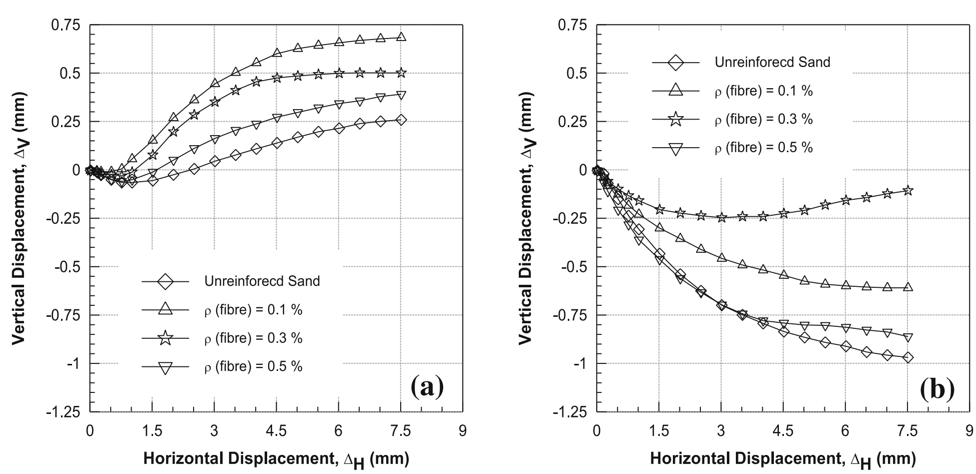

Fig. 9 Effect of the fibres on the vertical distortion of confining pressure of 200 kPa and a relative density $D_r = 48\,\%$: **a** variation of the vertical deformed depending on a horizontal distorted dry sand, **b** variation of the vertical deformed depending on the horizontal deformed with a water content $\omega = 3\,\%$

test. In the reinforced samples, we observed more decrease in the vertical displacement with increasing fibres content on the samples. The wet sand (in the right) shows that the presence of fibres decreases the volumes of the samples; that effect can minimize the expansion–contraction cracks in the sand, similar to the result for condensed layers of clay in the study of Ziegler et al. [4]. It is also noted that the fibre volumetric content of 0.3 % has the most effect against the deformations caused by loading tensile.

4.2.2 Dense Samples ($D_r = 87\,\%$)

Figure 10 shows a typical direct shear test representing strength development versus horizontal deformation at a con-

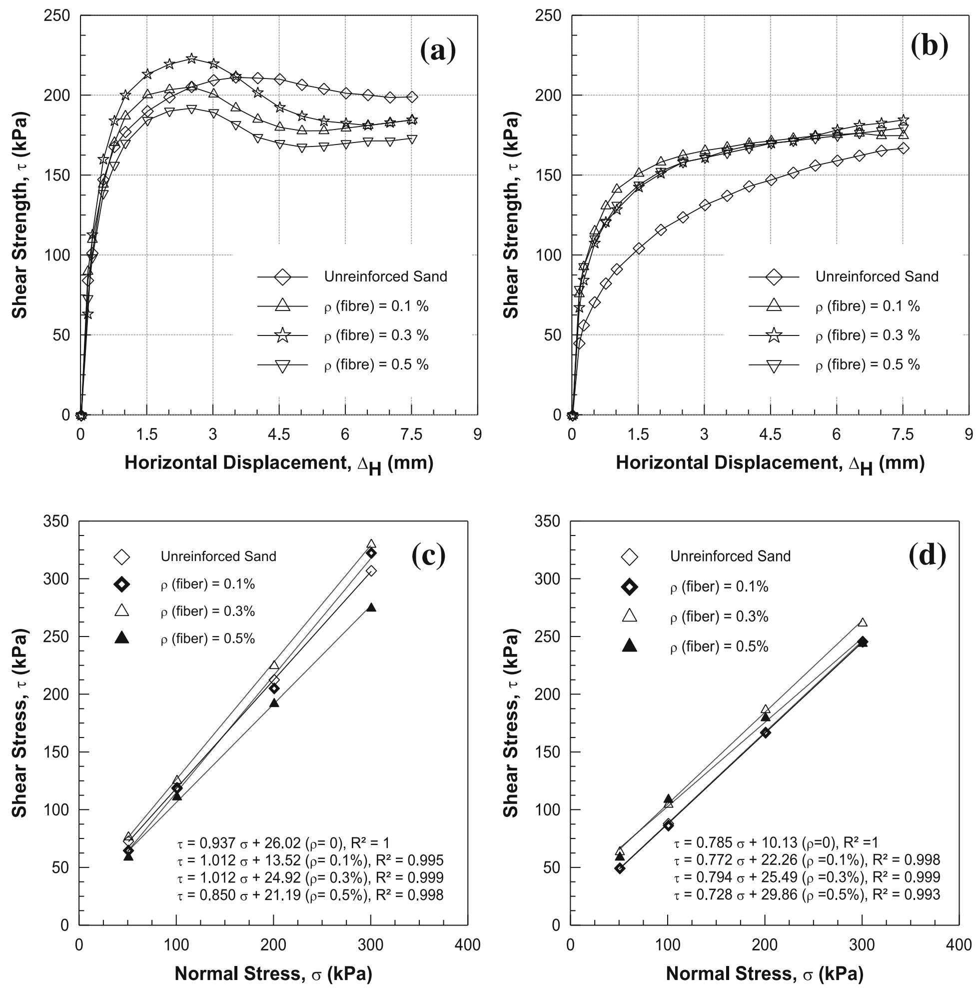

Fig. 10 Effect on the fibres to shear strength of confining pressure of 200 kPa and high relative density $D_r = 87\,\%$: **a** variation of the shear strength according to the deformed shape of horizontal dry sand, **b** variation of the shear strength as a function of the horizontal deformed with a water content $\omega = 3\,\%$, **c** intrinsic curve of a dry sample, **d** intrinsic curve with a water content of $\omega = 3\,\%$

fining pressure of 200 kPa for different samples with a fibre volumetric content ranging from 0.1 to 0.5 % and preparing with high relative density ($D_r = 87\,\%$) for two types of samples characterized by the water content. In the case of dry samples, Fig. 10a, c shows the shear strength development and the shear stress depending on the horizontal displacement and the vertical stress, respectively; same appearance has been shown comparing the case of average dense case with a high effect of the fibre volumetric content of 0.3 % at a horizontal displacement of 2 mm for the pic shear strength and even for the slope of intrinsic curve. It can be noted that the effect of the fibre content has a passive effect on the residual shear strength where it was between 170 and 190 kPa for the reinforced dry samples compared with unreinforced dry sample where it was 200 kPa.

For the wet samples with a water content of 3 % (Fig. 10b, d), graphs represent the variation in shear strength versus horizontal displacement and the shear stress versus vertical stress, respectively; the shape of the shear strength curve has a quasi-linear behaviour phase of all the samples, and this phase has changed after a horizontal displacement of 0.25 mm for the unreinforced sample and 0.5 mm for the reinforced samples. It is noticeable also that the fibre reinforcement is with more effectiveness on wet specimens, where the shear strength at the end of the test takes values of 170 and 185 kPa for the reinforced samples and 160 kPa for the unreinforced samples. The effect of fibres content on the slopes of the intrinsic curves (friction angle Fig. 13b) has been established by a higher value for fibres content of 0.3 % where it was with a value of 0.794, compared with the other fibre content where the slope takes the values of 0.772 and 0.728 for a fibres content equal to 0.1 and 0.5 %, respectively. The point of intersection with the ordinate axis (what representing the cohesion in Fig. 13a) was important for both cases of samples preparation and water content on a fibres volumetric content of 0.3 %.

Figure 11 shows the contribution of fibre reinforcement sand to minimize the dilatancy of the soil against loading; Fig. 11a represents the evolution of vertical displacements depending on the horizontal ones, and it can be observed that the samples reinforced with fibres have a low volume at the end of the test comparing to the unreinforced ones for both sides of samples preparation (dry case and samples with 3 % of water content). It is noticeable also that the dilatant

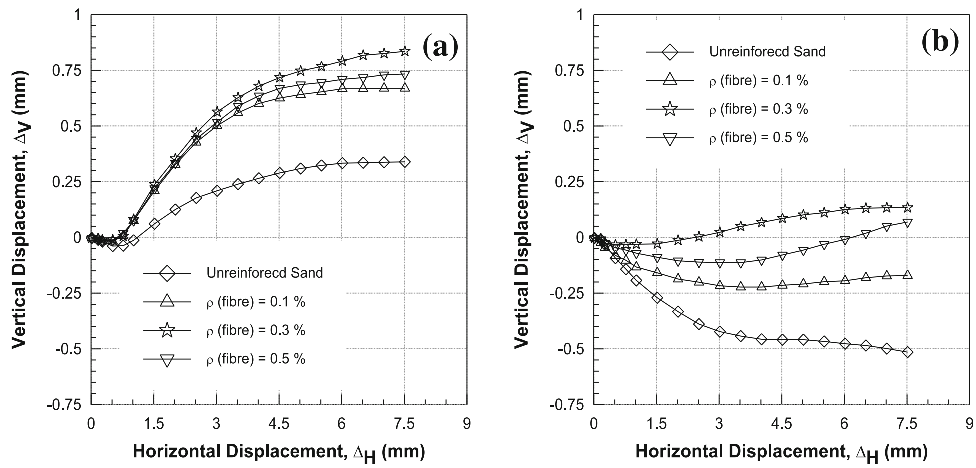

Fig. 11 Effect of the fibres on the vertical distortion of confining pressure of 200 kPa and a high relative density $D_r = 87\,\%$: **a** variation of the vertical deformed depending on a horizontal distorted dry sand, **b** variation of the vertical deformed depending on the horizontal deformed with a water content $\omega = 3\,\%$

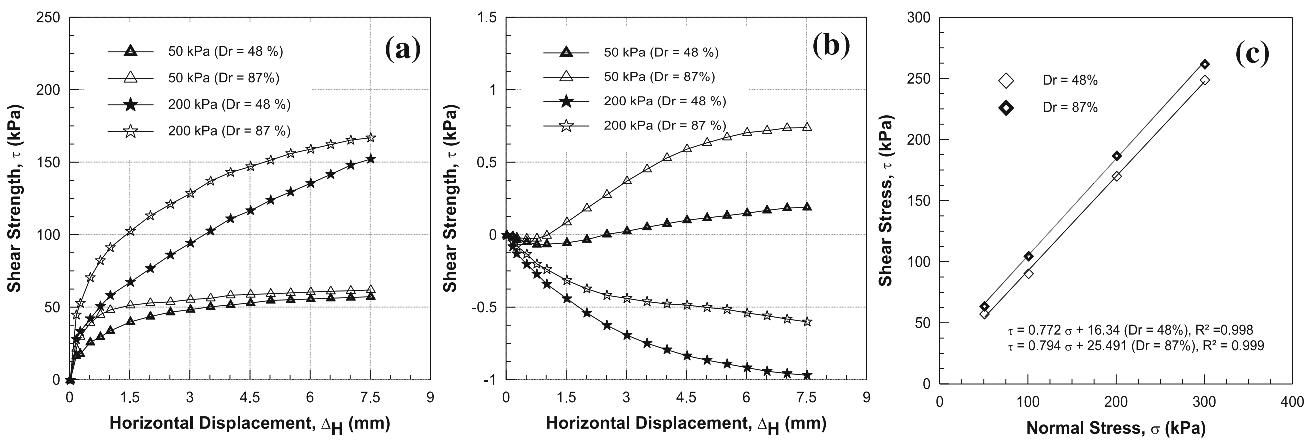

Fig. 12 Effect of the confining and the relative density of the shear strength of wet sand ($\omega = 3\,\%$) reinforced by a fibre volume content equal to 0.3 %: **a** shear stress as a function of the horizontal deformation, **b** effect of the confining and the relative density of the vertical deformation reinforced by a fibre volume content equal to sand 0.3 %, **c** intrinsic curve of equation $\tau = \sigma \cdot tg\varphi + c$

character of the wet specimens is greater than that of the dry specimens. The fibre volumetric content of 0.3 % is the most effective parameter to minimize the samples dilatancy that can result in better resistance against crack of the soil during external loading.

4.3 Confining Pressure and Relative Density Effect on Fibre-Reinforced Wet Sand

Figure 12a shows the effect of the confining pressure and the relative density on the shear stress; we can note that the higher confining pressure (200 kPa) has an effect as important as the low one (50 kPa) to improve the shear strength, and even for the development of the vertical displacement, we can see that the confining stress of 200 kPa reduces the dilatancy of the samples more than the confining stress of 50 kPa (Fig. 12b). The relative density has a similar effect as the confining stress to improve the shear strength; Fig. 12a shows that the shear stress of the dense samples is greater than the average dense samples. Figure 12b illustrates that a greater values of relative density increases the contractiveness of the samples, which results a similar (not an opposite) effect of the relative density on the development of the vertical displacement compared to the effect of the confining pressure.

Figure 13 shows the variation in the two parameters (cohesion and angle of internal friction) as a function of the volumetric content of the fibres. The cohesion increases proportionally and exponentially to the percentage of fibres in the specimen. The addition of fibre increases the cohesion value, for example for the medium dense samples 10 kPa for a fibre volume content of 0.1 %, to 16.5 kPa for a content of 0.3 % and to 22 kPa for a content of 0.5 %. It is noticeable from the results that the presence of fibres changed the characteristics of the mixture to make it react as a cohesive soil; change of characteristics is also presented in the form of curves of the variation in the shear force by mixtures fibre which has

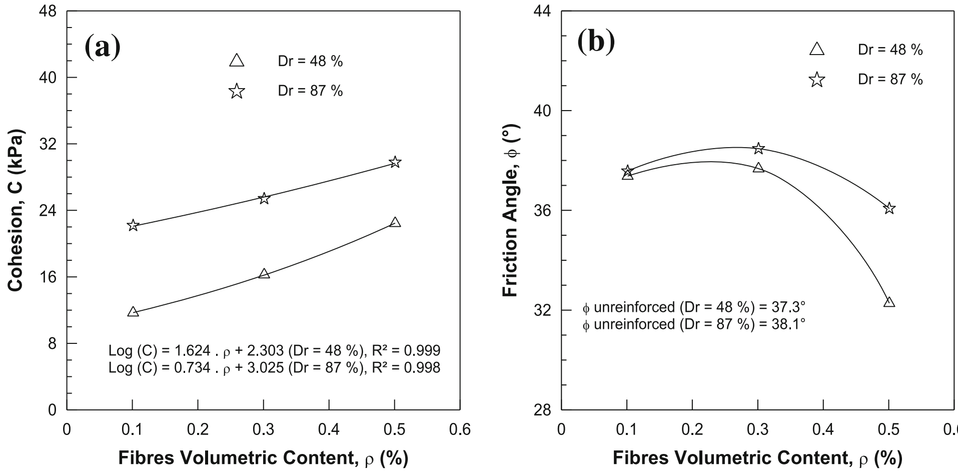

Fig. 13 Effect of fibre content on the cohesion and friction angle of wet specimens ($\omega = 3\,\%$): **a** variation of the cohesion, **b** variation of the friction angle

a peak and then a residual phase. This type of curve is characteristic of cohesive soil. And for the angle of friction, an increase in content for blends of fibres is equal to 0.3 % and a fall in the value for the fibre content is 0.5 %. We can see that the critical value of the volumetric fibre content approach is 0.3 %.

5 Conclusion

A laboratory experiment was conducted to study the effect of the inclusion of glass-fibres on the shear behaviour of a liquefiable sand of Chlef's region. Taking into account the data and the results obtained in this study, the following conclusions can be drawn:

1. Development of the shear stress of the studied sand strongly depends on the water content in the specimens examined, the fibre content and the state density.
2. For both densities to which the samples were subjected, a remarkable decrease in maximum and residual shear strength was observed with a lack of stability of the bearing shear stress, which results in a reduction in physical characteristics such as the angle of internal friction and cohesion with increasing water content in the samples.
3. The addition of glass-fibres has a positive effect in treating the scrap shearing force generated by the presence of water. An improvement has been well established by an increase in physical characteristics and a minimization in the development time of the shear stress. The addition of the fibres not only improves the shear strength of the soil, but also provides diversity in the resistance against the deformations imposed loads, which can result in a minimization of expansion–contraction cracks of the specimens of sand similar to the effect of fibres in condensed layers of clay. The percentage of fibre content is an important parameter to be equivalent to a fibre content of well-known critical improvement.
4. The relative density and confinement have the same effect on the mechanical behaviour for a shear effect proportional to the parameters of density.

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