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Effect Of Curauá Fibers Inclusions On The Mechanical Behavior Of A Sandy Soil

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SUMMARY: Soil reinforcements with synthetic and vegetal fibers have been widely studied. It is already known that the inclusion of fibers increases the peak resistance and decreases the post-peak resistance drop of non-cohesive soil under static load. However, the improvement or the alteration of mechanical properties of soil reinforced with fibers depends on the characteristics of the fibers (tensile strength, modulus of elasticity, length, content and surface roughness), of the soil (degree of cementation, size, shape and granulometry of particles and voids), of the type of inclusion (randomly distributed or in the form of layers), the confinement stress and the loading mode. This experimental study reports the behavior of a reinforced and unreinforced granular soil with the addition of short curauá fibers randomly distributed. These fibers are extracted from the leaves of plants of the Ananas erectifolius species, which are a naturally occurring bromeliads in the Amazon. These vegetal fibers were chosen because they have good mechanical properties. Conducting studies employing curauá fibers as soil reinforcement has the main objective to know their behavior aiming to be a sustainable alternative to replace the synthetic fibers used for the same purpose. The curauá fibers were mixed with granular sandy soil to evaluate its influence on the mechanical properties of the soil. A series of compression isotropic drained triaxial test was performed to seek to establish patterns of behavior that might explain the influence of the addition of curauá fibers, relating it to the shear strength and deformation parameters of the soil. The tests were performed on samples subjected to a relative density of 50 % and moisture content of 10 %, fibers content in proportions of 0 and 0.5 % of the dry weight of the soil and the fibers lengths of 25 and 50 mm. As a natural fiber, its diameter is not constant. Through the obtained results, it was observed that the addition of curauá fibers randomly distributed leads to significant improvements in the mechanical properties of the soil, since it was observed an increase in the cohesion and angle of friction of the mixtures compared to the values obtained for the pure soil. The results show the potential of curauá fibers being used as reinforcement of soils in earthwork subjected to static loads, such as landfills and embankments on soft soils.

KEYWORDS: Soil reinforcement, natural fiber, granular soil, strength and stiffness

1 INTRODUCTION

The technique of improving the mechanical properties of the soil with addition of fibers is long known and used by mankind. There are records of vegetal materials being used to give greater resistance to clay bricks dating back to ages before Christ (Palmeira, 1992)

The technique of soil reinforced with fibers is inserted in the technology of composite materials. According to Budinski (1996), a composite material is a combination of two or more materials that together have properties that the components do not have by themselves.

For Taylor (1994), Illston (1994) and Hannant (1994) is a consensus that the greatest potential of fiber composite materials is in the post-cracking state where the fibers contribute more effectively in the strength of the material, thereby increasing its energy absorption capacity.

Reinforcements in the form of steel strips, wire mesh and various types of synthetic materials have been widely used in geotechnical works. Such applications range from the conventional structures to stabilizing embankments on soft soil, passing through slope reinforcements, increase the bearing capacity of foundations and reinforcement of pavements (Palacios, 2012).

The development of composite materials reinforced by vegetal fibers is largely motivated by the greater environmental awareness due to waste disposal problems and petrochemical resources exhaustion (Dittenber and GangaRao, 2012).

Vegetable fibers, compared to synthetic fibers are inexpensive, easy to obtain, widely available, easy to handle, have good mechanical properties, do not generate excessive amounts of residues, employ relatively simple technology and require less energy in the production process, besides being renewable sources (Ghavami et al., 1999; Dittenber and GangaRao, 2012; Martins, 2014).

The improvement or alteration of mechanical properties of soil reinforced with fibers depends on characteristics of the fiber (tensile strength, modulus of elasticity, length, content and surface roughness), of the soil (degree of cementation, size, shape and particle size, ratio voids, etc.) of the confinement tension and load mode.

This work seeks to contribute to a better interpretation of the mechanical behavior of soil reinforced with natural vegetal fiber, aiming to enhance the use of these composite in earthworks.

2 EXPERIMENTAL PROGRAM

The experimental program consisted in the execution of triaxial compression tests to determine the strength parameters that were the basis for identifying and evaluating the effect of dispersed inclusions of curauá fibers on the mechanical properties of a granular soil.

2.1 Materials and Methods

2.1.1 Sandy Soil

A material with well-defined mechanical behavior was chosen in order to facilitate the interpretation of the effect caused by the addition of fibers. It was used a sand with uniform particle size from a deposit located in the city of Itaboraí in the state of Rio de Janeiro.

The particle size curve (Figure 1), and the physical indices of the material (Table 1) were determined at the Laboratory of Geotechnics and Environment (LGMA) from the Pontifícia Universidade Católica do Rio de Janeiro (PUC-Rio).

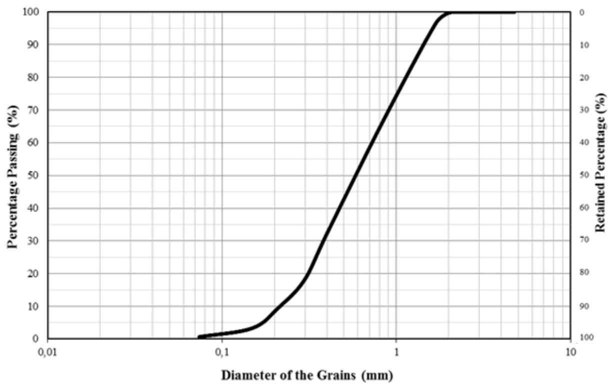

Figure 1. Particle size curve of the sandy soil.

Table 1. Physics index of the sandy soil.

Physics Index	Values
Specific Weight (Gs)	2,65
Effective Diameter D_{10}	0,22 mm
Average Diameter D_{50}	0,58 mm
Uniformity Coefficient (Cu)	3,27
Coefficient of Curvature (Cc)	0,87
Maximum voids index (e_{max})	0,96
Minimum voids index (e_{min})	0,71

2.1.2 Vegetal Fiber

The use of vegetable fibers, beyond ensure the production of an environmentally friendly product, can ensure a new alternative income for farmers in the producing regions when produced on an industrial scale.

The fiber used as soil reinforcement element was the Curauá vegetable fiber (*Ananas erectifolius*). These fibers are extracted from plant leaves, which are naturally occurring bromeliads in Amazon (Santiago, 2011).

Native and rustic species, curauá is not exigent about the soil, growing up in sandy and little fertile soil including degraded area. Curauá is among the most competitive fibers, ranks among the most economically viable (Santos, 2009).

The curauá fibers were purchased from Triangel Pematec of Brazil Company, in the city of Santarém / Pará.

Table 2 shows values available in the literature for the main characteristics of the fiber used.

Table 2. Properties of the curauá fiber

Diameter (mm)	Tensile strength (MPa)	Young's Modulus (GPa)	Strain at rupture (%)	Reference
0,071	543	63,7	1	Fidelis, 2014
0,092 - 0,127	492,62	11,54	3,02	Picanço, 2005
0,09	605	23	2,5	Santiago, 2011

2.1.3 Sample Preparation

Composites of sandy soil reinforced with curauá fibers dispersed in the matrix were tested. The variables investigated were fiber content (0 and 0.5%), fiber length (25 to 50mm) and initial effective stress (50, 100 and 150 kPa). Table 3 summarizes the variables investigated and adopted abbreviations.

The parameters for molding the soil and soil-fiber samples were the same used by Casagrande (2005), Girardello (2010), Santiago (2011), Sotomayor (2014) and Louzada (2015), who also worked with sandy soil, being moisture content of 10% and a relative density of 50%.

The preparation of the test specimens of pure sandy soil and soil-fiber mixture for conducting triaxial tests were made by compaction in a cylindrical tripartite mold directly positioned in the press where the test was performed. Samples were manually compacted in three layers, the added weight of the mixture and the height of the layers were controlled to obtain the desired density.

Table 3. Variables investigated and adopted abbreviations.

Content (%)	Length (mm)	Initial Effective Stress (kPa)	Abbreviation
0.0		50, 100 e 150	Sandy soil
0.5	25		SCA25
	50		SCA50

2.2 Triaxial Tests

Isotropic consolidated drained (CID) triaxial test were performed to obtain the strength parameters in sandy soil and soil-fiber composites samples. The available press at PUC -Rio is of controlled displacement velocity.

Samples dimensions of 4.0 cm diameter and 8.6 cm height were saturated using the techniques of backpressure and percolation of water. To ensure that the samples were saturated, it was used the Skempton's parameter B. The criteria presented by Head (1986) was used to define the shear velocity, with the rate of 0,030 mm / min used for all samples

3 RESULTS AND ANALYSES

Figure 2 shows the deviator tension (σ_d) and volume variation (ε_v) versus axial strain (ε_a) curves, corresponding to the CID triaxial test type with initial effective stress of 50, 100 and 150kPa related to the sandy soil and the sandy soil reinforced with curauá fibers randomly distributed with length of 25 and 50mm and the content of 0 and 0.5%.

For the materials tested, it is observed that the resistance increases with the increase of the confining pressure. It is possible to see that the shear strength increase due to the addition of the fibers in relation to the unreinforced material, being this increase greater than greater the length. In the volumetric variation curves, with the exception of the sample SCA 25 under initial effective stress of 50 kPa, there is a contraction tendency for all samples in all employed confining stresses, being this contraction greater with larger value of the confining pressure.

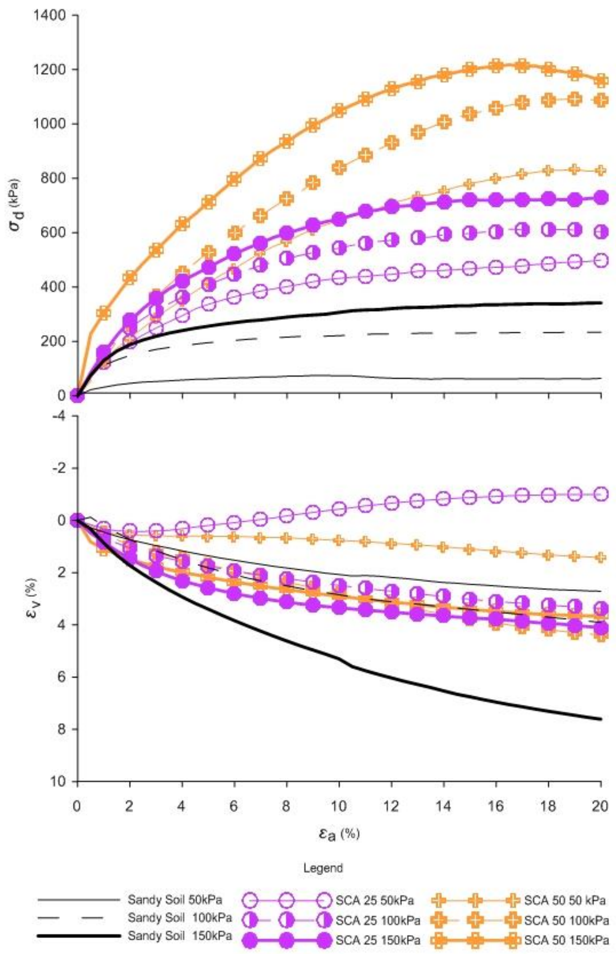

Figure 2. Curves deviator tension and volumetric strain vs. axial strain to the sandy soil and sandy soil reinforced with curauá fibers.

Under lower initial effective stress (50 kPa), the random inclusion of curauá fibers on sandy matrix, regardless of the length, resulted in a constant increase in resistance with increasing axial deformation, featuring an elastic-plastic stiffening behavior.

Under higher initial effective stress (100 and 150 kPa), the random addition of curauá fibers on sandy matrix, regardless of the length, resulted in curves with a resistance peak, after which the resistance is made constant or has suffered a decrease with increasing the axial deformation.

It is noted that the stiffness of the materials tested increases with increased confining stress. For the same effective confining stress, the sand composites reinforced with curauá fibers, regardless of length have a higher stiffness than the sand without reinforcement. This behavior indicates that the incorporation of fibers in a sandy matrix generates changes in the structure of this material exerting influence on its rigidity.

It can be seen that the tenacity of the materials tested increases with increased confining stress. For the same effective confining stress, the sand composites reinforced with curauá fibers, regardless of length have greater deformation energy absorption capacity when compared to sand unreinforced

Also is possible to notice that the fibers begin to contribute in the resistance increase of the material at the start of the test, when the axial deformation is around 2.5%. After this deformation becomes apparent the difference in behavior between the deviator tension vs axial strain curves of the tested materials, and the contribution of the fibers addition remains visible until the measured axial strain limit of 20%.

Figure 3 presents the strength envelopes as well as the values of cohesive intercept and the internal friction angle obtained for the soil and the soil-fiber at 20% of axial strain. This was because the tests on the fiber-reinforced soil were generally experiencing slight strain hardening until the maximum strain that the apparatus could reach, as can be seen in the stress-strain data in Figure 2, so that a “strength” had to be defined at a particular strain.

The addition of curauá fibers in a sandy soil caused an increase in both the cohesive intercept and the friction angle of the material. During the mixing process of the soil with fiber randomly distributed, it was clearly noted that the fibers afforded a tangle involving and somehow tied the soil grains, promoting an anchoring effect. This observation has been translated in the increase of the cohesive intercept and friction angle and proven by the values obtained.

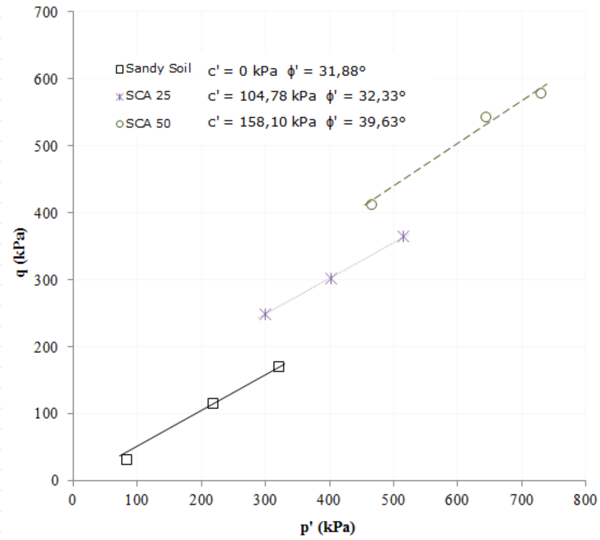

Figure 3. Resistance envelopes to the sandy soil and soil reinforced with curauá fiber at 20% of axial strain.

4 FINAL CONSIDERATIONS

From the conventional triaxial compression tests performed on sandy soil and soil-curauá fiber mixtures with 25 and 50mm in length, content of 0 and 0.5% and initial effective stress of 50, 100 and 150kPa were established some conclusions reported below:

The inclusion of curauá fibers, regardless of the length caused an increase in cohesive intercept and friction angle of the material and consequently the material strength.

The addition of curauá fibers, regardless of length, caused an increase in stiffness and tenacity of the sand.

For the evaluated fiber lengths, the greater the fiber length, the greater the mechanical strength gain.

The stress vs strain behavior of the soil reinforced with curauá fibers is influenced by the initial effective stress. The identification of elastic-plastic hardening behavior under confining pressure of 50 kPa indicates that the fibers act more effectively at lower initial effective stress.

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