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Shear Resistance of Siltous Sands Improved with *Bridelia* Tannins

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Abstract

The ruin of several civil engineering works occurs due to shear rupture of the ground. When the stress is greater than the shear resistance, the internal friction angle and the cohesion of the soil loosen and rupture occurs. Cement and lime are often used to stabilize soils and improve soil strength. The costs and environmental problems of these technologies raise concerns and challenge researchers to innovate with clean, inexpensive materials, accessible to the most disadvantaged social classes. The question that this study seeks to answer is whether the binders derived from plant tannins, which also stabilize soils, improve the shear resistance of these soils. To do this, we determined for silty sand the shear parameters, notably the cohesion and the angle of internal friction in the non-stabilized state and when they are stabilized with the powder of the bark of the *Bridelia* under different water states. The results show that the addition of *Bridelia* powder to silty sand increases the cohesion of the soil by nearly 70.71% and the friction angle by 4.31%. But in unfavourable water conditions, the cohesion and internal friction angle of the silty sand material improved with *Bridelia* bark powder drops drastically by nearly 81.56%. but does not dissolve completely as for the same material. When it is not stabilized. This information is an invaluable contribution in the search for solutions to increase the durability of earthen constructions by improving the water-repellent properties of soils.

Keywords

Silty Sand, *Bridelia* Tannins, Shear Resistance, Cohesion, Angle of Friction

1. Introduction

Today more than ever, research on local materials, especially those of plant origin [1] [2] [3] [4] [5] gives us hope that we can decently build our habitation without ravaging the earth in search of ores to make cement or lime but better still the habitation can be built by restoring biodiversity by planting trees such as African locust bean, *Bridelia*, Indian tamarind, etc. [6] [7] [8] [9]. From these plant species, we can extract tannins for various uses in buildings [10] [11].

A review of previous publications also shows that various tropical wood wastes have already been used in composites [12] and the thermal stability of their tannins has been studied for green adhesives [13]. Wood today is used as construction materials but also as packaging due to their advantages such as lightness, thermal insulation, fireproofing, sound insulation [14] [15] [16] [17]. Various local materials are also used in traditional practice to protect the exterior facings of raw earth walls against bad weather and shocks [18] [19]; here again tannins are used. It is also worth noting that tannins have received renewed attention in recent decades for their use in several areas such as environmentally friendly biobased polymer materials [20] [21] [22]. Tannins are significantly involved in the distillation process of drinks such as brandy, whiskey, grappa, and cognac [23]. Their use as adhesives for wood has been known since the middle of the last century [24] [25], and their application for wood preservation is more recent [26] [27]. Tannins have been suggested as alternatives to plastics and synthetic coatings [28]. Furan bioplastics have been successfully produced [29]. Over the last decade, other technical materials have been produced from tannins: insulating foams have been used in the construction of green buildings [30] [31].

It is in the context of multiple characterizations and the use of tannins in several fields [32], that the present study is located, which sets itself the objective of verifying the behavior of soil shear parameters: cohesion and angle of friction of silty sands enhanced with *Bridelia* tannins. To obtain samples of silty sand, they were characterized and then improved to an optimal rate of 12% *Bridelia* bark powder. The soil thus stabilized is tested with the rectilinear shear test to determine the cohesion and the angle of friction.

2. Material and Methods

2.1. Test Material

The equipment used for the tests carried out are: Tares, AFNOR series sieves, an electric sieve, an electronic balance, a Casagrande cup, a groove tool, a smooth marble plate, an oven, a dryer, and the rectilinear shearing apparatus.

2.2. Material Used

The soil used in this study is silty sand taken from Cacaveli at Lomé in TOGO. The binder used is a tannic powder of the bark of *Bridelia*. To obtain this powder, we took the bark of *Bridelia* which underwent several operations which are: drying at 50˚C, sorted by hand to rid the bark of all foreign bodies, pounded with mortar to reduce the bark into smaller pieces, passed through a mill to grind. The powder obtained is sifted through a 1mm sieve. It is therefore this fine beam passing through a 1 mm sieve which served as a binder to be mixed with the soils to stabilize.

2.3. Experimental Methodology

Four types of tests in particular: particle size analysis (NF P 94-056 standard), specific weight (NF P 94-054 standard), Atterberg limits (NF P 94-051 standard) were used to characterize the ground and the rectilinear shear test with the Casagrande box (Standard NF P 94-078), was used to determine the cohesion and the angle of internal friction. The soil was first stabilized by adding *Bridelia* bark powder at the optimal rate of 12%, we then obtained a sample of composite material ready for the shear test. This test first consists of reconstituting the soil by compaction following the methodology of the modified Proctor test. For each reconstituted sample, two series of test samples are taken from four shear boxes labeled 1 to 4. The first series is soaked in water for 1 hour, the second series is not soaked. We also take a third series but this time on the non-stabilized soil which will serve as a control. The four series taken are sheared under the same conditions by applying normal stresses of 0.0177 MPa, 0.0354 MPa, 0.0531 MPa and 0.0707 MPa respectively and the material is sheared according to standard NF P 94-078. The stresses and deformations during shearing are determined for each test.

3. Results and Discussion

3.1. Results

3.1.1. Soil Characterization Results

The results of the granulometry analysis tests are provided. The results contained in **Table 1** and the curve in **Figure 1** is the representation of the granulometry distribution of this soil. The liquid limit is 38.28% and the plasticity limit is 15.35%, the Proctor optimum dry density is 2.06 g/cm^3 and the Proctor optimum water content is 9.28%.

3.1.2. Result of Shear Tests on Non-Stabilized and Unsoaked Silty Sand

Figure 2 gives the stresses and strains result obtained during the shear test of non-stabilized, non-soaked silty sand, for different load forces. **Table 2** gives the values of the shear stresses as a function of the normal stresses; these stresses made it possible to trace the intrinsic line in the Mohr plane of **Figure 3** which reflects the transition from the quasi-elastic state to the plastic state of the soil

Table 1. Granulometry distribution.

Diameter (mm)	4	3.15	1	0.8	0.63	0.5	0.4
Passers-by percentage	100	96.96	93.99	90.15	84.34	73.95	62.54
Diameter (mm)	0.315	0.25	0.20	0.16	0.125	0.10	0.08
Passers-by percentage	49.51	37.29	30.00	25.75	21.90	20.22	19.20

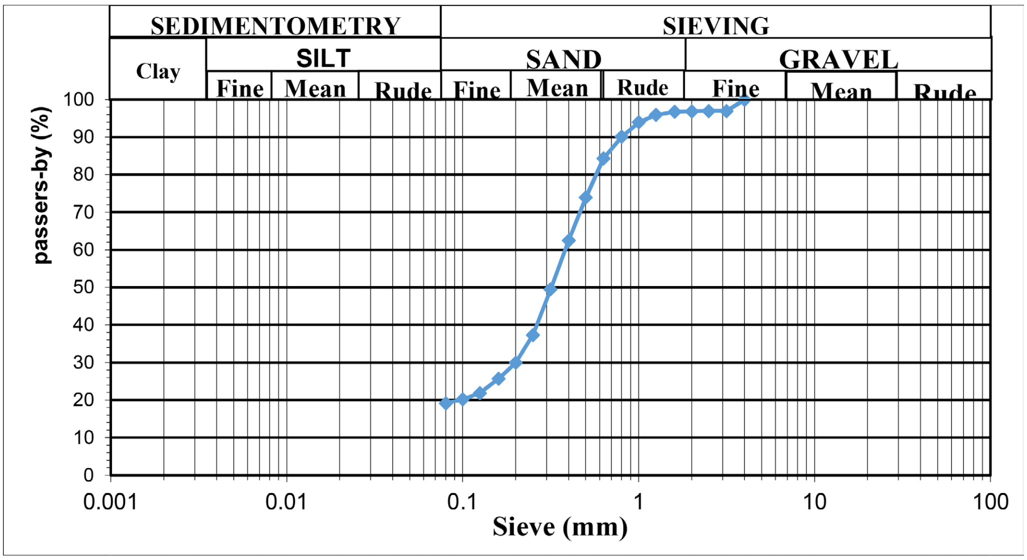

Figure 1. Granulometric curve of silty sand.

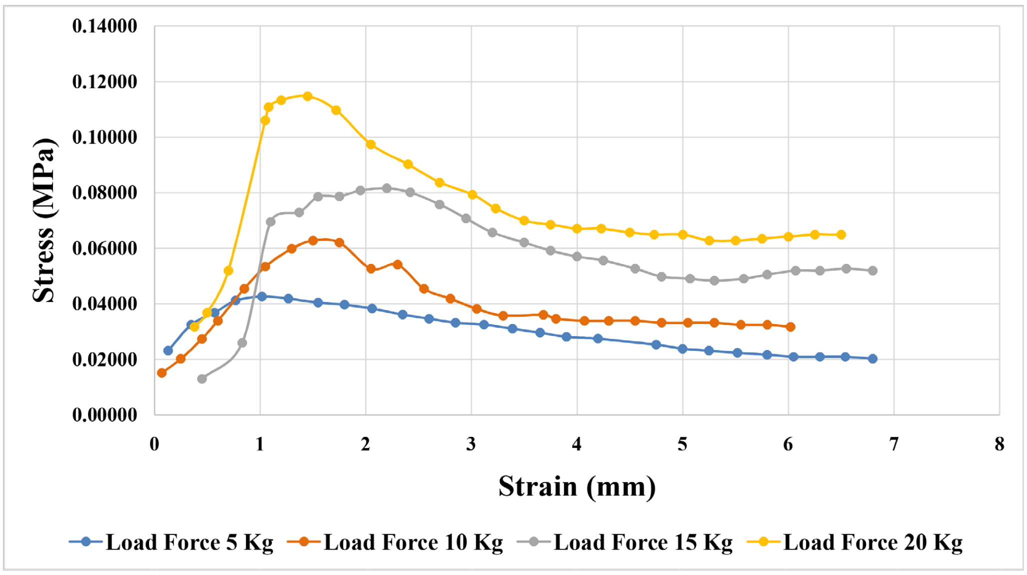

Figure 2. Stress and strain curves of non-stabilized, non-soaked silty sand.

Table 2. Shear stresses as a function of normal stresses of non-stabilized and unsoaked silty sand.

Normal stress σ (MPa)	0.0177	0.0354	0.0531	0.0707
Shear stress τ (MPa)	0.0426	0.0628	0.0815	0.01147

and deduced cohesion which is 0.0165 MPa and the friction angle of 53.07˚.

3.1.3. Result of Shear Tests on Non-Stabilized Silty Sand Soaked in Water

When the raw silty sand is soaked and sheared, zero cohesion and a friction angle of 54.64˚ were obtained. Figure 4 gives the results of the stresses and strains, for different load forces, Table 3 the values of the shear stresses as a function of

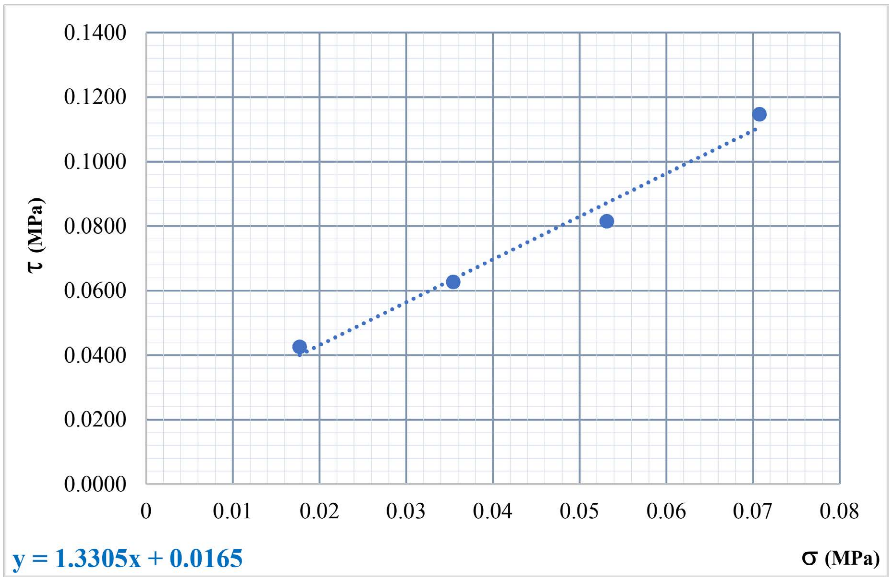

Figure 3. Intrinsic line of non-stabilized, non-soaked silty sand.

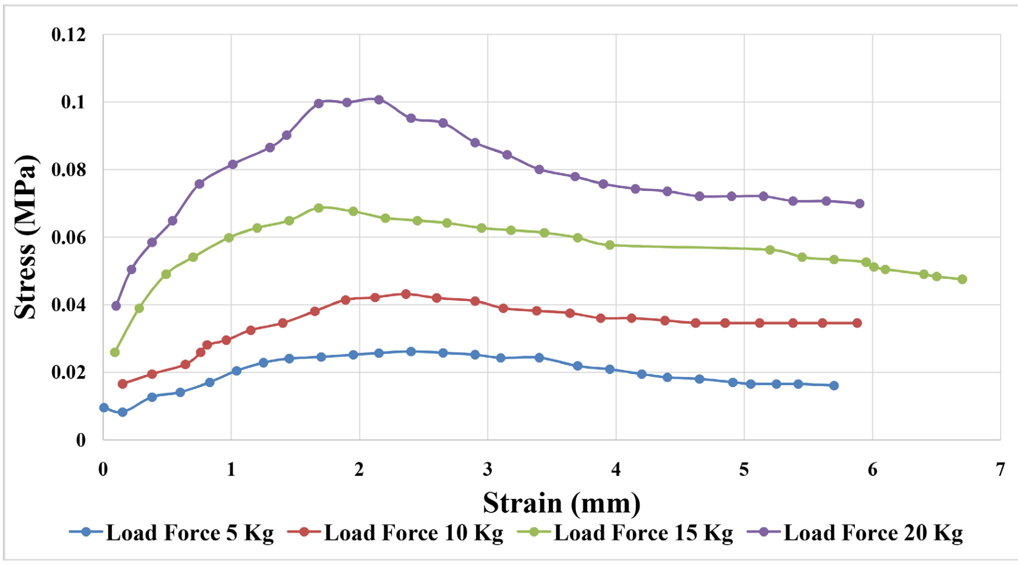

Figure 4. Stress-deformation curve of non-stabilized silty sand soaked in water.

Table 3. Shear stresses as a function of normal stresses of non-stabilized silty sand soaked in water.

Normal stress σ (MPa)	0.0177	0.0354	0.0531	0.0707
Shear stress τ (MPa)	0.02619	0.04317	0.06865	0.10071

the normal stresses, and Figure 5 the intrinsic line of the sheared soil.

3.1.4. Result of Shear Tests on Non-Stabilized Silty Sand Not Soaked in Water

The cohesion and friction angle obtained for the shear test of stabilized and unsoaked silty sand is 0.0282 MPa for cohesion and 55.63˚ for the friction angle. Figure 6 gives the stresses and strains (for different load forces), Table 4 the

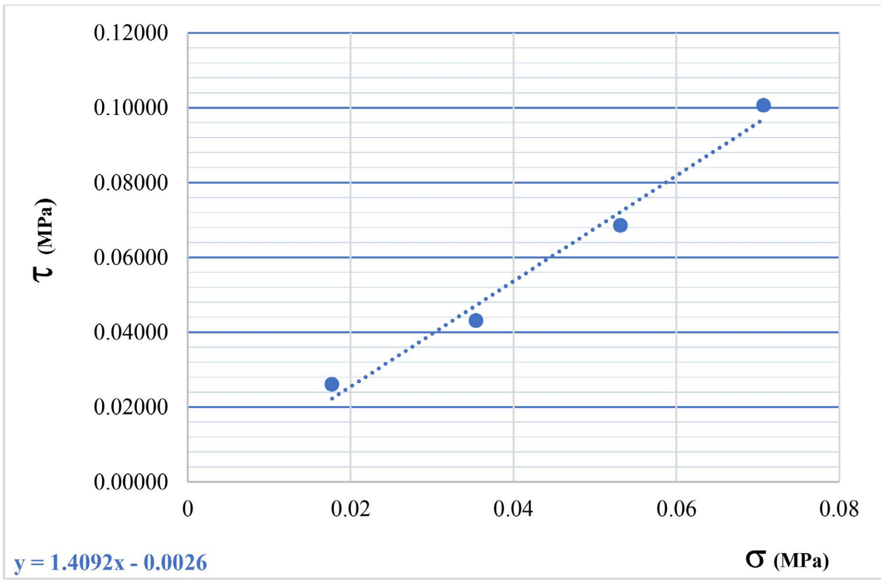

Figure 5. Intrinsic line of non-stabilized silty sand soaked in water.

Table 4. Shear stresses as a function of normal stresses of stabilized silty sand non soaked in water.

Normal stress σ (MPa)	0.0177	0.0354	0.0431	0.0707
Shear stress τ (MPa)	0.0426	0.0628	0.0815	0.01147

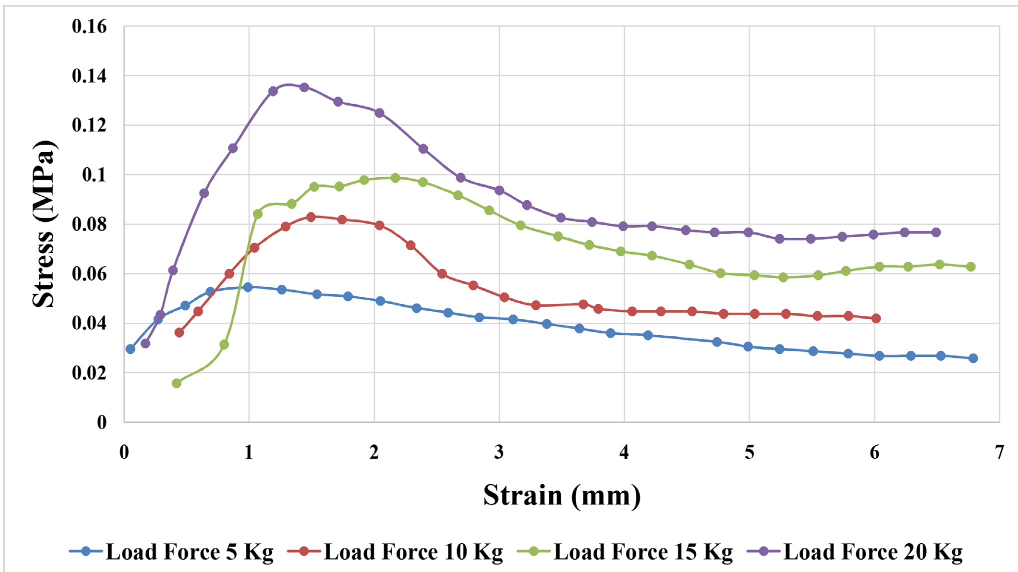

Figure 6. Stress-deformation curve of stabilized silty sand not soaked in water.

values of the shear stresses as a function of the normal stresses, and Figure 7 the intrinsic line of the sheared soil.

3.1.5. Result of Shear Tests on Silty Sand Stabilized and Soaked in Water

The shear test of the silty sand stabilized and soaked in water gave cohesion of 0.0052 MPa and a friction angle of 53.40˚. Figure 8 gives the stresses and strains.

Table 5 gives the values of the shear stresses as a function of the normal stresses. These stresses made it possible to draw the intrinsic line in Figure 9.

3.2. Results Analysis

To allow easy exploitation of the results of the shear tests of the material studied under different aspects, the results are summarized in Table 6. It can be seen from these results that when the soil is:

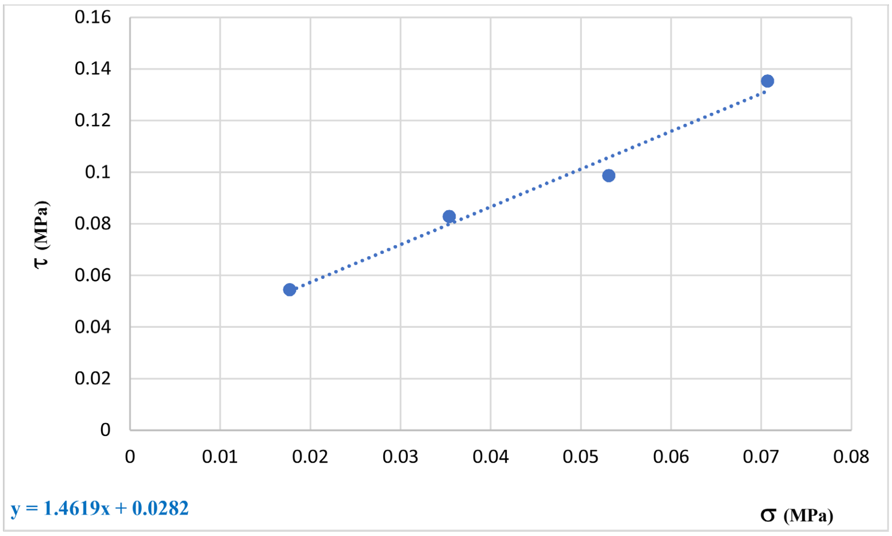

Figure 7. Intrinsic line of stabilized silty sand not soaked in water.

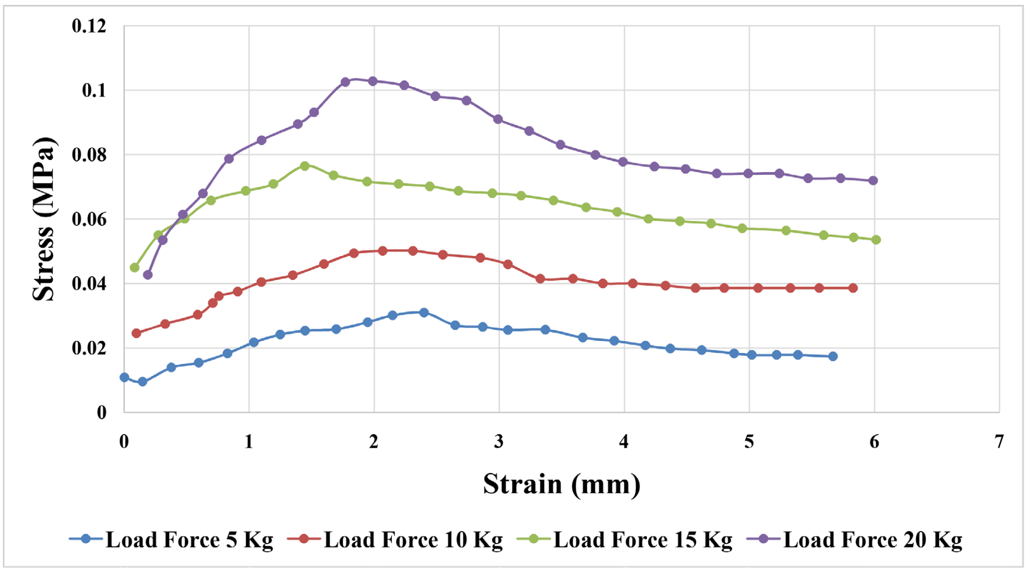

Figure 8. Stress-deformation curve of silty sand stabilized and soaked in water.

Table 5. Shear stresses as a function of normal stresses of silty sand stabilized and soaked in water.

Normal stress σ (MPa)	0.0177	0.0354	0.0531	0.0707
Shear stress τ (MPa)	0.03096	0.05017	0.07652	0.10151

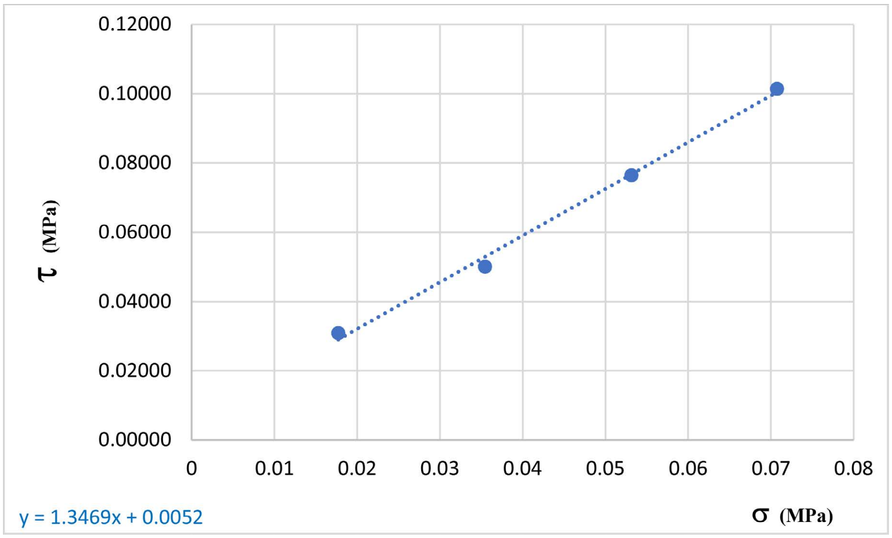

Figure 9. Intrinsic line of silty sand stabilized and soaked in water.

Table 6. Shear test results summary.

Material condition	Raw silty sand	Soaked raw silty sand	Stabilized silty sand	Stabilized and soaked silty sand
Cohesion (MPa)	0.0165	0	0.0282	0.0052
Friction angle (degree)	53.07	54.64	55.63	53.40

- Not stabilized, its cohesion is 0.0165 MPa and the angle of friction is 53.07˚, when it is soaked in water, the water acts and dissolves the cohesion which becomes zero, however the angle of friction increases and passes at 54.64.
- Stabilized its cohesion is 0.0282 MPa. It increases by 70.71% compared to its non-stabilized state and the friction angle of 55.63˚, an increase of 4.31%. When the stabilized soil is soaked in water, the cohesion is 0.0052 MPa, a drop of nearly 81.56%. Stabilization makes the material more water-repellent.

4. Conclusion

This study aims to assess the influence of tannic powder of *Bridelia* bark on the behaviours of the shear parameters of the silty sand *Bridelia* bark powder composite material and to evaluate the durability of these parameters under the effect of water. Straight shear tests were carried out on the samples of non-stabilized silty sand, soaked non-stabilized silty sand, unsoaked stabilized silty sand, and stabilized and soaked silty sand. The results show that the cohesion and the friction angle of the silty sand-*Bridelia* bark composite material increase by nearly 70.71% for the cohesion and 4.31% for the friction angle. We also note that when this composite material is saturated with water, the cohesion drops by nearly 81.56%, but does not dissolve completely as for the same material when it is not stabilized. This information is crucial in the valorization of earth material since its durability discourages its use in the construction of buildings. In fact, in the long term, water dissolves the cohesion of the material and ends up demolishing the structure, but the present study informs us that the cohesion of the earth-powder composite material of the *Bridelia* bark does not disappear when the material is saturated. The composite material then becomes more water-repellent, this property is so sought after for soils in the construction of civil engineering works because for civil engineering water is the primary enemy of the soil and it is therefore necessary to find binders once in the soil increases the water-repellent properties of the soil. Further studies should focus on the use of this composite material in roadworks and dams.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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