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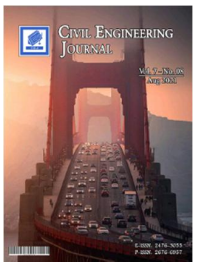

Effect of Grain Size and Distribution on Mechanical Behavior of Dune Sand

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Abstract

Sand is a major component of soils. It is widely used in manufacturing and construction. In geomechanics, one characterizes sand according to various aims. This paper investigates, for local sands, the effect of grain size and granular distribution on the mechanical behavior in terms of strength and stress-strain relationship. For this purpose, dune sands of the great Occidental Erg, from Algeria, are analyzed, according to the Mohr-Coulomb criterion. The study uses three kinds of sands. Every kind is divided into three sizes classes. Then, the experimental program conducts a set of direct shear tests, under various vertical stresses, using the small shear box (60 × 60 mm). The results show that the particle size and distribution have a direct effect on the mechanical behavior of the dune sand. Then, the dominant size class governs the natural sand behavior. Moreover, the peak shear strength increases as particle size increases. This indicates that there is an increase in peak friction angle with the increase of particles size and the sands consider as a purely cohesionless material. In addition, the experimental analysis shows that density and confinement stress is not sufficient to interpret the mechanical behavior. Indeed, mineralogy and surface state can influence the shear strength. These conclusions lead to the relevance of the sand genesis and the importance of the local materials thematic.

Keywords: The Great Occidental Erg; Dune Sands; Grain Size; Direct Shear Test; Shear Strength; Mohr-Coulomb Criterion; Soil Behavior; Local Materials.

1. Introduction

Arid and semi-arid areas cover thirty percent of the world's land surface [1]. The second largest erg in northern Algeria, after the Great Oriental Erg, is the Great Occidental Erg also known as the Western Sand Sea. It covers approximately an area of 100,000 km^2 [2].The sand dunes in the erg are formed by the wind, and can be up to 120 meters high [3]. Due to its abundance, it can be employed as a raw material in various engineering applications. The latter has been adapted to environmental issues by applying naturally available sands in building and industry. For some others applications, sands are treated with a special process. Many studies have investigated the aeolian sands to several targets as, geotechnical characterization [4], operating in pavement and concrete [5, 6], and soil reinforcement with sands [7, 8].

In this context, the direct shear test has served over the past 50 years in geotechnical engineering. Applications' owing to it is simplicity, repeatability, and necessity in soil characterization and work design [9]. The most important data obtained from a direct shear test for cohesionless materials are peak and residual strength and the friction angle

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corresponding to these two stress states [10]. Most of the geotechnical laboratories used the direct shear box (DSB) to measure the shear strength parameters (cohesion c, and friction angle φ) [11]. The Mohr-Coulomb theory uses these parameters to analysis the shear strength, in the frame of the limit equilibrium analysis [12]. The parameters cohesion and friction angle are relevant to the type of sand, grain form and size, and water or clay content [13].

The theoretical approach [14] indicates that strength characteristics are influenced by grain size and their distribution during the plastic deformation of granular materials. Many studies have investigated the effects of particle size on (stress-strain, friction angle, and cohesion) and volumetric strain behaviour. Indeed, according to Fredrick [15], particle size affects the macroscopic response of sands. Kolbuszewski and Frederick [16] reinforced soil by ballotini (glass beads) and reported that maximum porosity decreases and compressibility increase with particle size. Zolkov and Wiseman [17] found that the angle of shearing resistance increases as particle size increases. The study of Kirkpatric [18], showed the opposite, the friction angle decreases with an increase in particle size of two cohesionless materials. This was confirmed by Marsal [19] and Zelasko [20].

Wang and Wan Li [21] noticed that the particle crushing of soil in the process of loading would seriously affect the mechanical deformation performance of soil. Wang et al. [22] conducted tests to study the effect of particle size distribution, including the median particle diameter. The results demonstrate that the friction angle is increasing with increasing of the median particle diameter. Kara et al. [23] concluded that peak friction angle increases when the size of particles increases. Grains size does not have a significant influence on internal friction angle. In the conclusion of Alias et al. [24], the effective internal friction angle can be dependent on particle size and tests with larger size particles produce higher effective internal friction angle and develop high shear strength. Zhang and Tahmasebi [25] also concluded that the deformation declines with the decrease in particle size.

This study sets up an experimental program to analyze the effect of particle size and granular distribution on sands' shear strength and behaviour. The material subject of analysis is the local dune sand drawn from Bechar district, Algeria. This allows, first, to contribute to the characterization of the Great Occidental Erg sands as local resources. Second, geomechanical engineering uses directly the results in the design of geotechnical structures in various works of the district. In addition, several studies have been concerned with the use of the dune sand as a stabilization addition of expansive clay [26] and in high performance-high strength concrete manufacturing [27]. Also, the determination of the mechanical behaviour and associated parameters acts as data entries in numerical modelling of geotechnical problems [28].

Actually, in the research area, we focus our interest on similar questions through parallel research in finite element simulation of hydromechanical coupling in soil-structure-environment [29] and the simulation of soil-structures interfaces [30] that need numerical data of soils materials. Particularly, direct shear is a simple and inexpensive test to characterize the mechanical properties of interfaces in soil-structure interaction. That is, our fundamental hypothesis in conducting the present research is to confirm that the interface parameters depend –among other effects- on the granular distribution and the particles sizes at the interface.

2. Materials and Methods

2.1. Tested Materials

In the present study, the three tested soils are all based on sand obtained from the Great Occidental Erg, BECHAR region. The site locations are shown on the map (Figure 1.).

Gouray Sand

The grain size distribution according to [NF P94-056] is shown in Figure 2. According to the Unified Soil Classification System (USCS), the sand is classified as poorly graded sand (SP) with a dominant particle size of 0,125 mm and contains 2,54 % of fines.

Kenadsa Sand

The sand is taken from Kenadsa road situated 22 km west of BECHAR. Grain size distribution is shown in Figure 2. According to USCS, the sand is classified as poorly graded sand (SP) with a dominant particle size of 0,315 mm and contains 0, 96 % of fines.

Taghit Sand

Taghit city is situated 93 km south-east of BECHAR. The grain size distribution is shown in Figure 2. The USCS, class the sand as poorly graded sand (SP) with a dominant particle size of 0,16 mm and contains 0,69 % of fines. The microscopic observations were made on this sand.

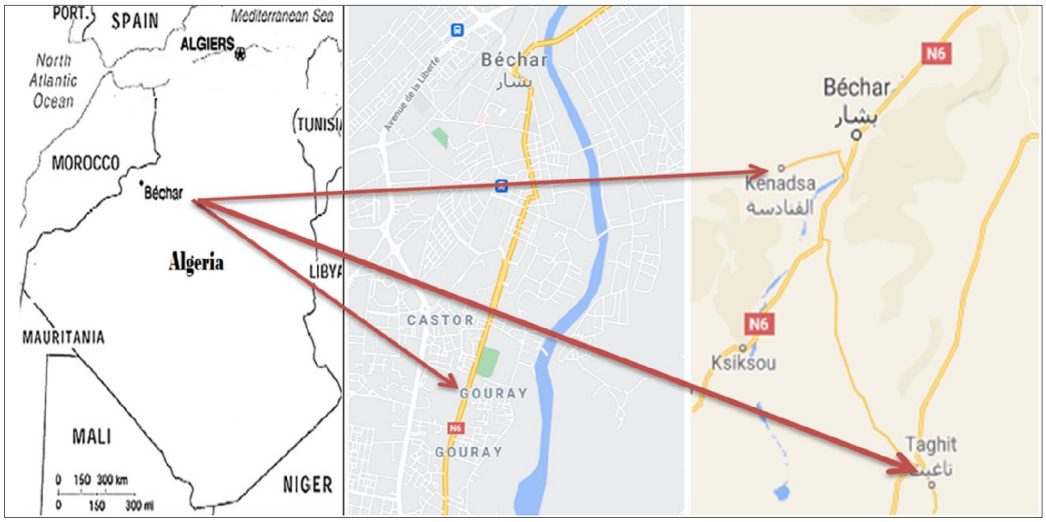


Figure 1. The sites locations

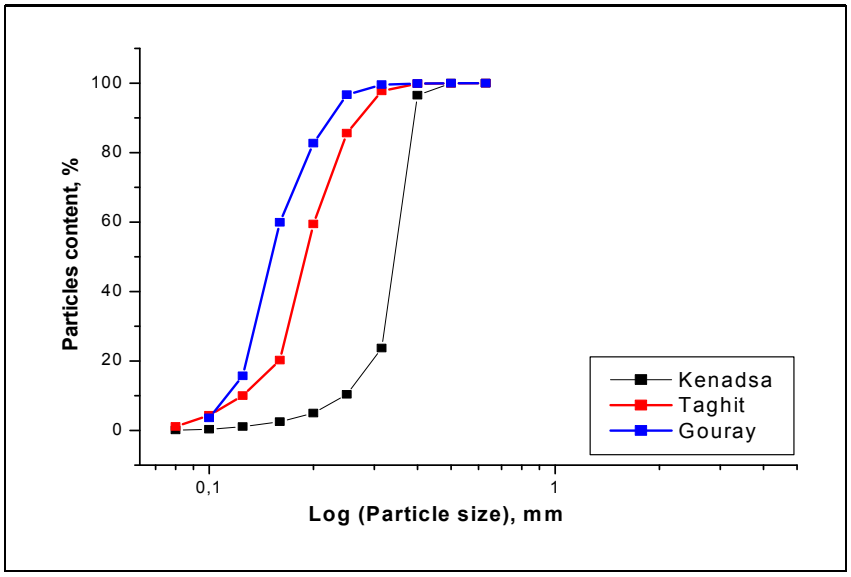


Figure 2. Grain size distribution

The physical properties of the three sands are tabulated below (Table 1.). The table demonstrates that the densities vary in the order of 3 % around the typical density of sand which is close to that of Gouray sand. It also displays that Taghit and Kenadsa are characterized as sandy soil, while Gouray sand contains silt according to VBS.

Table 1. Granular properties of the sample

Sand Origin	w %	UC	CC	D_{10} (mm)	D_{30} (mm)	D_{50} (mm)	ρ (g/cm^3)	ρ_s (g/cm^3)	ES (%)	VBS (%)
Taghit	0.2	1.6	1.16	0.125	0.17	0.19	1.52	2,51	93.33	<0.4
Gouray	0.4	1.37	1.00	0.117	0.137	0.148	1.43	2.53	68	<1.2
Kenadsa	0.1	1.6	1.23	0.225	0.315	0.34	1.48	2.50	98.33	<0.6

2.2. Experimental Setup

All tests are conducted in the laboratory of technology at the Tahri Mohammed University of Bechar, Algeria. An advanced automated direct shear testing apparatus (SHEARMATIC EmS) is used for direct/residual shear testing. It is based on the conventional direct shear test apparatus used by Taylor [31] and, Skempton and Bishop [32], which includes an upper and a lower shear box (Figure 3), and the sample is sheared along the interface plane by pushing the lower half shear box, horizontally, while a constant normal (vertical) load acts on the upper half shear box. Figure 4 presents a general view of the setup showing the direct shear box and the data acquisition system. According to SHEARMATIC EmS Manuel, the axial transmission of the horizontal force is accurately ensured by a straight

connection between the shear box, shaft and load cell. The digital controller reads and processes the vertical and horizontal forces and vertical and horizontal displacements readings and drives the motor accordingly for the proper automatic test execution under closed loop PID control. The maximum particle size of the soil determines the DSB shapes and sizes [33, 34]. The DSB width must be 10 times the maximum particle size, and the initial specimen thickness must be 6 times the maximum particle size of the tested soil [NF P94-071-1].

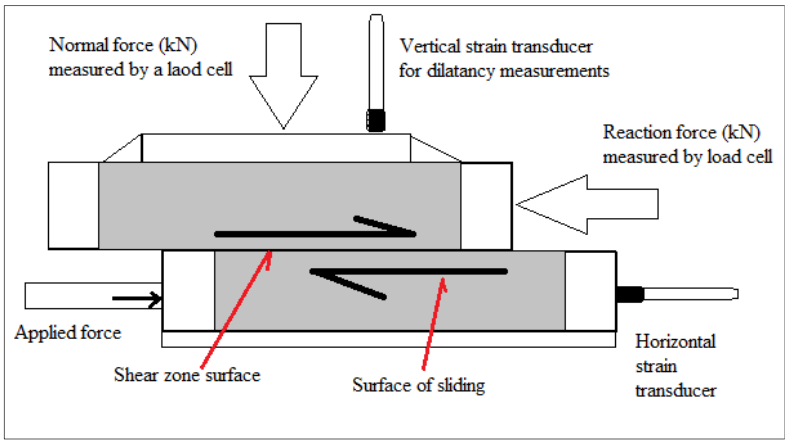


Figure 3. Scheme of direct shear apparatus

Figure 4. View of experimental device

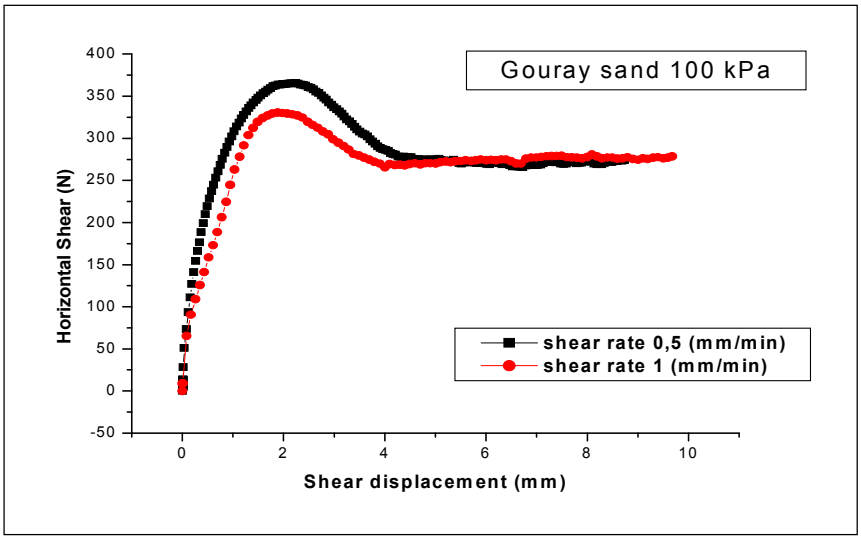
3. Direct Shear Test

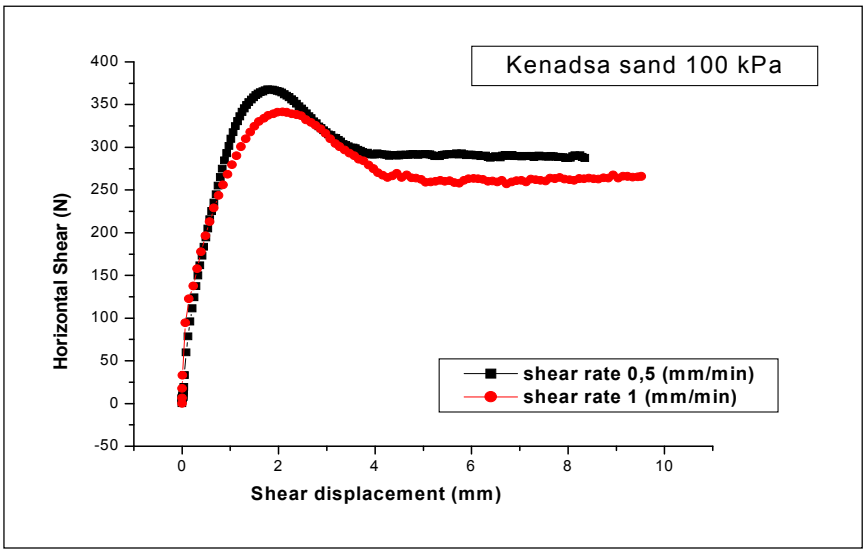
3.1. Shear Rate Determination

In the unsaturated soils testing, the shear rate is chosen in order to dissipate any pore water pressure feedback. Then, the shear rate should be determined according to the soil permeability coefficient [35]. At first, two shear rates of 0.5 and 1 mm/min are tested out, using constant normal stress σ of 100 kPa. The results presented in Figure 5, indicate that peak shear stress is higher when a lower shear rate is used. Therefore, we use in the next tests, the constant horizontal displacement rate of 0.5 mm/min.

3.2. Sample Preparation

To investigate the effect of particle size, two types of samples are selected: natural sample and sieving sample (particles passing sieve opening). Nine (9) samples (Figure 6.) are considered, which can be divided under three headings according to Magnan [36]. The maximum diameters of the examined sand particles varied within the boundaries of 0.063 and 2.0 mm. Size distribution defines three sand fractures identified by [NF P94-056] performing usual sieve analysis: Fine Sand (0.063 mm, 0.200 mm), Medium Sand (0.200mm, 0.630 mm), and Coarse Sand (0.630 mm, 2.00 mm). The material is placed in the shear box in three equal layers. Each layer is compacted with constant compaction energy [37].





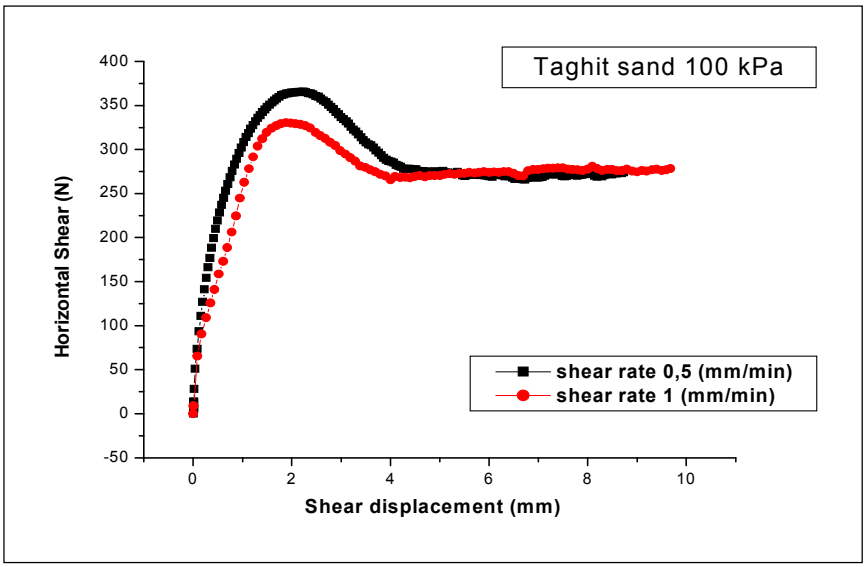


Figure 5. Results of shear tests with different shear rates

Figure 6. Samples used in Test

3.3. Test Procedure

In order to analyze the effect of grain size on the soil behavior, shear failure envelop accordingly determines cohesion and friction angle. A set of experimental direct shear tests (DST) are conducted on the natural sand and its sieving samples (Figure 7). Three to five tests were conducted at each stress level to check repeatability. The DST box dimensions are 60×60×20 mm. For each test, five normal stresses (σ_n) of 50, 100, 200, 500, and 1000 kPa are used. The constant horizontal displacement rate is 0.5 mm/min, with a maximum displacement reaching up to 10.0 mm or until certain signs of failure appear on the load cell. When the same operator, performs the direct shear test, under the same conditions, the results are so highly reliable [38]. The minimal number of tests should be from 2 to 4. However, processing data on 2–4 tests end in the large distribution of strength properties, which finally results in a significant reduction of characteristic shear strength parameters [39]. Such quantity of tests allows avoiding the influence of the magnitude factor of the vertical load, for determining shear strength parameters [40].

4. Results and Discussion

The results of the direct shear tests include shear stress versus shear displacement curves, peak shear strengths, and residual shear strengths of natural Gouray, Kenadsa, and Taghit sands and their sieving specimens.

4.1. Effect of Stress Levels on Shear Behaviour

Figures 8 to 10 show the shear stress-shear displacement average curves for natural sands, medium and fine particles. To ensure the repeatability of the tests, two to four tests were conducted for the natural, and sieving specimens at each stress level.

Figure 8 shows the case of Gouray sands. The shear stress-shear displacement curves for Gouray sands include the natural sample, medium particles, and fine particles. It is found that the shear stress increases with the increase of the normal stress. The shear stress gradually increases to a peak during the testing and then decreases to residual stress at large displacement. The increase in normal stress makes the sands denser and the peak shear strengths higher than that of lower normal stress. In Figure 8 the curves show that the peak shear strengths and residual shear strengths for both the natural sample and medium particles are very similar. It is explained by the effect of medium particle's which is considered as the highest particles in the natural sample. The peak shear stresses of fine sand are lower than that of natural and medium specimens in all stress levels

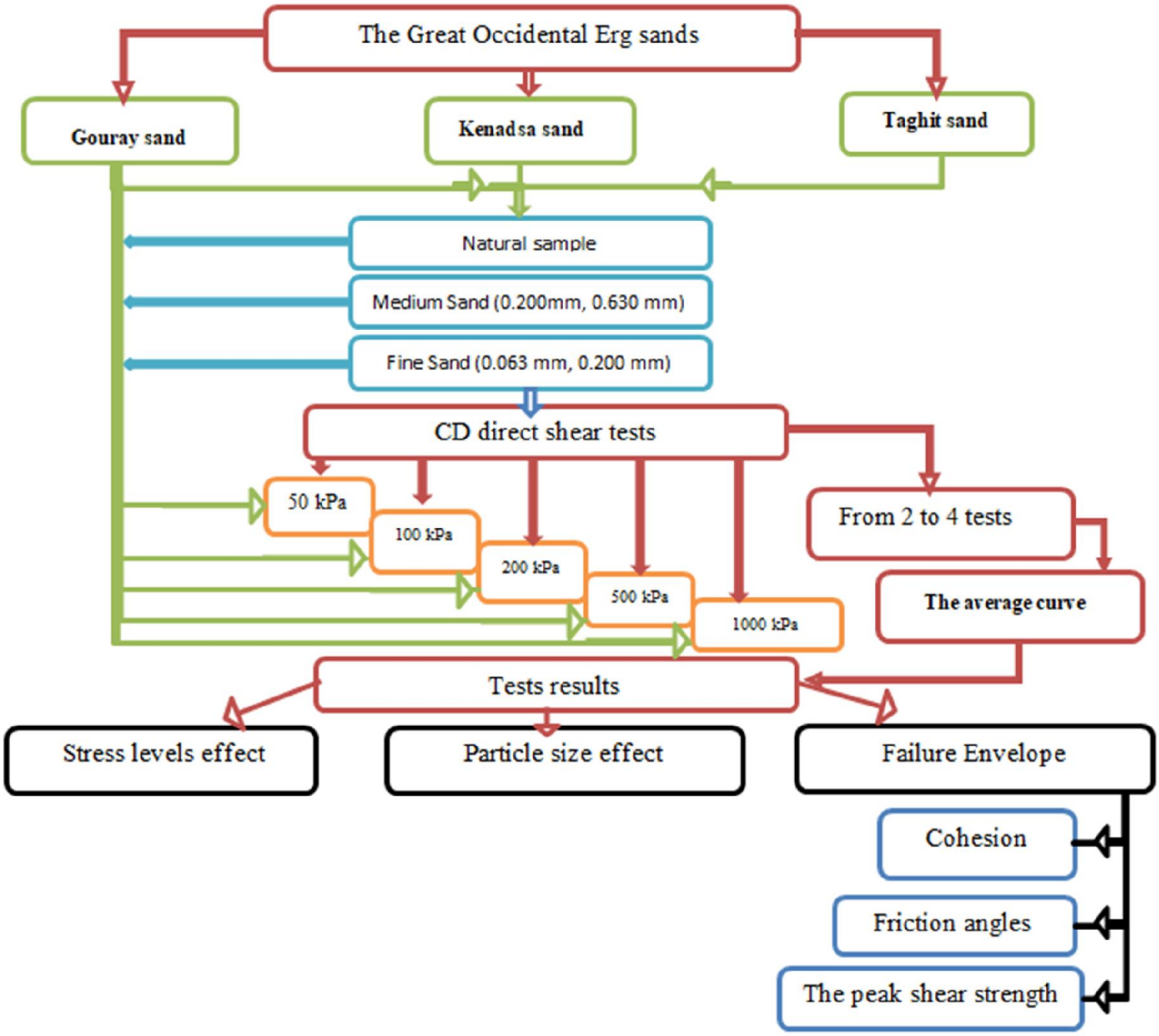
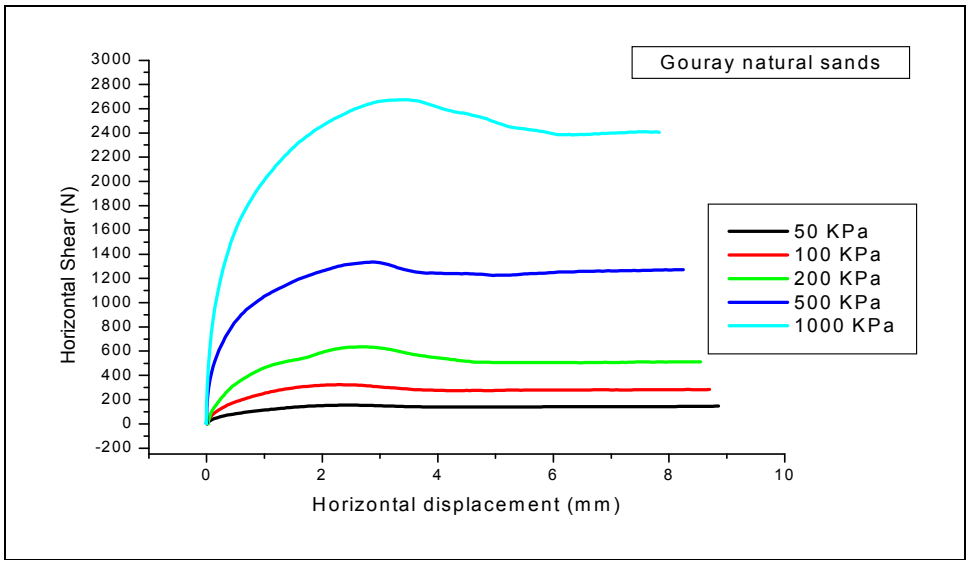


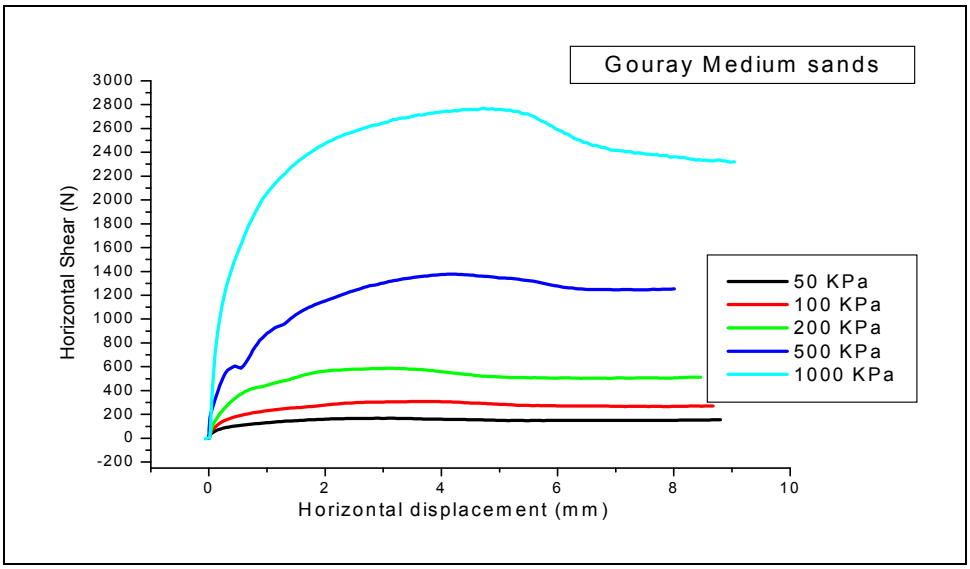
Figure 7. Flowchart of methodological research

Figure 9 shows the plots of shear stress versus shear displacement for Kenadsa natural sands, medium and fine aggregates. The peak-shear strength increases with the increase of the normal stress. The shear stress of tested sand increases from zero to a peak value and then gradually decreases and reaches an ultimate or residual value. It is clear that some of the displacement–stress relationship (especially under smaller applied stress, such as 50 kPa) tends to soften, and another displacement–stress relationship (especially under larger applied normal stress, such as 500 kPa) tends to harden. The curves of Kenadsa natural sands show a denser behavior comparing with that of medium and fine particles at 500 and 1000 kPa. The peak shear stresses and residual shear strengths of Kenadsa natural sands are larger than that of medium and fine particles at 50, 100, 200, and 500 kPa. It is also noted that this difference becomes smaller at 1000 kPa.

Figure 10 shows the plots of shear stress versus shear displacement for Taghit natural sands, medium and fine particles. The effect of normal stress on the stress–displacement behavior can be observed by comparing the test results of the five different stresses. An increase in normal stress, leads to an increase in horizontal shear for Taghit natural sands, medium and fine particles. Both of Taghit natural sands and medium particles curves show instability in elastic behavior at 500 and 1000 kPa. Taghit natural sands, medium and fine particles possess similar behaviors at 50, 100, and 200 kPa. However, the results of shear stress versus shear displacement still clearly show that peak shear stress of Taghit natural sands is not distinct from the medium and fine particles.

As Ziaie Moayed et al. [41] notice that the general forms of shear stress–shear displacement curves, for large normal stress, are similar to the dense sand behavior. On the other hand, for weak normal stress, the force-displacement peak is missed or not marked. This is typically the behavior of loose sand.





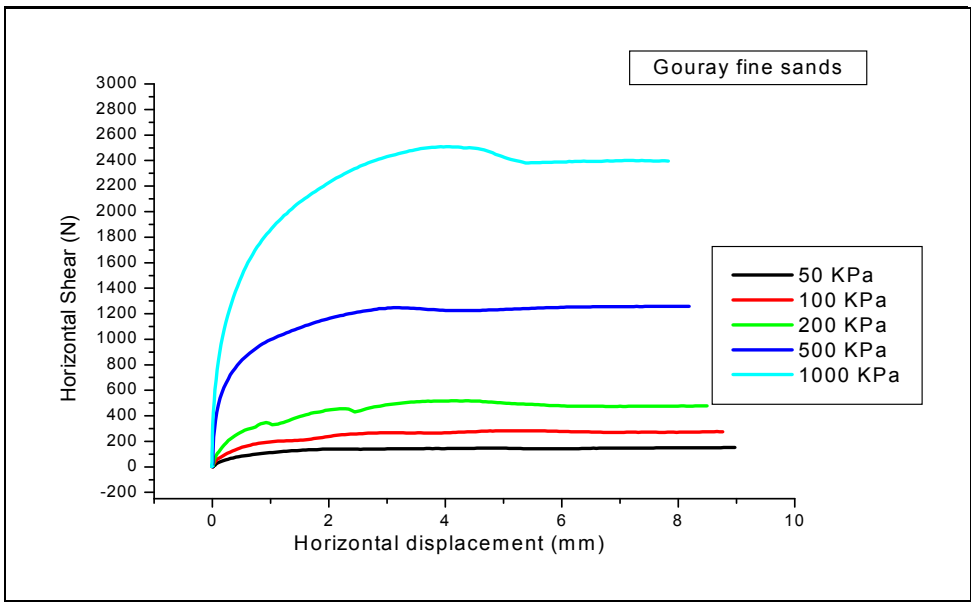


Figure 8. Results of the shear-displacement, Gouray sands

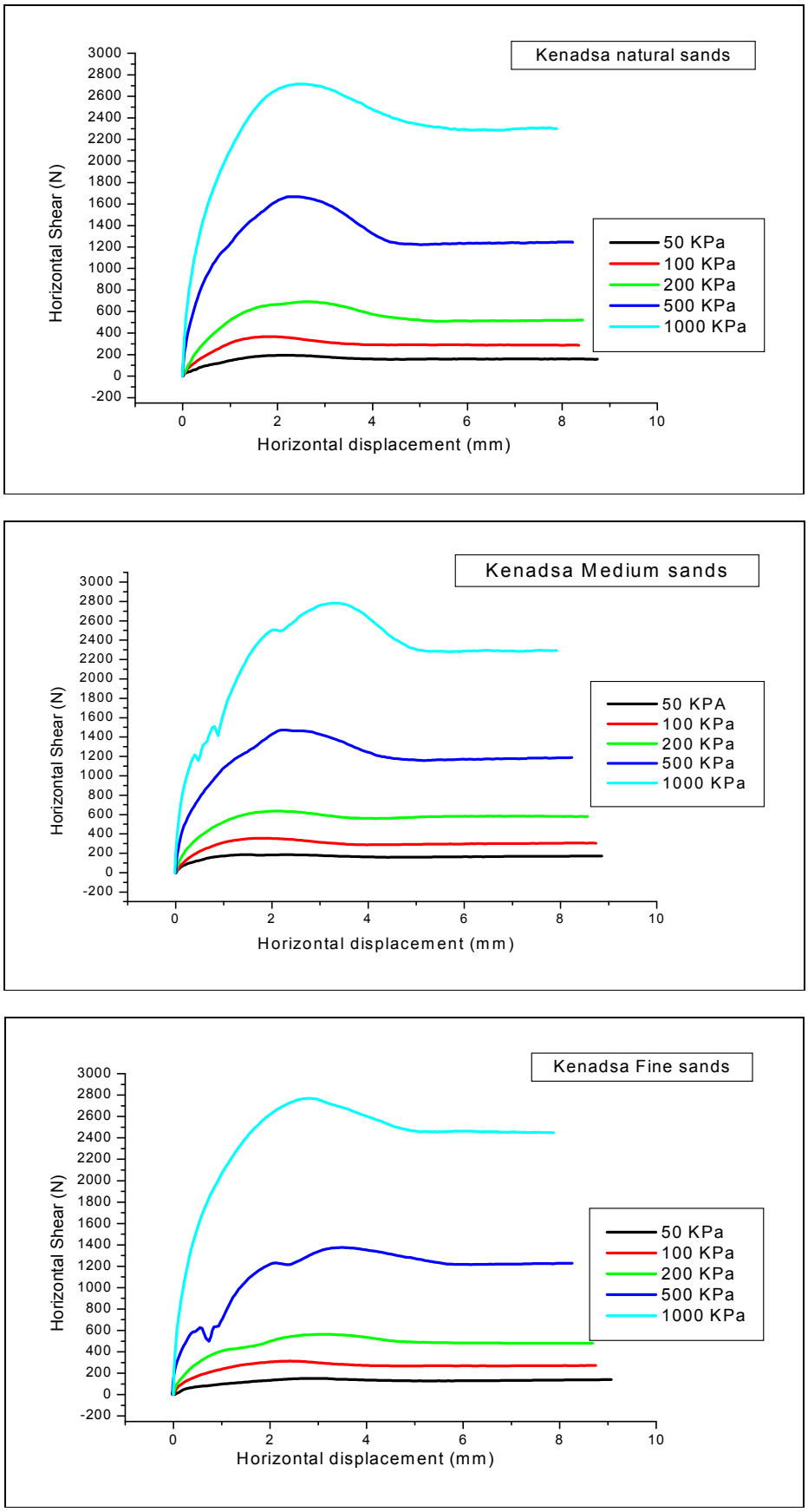


Figure 9. Results of the shear-displacement, Kenadsa sands

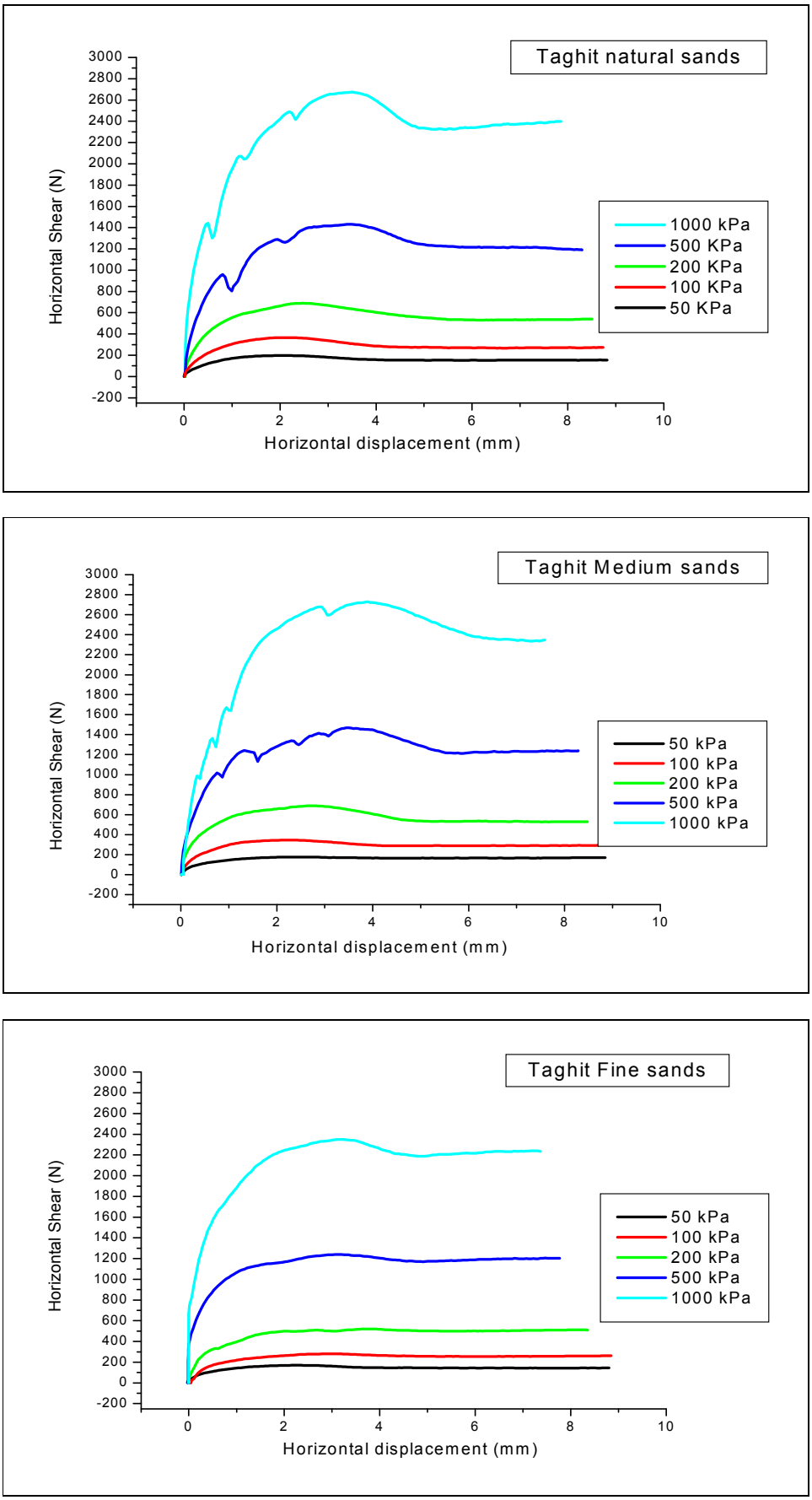
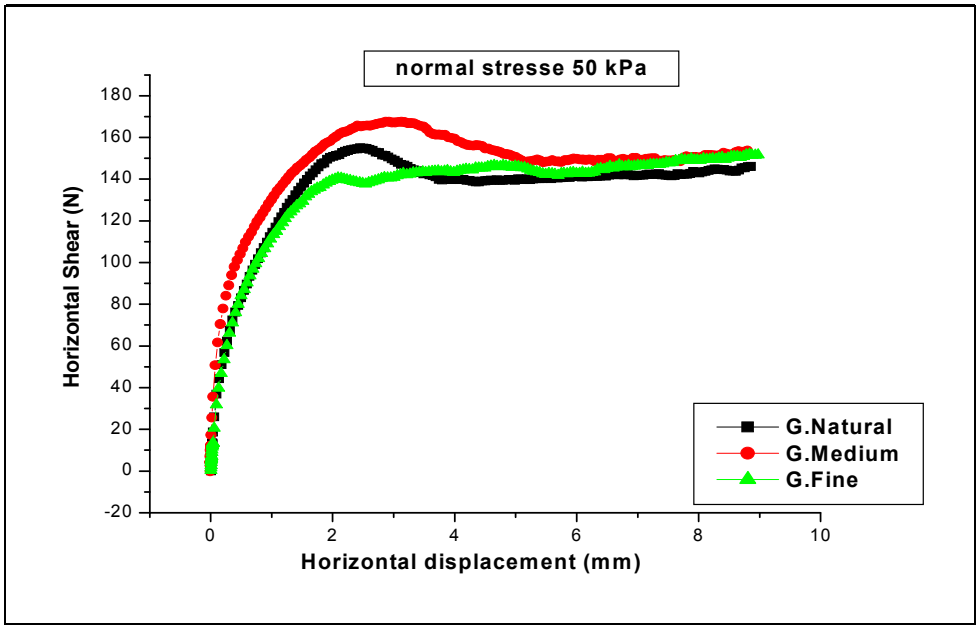


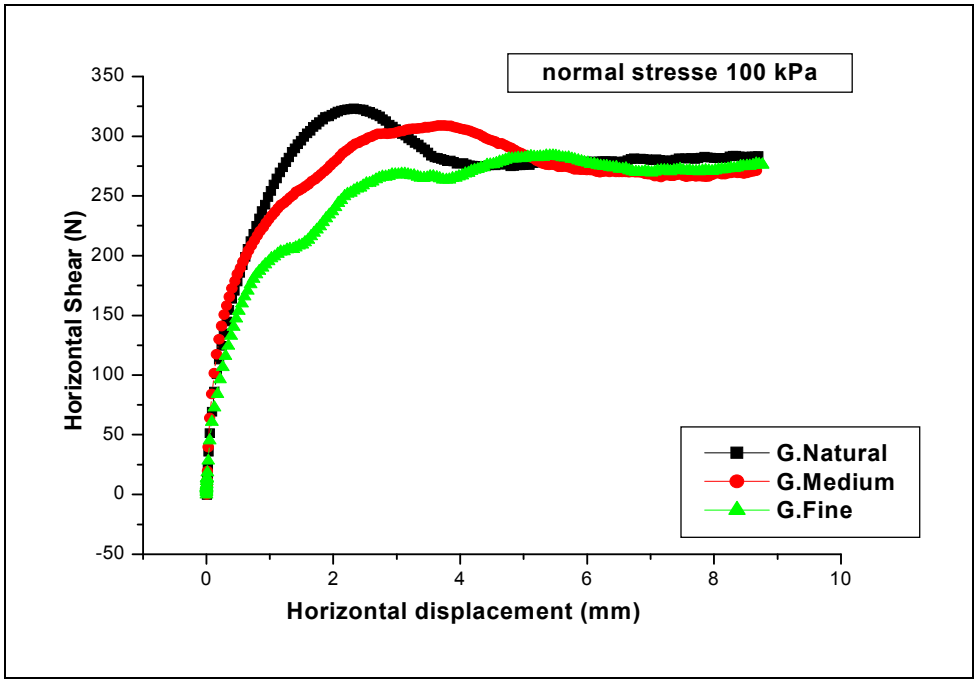
Figure 10. Results of shear-displacement, Taghit sands

4.2. Effect of Grain Size and Distribution on Shear Behaviour

Gouray Sand

Shear–displacement curves for natural, medium and fine Gouray sand, that have been loaded in five normal stress (50, 100, 200, 500, 1000 kPa) are presented in Figure 11 respectively. It can be noticed that for each range of size particle, the horizontal displacement at failure is variable. The results show that both natural and medium particles have peak shear strength, but for fine sand, it appears, even flat, with 200 and 1000 kPa normal stress only. One sees that the peak shear stress, in medium sand, is higher than the fine sand. This is in agreement with the previous studies of Nakao and Fityus [42], Islam et al. [14]. The results show that the residual shear strength in all tests is not significantly affected by particle size. Also, one observes, that the mechanical behaviour of natural sand displays peak shear strength typical than that of fine and medium particles, due to the distribution of particle range in natural samples (Table 2.). The whole tests show that, the natural sand reaches early the ultimate state compared to the medium one. Finally, fine sand shows a non-smooth shear strength-displacement curve, until the normal stress of 200 kPa. For the last normal stress, there are several failures and instabilities states.





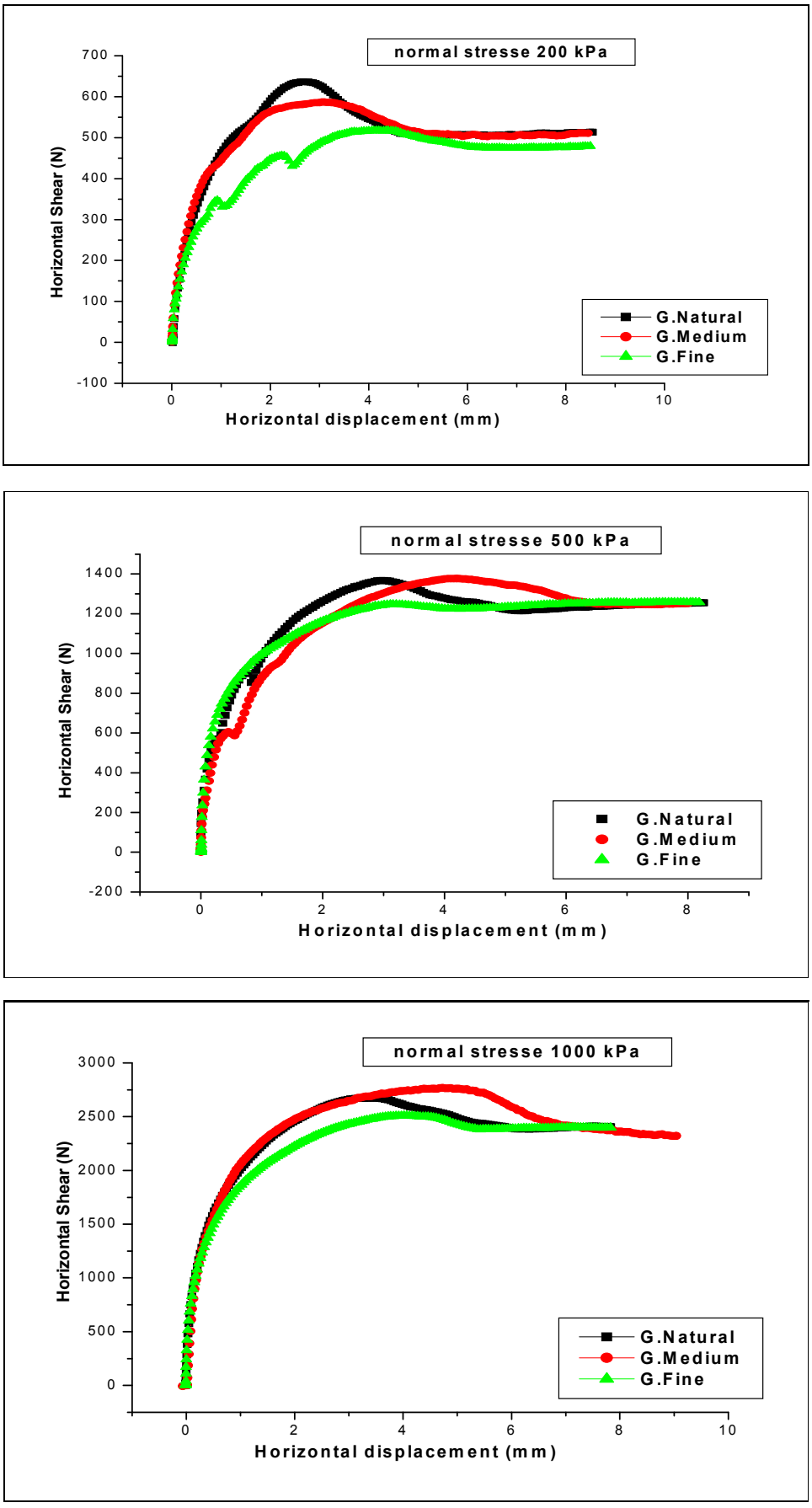


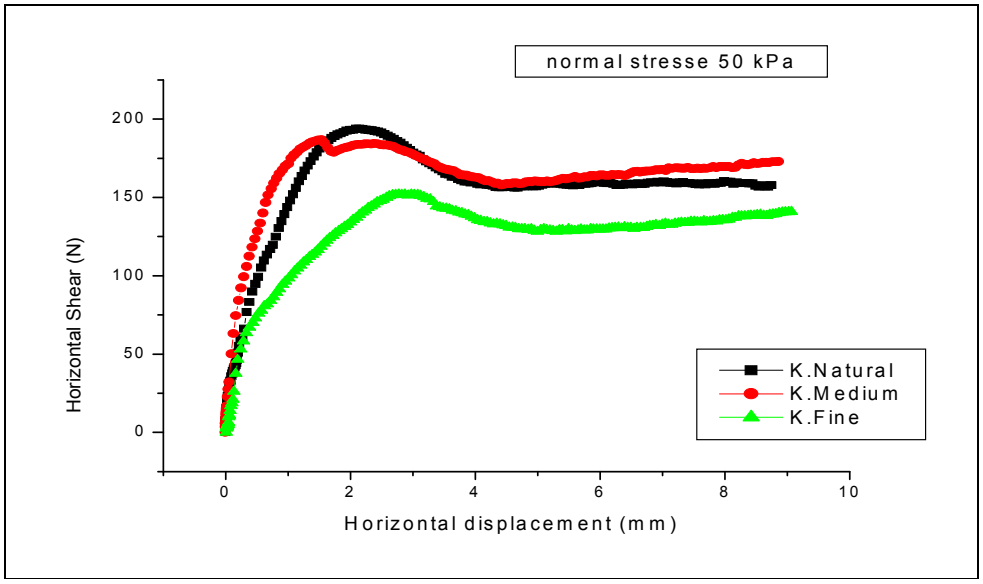
Figure 11. Shear-displacement curves for Gouray sands

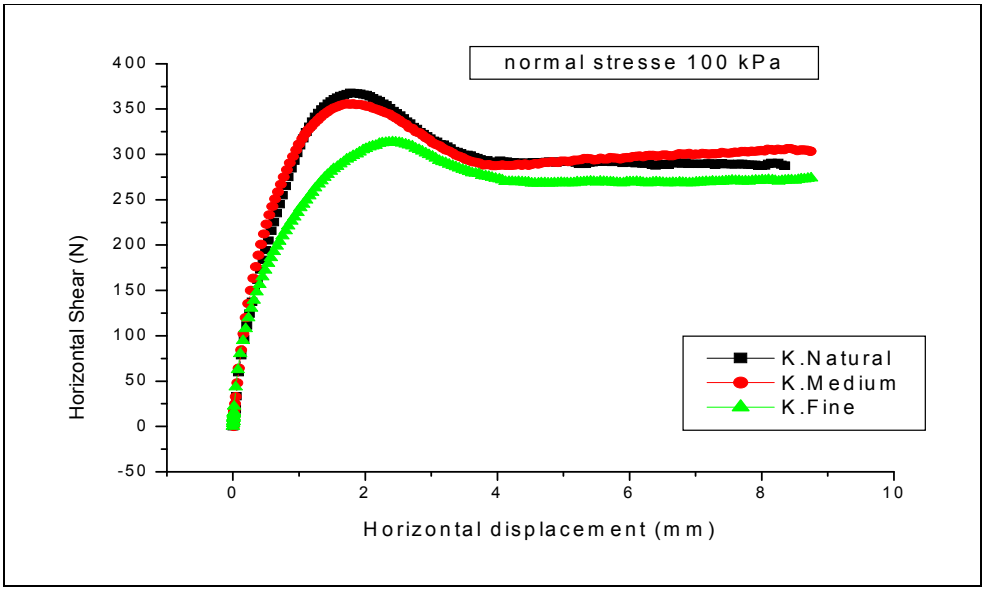
Table 2. Density of Gouray samples

Gouray Sand	ρ (g/cm^3)	ρ_s (g/cm^3)
Natural	1.43	2.51
Medium	1.40	2.52
Fine	1.42	2.54

Kenadsa Sand

Shear–displacement curves for natural, medium and fine Kenadsa sand, that have been loaded in five normal stress (50, 100, 200, 500, 1000 kPa) are presented in Figure 12 respectively.The shear-displacement relationship of the three range particles of Kenadsa sands exhibits well-defined peak softening behaviour (Figure 12.). The shear stress reaches the peak value within small horizontal displacement. It can be seen that the shear curves of fine sand, for 50, 100, 200 and 500 kPa are below the shear curves of medium sand. The results show that the peak shear strength increases as particle size increases. Similar results were obtained by Kara et al. [23], Alias et al. [24]. In high normal stress of 1000 kPa, natural, medium and fine Kenadsa sand have globally, the same behaviour. Although, medium sand exhibits this normal stress level some local instabilities. The natural sand specimens show similar behaviour as medium ones in 100 kPa. While it presents a higher strength in 200 and 500 kPa. Results show that the peak shear stress of the natural sample corresponds to high density (Table 3.), because of the combination of the various particles size ranges.





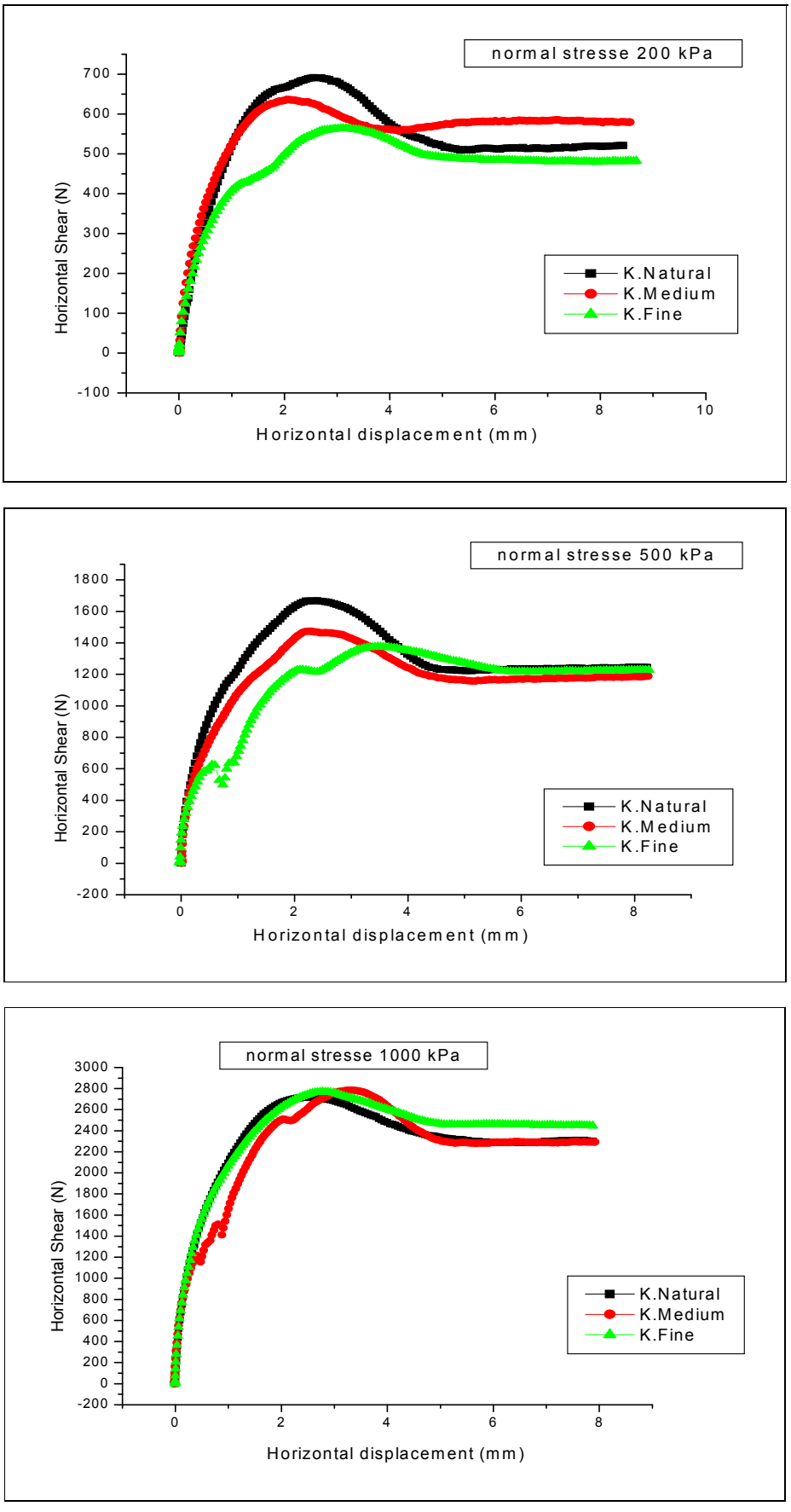


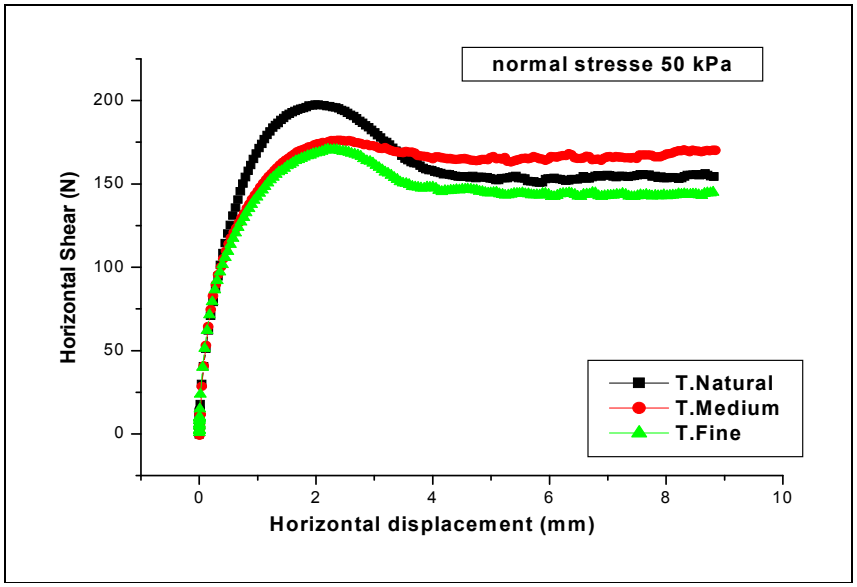
Figure 12. Shear-displacement curves for Kenadsa sands

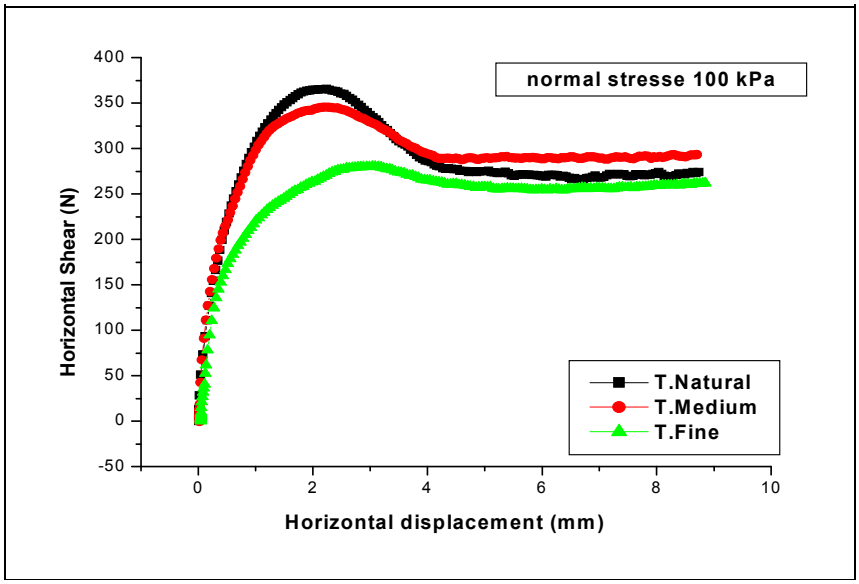
Table 3. Density of Kenadsa samples

Kenadsa Sand	ρ (g/cm^3)	ρ_s (g/cm^3)
Natural	1.48	2.5
Medium	1.45	2.54
Fine	1.42	2.6

Taghit Sand

Shear–displacement curves for Taghit natural sand, and their sieving specimens that have been loaded in five normal stress (50, 100, 200, 500, 1000 kPa) are plots in Figure 13 respectively. Note that all of the tested specimens exhibit hardening behaviour. As shown in Figure13, peak stress is affected by the particle size of the specimen. In general, the specimen with larger particles tends to have a higher peak of shear stress. From Figure 13, it can be seen that the shear displacement curves of fine sand for almost the normal stress 100, 200, 500 and 1000 kPa are below the corresponding curves for medium sand. The results show a direct relation between particles size and peak shear strength, as is previously noted by Wang et al. [22], Zhang and Tahmasebi [24]. The strength response for natural Taghit sand defines stress shear gradually increasing up to the peak, and then being constant at large horizontal displacement. The curve of the specimen with a single size range of particles is not identical comparing with the natural specimen that has a typical curve of «strain-softening. Several instabilities characterize the shear curves for natural and medium sand under 500 and 1000 kPa.





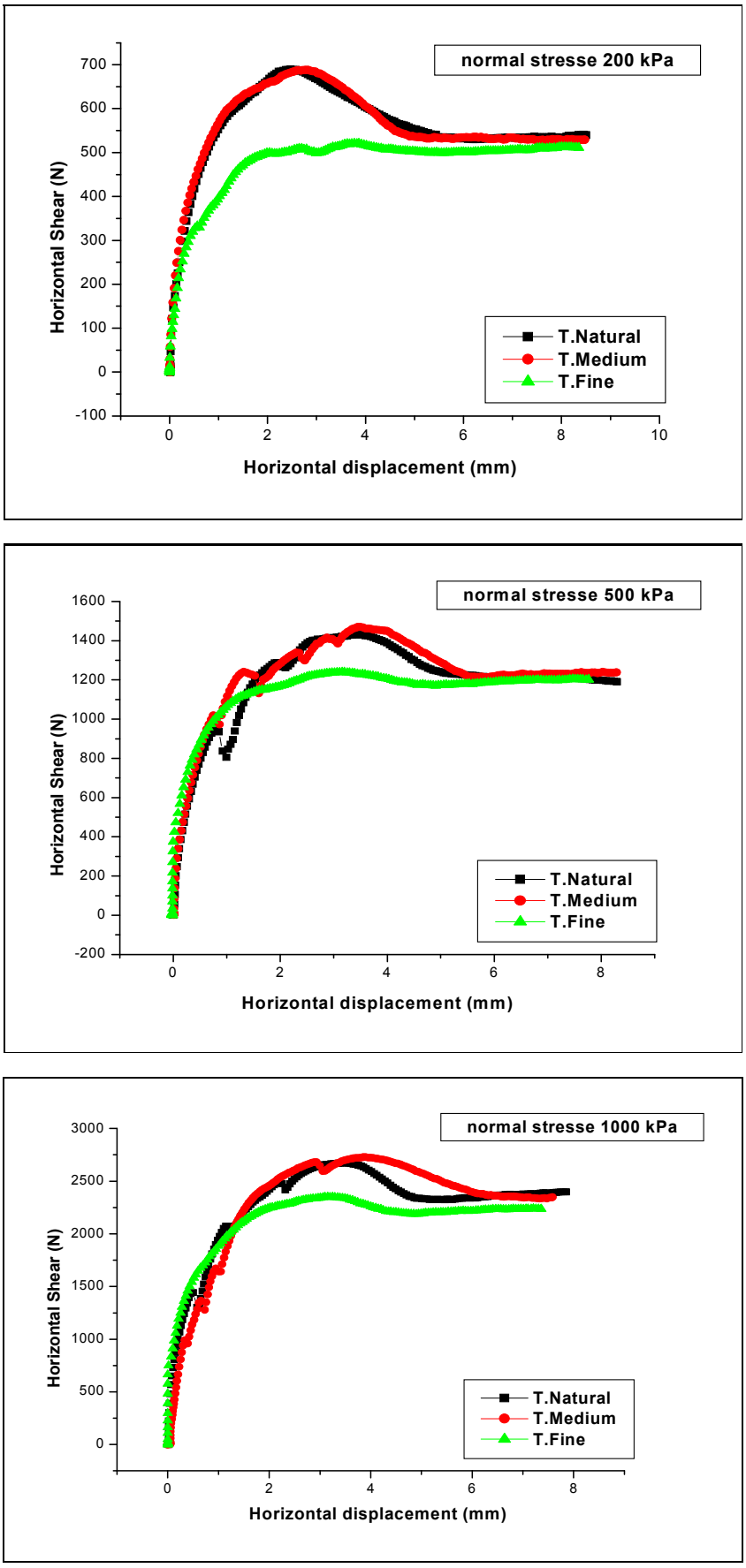


Figure 13. Shear-displacement curves for Taghit sands

Table 4. Density of Taghit samples

Taghit Sand	ρ (g/cm^3)	ρ_s (g/cm^3)
Natural	1,52	2,51
Medium	1,52	2,52
Fine	1,51	2,56

4.3. Failure Envelope

For each sand, three curves are drawn. Mohr–Coulomb criterion can be applied to express interface shear strength: $\tau = c + \sigma \tan \varphi$, where c is the interface apparent adhesion, φ is the interface friction angle, and R^2 is the correlation parameter of the envelope curves [43]. Table 5 gathers the values of the friction angle and cohesion, for all samples.

Gouray Sand

The strength envelopes of natural, medium, and fine sand are presented in Figure 14. The friction angles are computed by considering the linearity of failure envelopes. The peak shear stress represents the best mobilization in medium particles. In Figure 14, test results show a good linear relationship between peak shear stress and normal stress with a relatively high correlation coefficient R^2 (R^2 0.9999). In Gouray natural, medium and fine sand the apparent adhesion (c) are 17.45, 8.86, and 6.76 kPa, respectively, and the friction angles (ϕ) are 36°, 37,17°, and 34,53°, respectively. It can be noticed that there is an increase in peak friction angle with the increase of particles size 37,17° and 34,35° for medium and fine sand respectively. In this testing, the Gouray dune sand has quite larger cohesion than expected 17, 45 kPa for natural sample (contains Silt) which is 96.9% higher than that in the medium particles. The failure envelope does not pass through the origin while it can be explained by the quantity of fine sand which covers more than half of the natural sample.

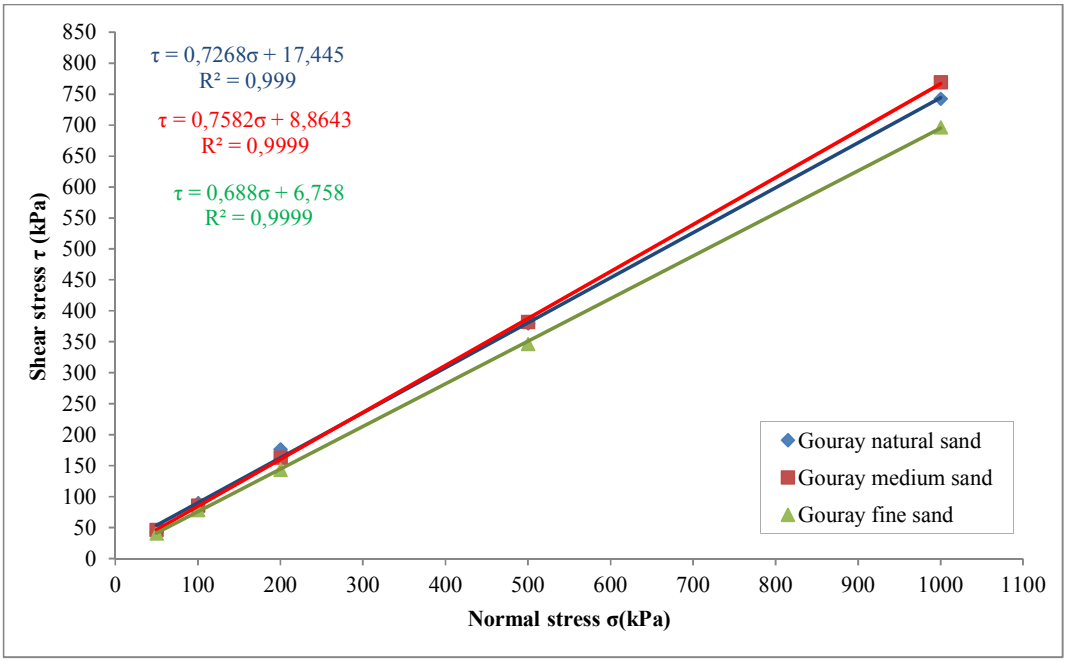


Figure 14. The strength envelopes of Gouray sand

Kenadsa Sand

Pure Kenadsa sand and its sieving specimen's failure envelopes are exhibited in Figure 15. test results of Kenadsa sieving particles show a good linear relationship between peak shear stress and normal stress with a relatively high correlation coefficient R^2 (R^2 0.99). One exception is the relationship between the shear stress and normal stress in natural sands with a relatively low R^2 of 0.97. This may be caused by abrupt particles breakages. The results from table II define that the sand does not have any cohesive characteristics. Natural and medium sand show almost identical friction angles 38,52° and 38,22°, respectively. The mechanical behaviour of natural sand can also be explained by its large grain size.

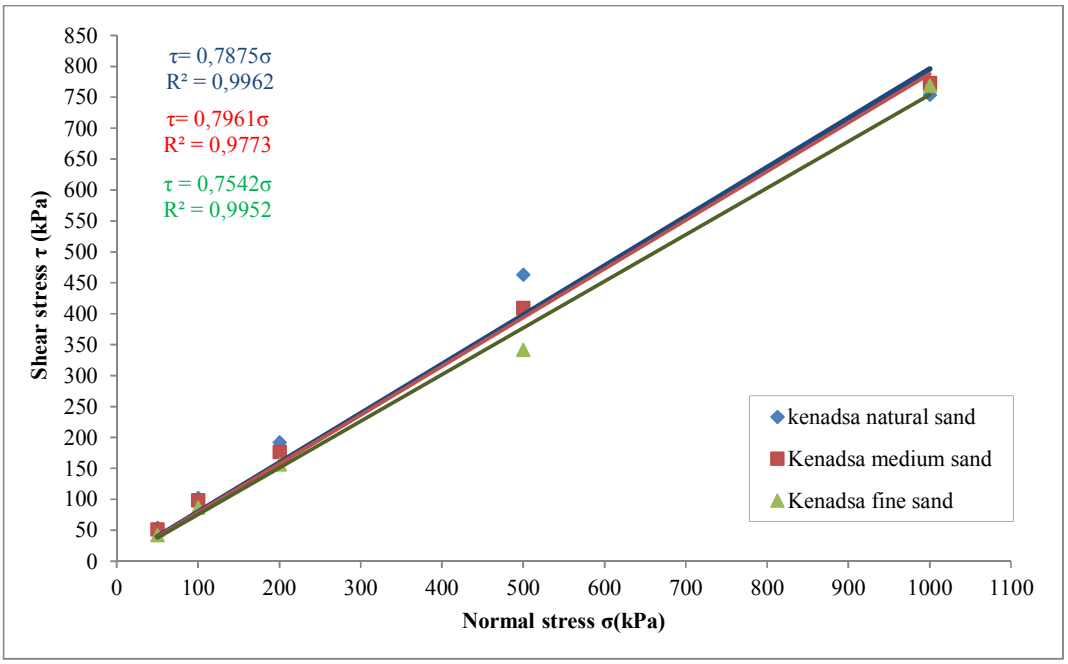


Figure 15. The strength envelopes of Kenadsa sand

Taghit Sand

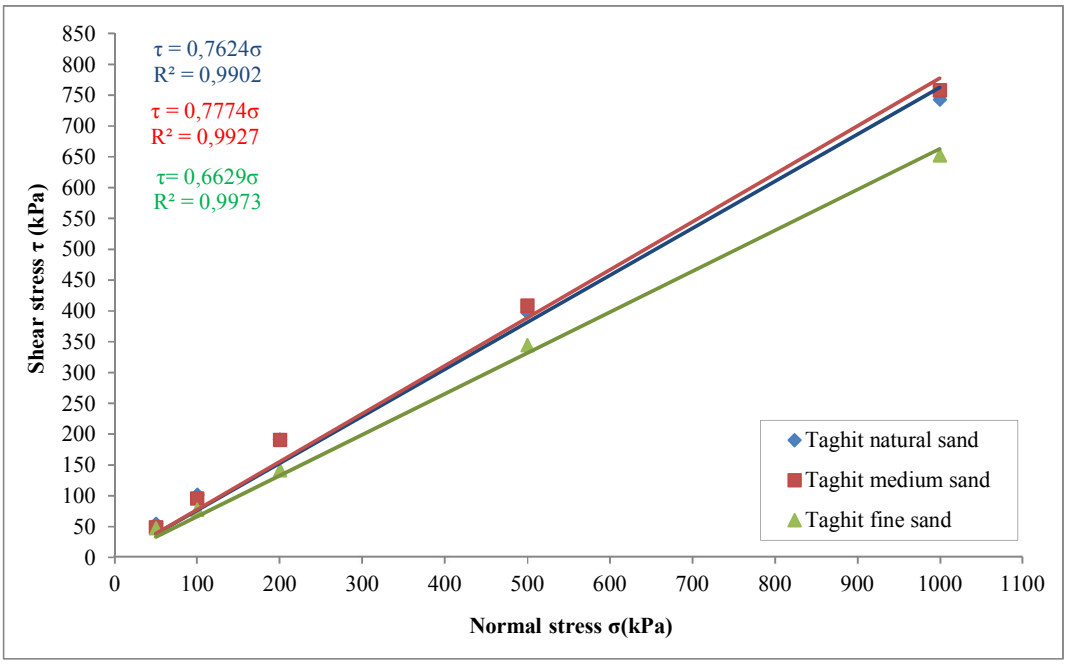


Figure 16. The strength envelopes of Taghit sand

Figure 16 demonstrates the Mohr-Coulomb failure envelopes for Taghit sand. The peak shear stress represents the best mobilization in medium particles. In Figure 14, test results display a good linear relationship between peak shear stress and normal stress with a relatively high correlation coefficient R^2 (R^2=0.99). It is noticed that the friction angle of medium sand is larger than that of fine sand; medium sand exhibits a maximum friction angle value of 37,86°, whereas the fine sand friction angle is evaluated as 33,54°. This difference in friction angle is due to the grain size of the particle. The results have pointed out that the cohesion parameter is equal to zero and the sand is considered as a purely cohesionless material.

Table 5. Friction angle and cohesion for specimens at peak

$\tau = c + \sigma \tan \varphi$		φ (degree)	c (kPa)
Gouray sand	Natural	36	17,45
	Medium	37.17	8,86
	Fine	34.53	6,76
Kenadsa sand	Natural	38.52	0
	Medium	38.22	0
	Fine	37.02	0
Taghit sand	Natural	37.23	0
	Medium	37.86	0
	Fine	33.54	0

5. Comparative Study

In order to investigate the effects of grains size on the mechanical behaviour of soils, various studies were done. To analyse the shear strength of sand, they used the direct shear test in different sets of experimental procedures. Uniform particles of eight samples (0.075, 0.15, 0.212, 0.300, 0.600, 1.18, 1.72 and 2.76 mm) and graded particles of two samples (0.075-1.18 mm and 0.075-2.36 mm) from the Padma River Sand (Bangladesh) were analysed by Islam et al. [14]. Three sets of loading (0.05, 0.10 and 0.15 kN) were selected for each of eight particle sizes. Eighteen samples referred to above (one of actual Tergha sand (Algeria), seven samples with different particle size ranges and ten reconstituted samples with random percentages of particle size ranges) loading under five normal stresses (100, 200,300,400 and 600 kPa) were analysed by Kara et al. [23]. Granular materials from Nilai quarry (Malaysia) were divided into two groups: particles passing the sieves with an opening size of 2.36 mm and particles passing the standard 20 mm sieves loading under 100, 200 and 300 kPa were analysed by Alias et al. [24].

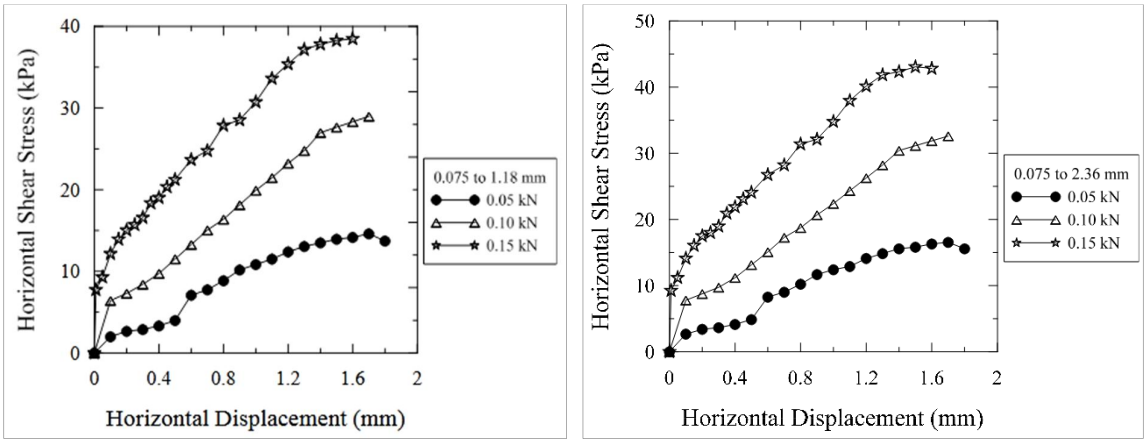


Figure 17. Effect of Normal Load in well graded samples Padma River Sand [14]

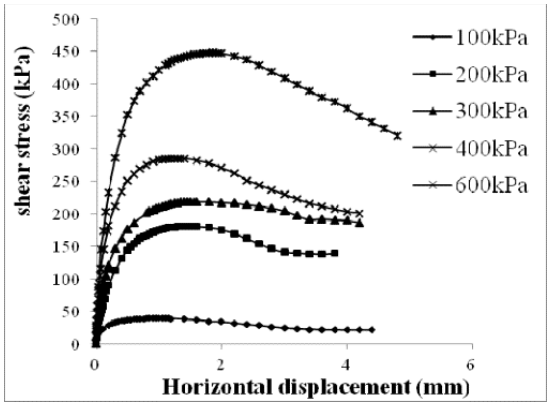


Figure 18. Results of direct shear test on Tergha sand [23]

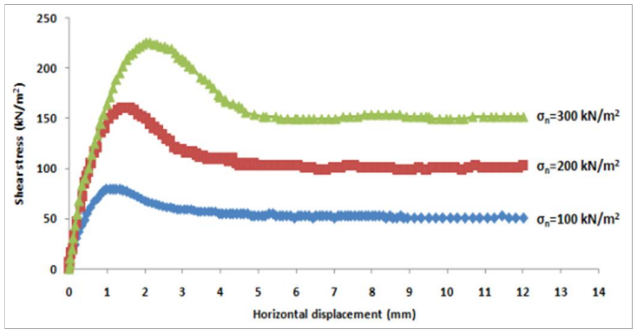


Figure 19. Shear stress versus normal stress, Nilai quarry sand [24]

Figure 17 shows that with the increase of normal load shear strength increase in well graded samples and this were the same for uniform particles. Figure 18 shows an increase in the peak shear with the increase of normal stress on Tergha natural sand. The shear stress for the specimen sheared under normal stress of 300 kN/m^2 is higher than the sample sheared under normal stress of 200 and 100 kN/m^2 in the sieving particles of Nilai quarry sand (Figure 19.). This has confirmed our results in the 4.1 section.

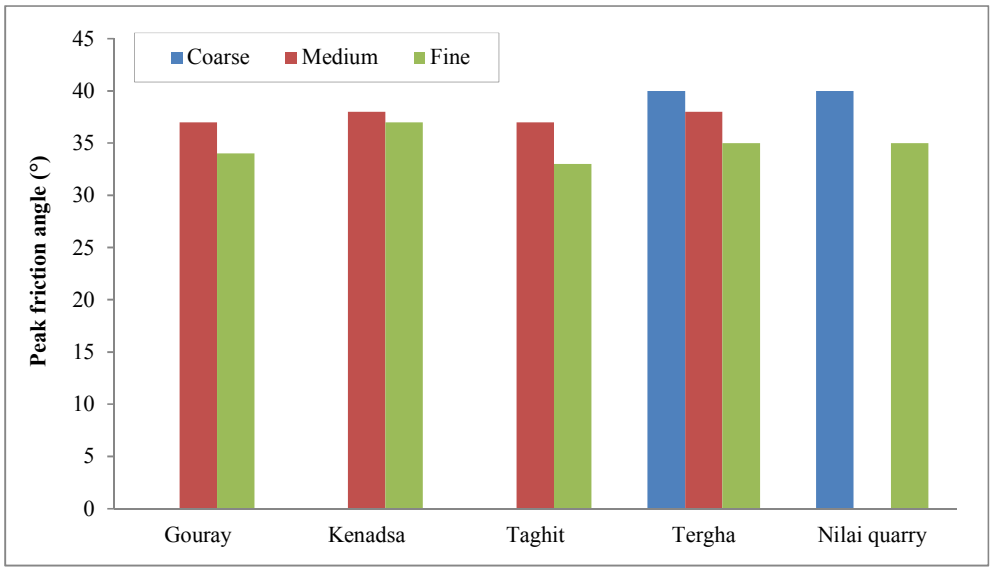


Figure 20. Comparison between peak friction angles

In the results obtained by Kara et al. [23], it is noted that there is an increase in peak friction angle with the increase of particles size (Figure 20.). They concluded that if we know the size of particles of marine sand we can deduce directly the value of peak friction angle. Alias et al. [24] found that the peak shear of particles passing the sieves with an opening size of 2.36 mm is lower than the particles passing the standard 20 mm sieves. These results are in agreement with our sands results which clearly present in Figure 20.

6. Conclusion

The study explores sand's grain size and distribution effects on mechanical behaviour. The tested Gouray, Kenadsa, and Taghit dune sands are obtained from the Algerian Great Occidental Erg. Natural and Fine (0.063 mm-0.200 mm), Medium (0.200 mm - 0.630 mm) and Coarse (0.630 mm - 2.00 mm) Sands have been loaded in five normal stresses (50, 100, 200, 500, 1000 kPa). The tests are performed with the small shear box (60 × 60 mm).

We summarize the main results as follows. The shear strength shows elastoplastic behaviour. The initial response is elastic within a very limited range of shear displacement. After that, the interface connection begins to brake slowly. When the strength reaches a peak, the damage of the cohesive stress along the sheared interface is total. Hence, the strength falls slowly and tends towards the residual strength for large displacement. Therefore, in the range of large displacement, the shear strength is due to frictional sliding. This is valid for large confinement or normal stress. When the normal stress is relatively weak, there is no peak in the strength-displacement relationship. This means that the interface cohesive stress is missing. Then, the shear tests define strain-softening behaviour, and the peak shear strength increases while increasing the normal stress in all tests. Between low and high normal stress, the sands react in a different way. For weak normal stress, the peak is missing, or flat. For large confining, the peak response is present. The various tests for the same sand, in natural, medium or fine class, show that the density is not sufficient to interpret the mechanical behaviour. Indeed, the mineralogy and the interface state can influence the results of the shear test. In addition, one concludes that the dominant size class governs the natural sand behaviour. The increase in the peak friction angle can be a result of the increase of particles size that favors the friction along with the interface particles.

These conclusions suggest adding microscopic studies to characterize the surfaces of the physical grains. Due to the large surface covered by the Great Erg Occidental dune, the sand can present various shear strength parameters according to its physical characteristic (grain size and shape) and its mineralogical characteristic that requires more tests as geological and chemical investigations. Through this study, we recommend avoiding the generalization of the mechanical behavior, of the Great Erg Occidental sands, and to conduct testing and characterization for each particular site. This reveals the relevance of local material as a research thematic. On another side, the existence of a

peak in the stress-strain relationship is the indication that cohesive strength is acting at the sheared interface. Then, one concludes that dune sands from the Great Erg Occidental, can present a cohesive behaviour according to the confinement level. This relevant conclusion can be proved using the present results in numerical simulation. Indeed, the finite element method allows the modelling of the shear behaviour and helps to deduce the mechanical interface parameters, like stiffness, friction, or adherence coefficients, by fitting, optimization, or inverse algorithms. This is particularly useful in the simulation of soil-soil interfaces problems as in embankments, or the soil-structure interaction problems as in deep foundation and retaining wall.

7. Declarations

7.1. Author Contributions

A. Boudia and A. Berga contributed to the conception and design of the study; A. Boudia performed the experimental tests and analyzed the data; A. Boudia wrote the first draft of the manuscript; A. Berga guided and supervised the research work and commented on the previous version of the manuscript. All authors have read and agreed to the published version of the manuscript.

7.2. Data Availability Statement

The data presented in this study are available in article.

7.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

7.4. Acknowledgements

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7.5. Conflicts of Interest

The authors declare no conflict of interest.

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