Shear Strength Properties of a Lateritic Fine-Grained Soil Treated with Cement and Polyethylene Strips

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ABSTRACT

The addition of cement as a stabilization technique is widely discussed in the literature, as well as the addition of PET strips in the soil. In the case of simultaneous inclusion of cement and plastic strips, the literature shows that higher strip content gives greater post-cracking resistance to the soil and a smaller cracking size. This research evaluated the influence of cement and Polyethylene Terephthalate (PET) fibers in the shear strength of a lateritic fine-grained soil. Direct shear tests were conducted with cement-treated soils in the contents of 2, 6 and 10% (in relation to soil dry mass). In order to evaluate the influence of PET strips, direct shear tests were conducted on the lowest content of cement addition (corresponding to 2%). Strips, taken from disposable bottles length presented the highest values of friction interface and, in relation to the cohesive intercept, the highest values presenting lengths of 10, 15, 20 and 30 mm and width of 1.5 mm were randomly added to the soil in percentages of 0.75,1.0,1.5 and 2.0%. The results showed that the higher the percentage of cement increment, the greater was the increase in soil shear strength. In the case of soil-cement-strip, it was verified that the inclusion of 1.0% of strips of 15 mm in obtained were obtained when using 2.0% of fibersand length of 20 mm. Overall, the behavior of the strips showed that longer lengths lead to a higher shear strength of the composite.

RESUMO

A adição de cimento como uma técnica de estabilização é amplamente discutida na literatura, assim como a adição de tiras plásticas no solo. No caso da inclusão simultânea de cimento e tiras, a literatura mostra que uma alta taxa de tiras acarreta uma melhor resistência pós-fissuração para o solo e menor dimensão das fissuras. Essa pesquisa avaliou a influência do cimento e tiras de Polietileno Tereftalato (PET) na resistência ao cisalhamento de solo arenoso. Ensaios de cisalhamento direto foram realizados com solo-cimento nas porcentagens de 2, 6 e 10% (em relação à massa seca do solo). A fim de analisar a influência das tiras, os mesmos ensaios foram realizados na menor resistência de adição de cimento (correspondente a 2%). Tiras, cortadas a partir de garrafas PET descartadas, apresentando comprimentos de 10, 15, 20 e 30 mm e largura de 1,5 mm, foram adicionadas aleatoriamente ao solo nas porcentagens de 0,75; 1,0; 1,5 e 2,0%. Os resultados mostraram que quanto maior a porcentagem de adição de cimento, melhor o aumento na resistência do solo. No caso de solo-cimento-tira, foi verificada que a inclusão de 1,0% de tiras de 15 mm de comprimento apresentaram os maiores ângulos de atrito e, em relação à coesão, os maiores valores obtidos foram com a percentagem de 2,0% e comprimento de 20 mm. Em geral, o comportamento das tiras mostrou que maiores comprimentos levaram a maiores resistências de cisalhamento do compósito.

1. INTRODUCTION

With the increase in the cost of building materials and reduction in the availability of natural materials, among other factors, it became necessary to create composites that replace materials already used with equal or greater efficiency. This is how the importance of using soil-cement as building materials emerged in geotechnics. The use of cement in soils has thus become an usual practice in civil engineering over the years. Cement contents of up to 10% (high content) are commonly used today.

Cement-treated soils have shown a significant increase in strength and stiffness when compared to natural soil, what makes them to have a variety of applications: shallow foundations, slope protection, dam, and especially in the base and subbases of flexible pavements.According to Pitta (1984), soil-cement are stabilized earth materials with cement contents between 5 and 10% in relation to soil dry mass withstrict quality standards (durability and uniaxial strength).The soil improved with low contents of cement, with typical range of 2 and 5% has chemical and mechanical properties normally inferior to traditional cement soil. Inclusion of high levels of cement (higher than 8% in relation to dry mass of soil) makes the soils, despite its high strength, show a behavior of a fragile material, having its tensile strength. In this context, the use of strips in cemented-treated soils results in similar shear strength properties with low cement contents (2 to 4%). The addition of polymeric strips in cemented soils appears as a viable alternative, as it can achieve the same strength results as the compound using low cement contents.

It is notable the importance of the knowledge onthe interaction soil-strips or soil-fiber mechanisms in order to understand the response of the mixture in relation to the mechanical behavior. This mechanism depends on several factors related to the matrix (soil, soil-cement or soil-lime), such as particle size, voids index and cementation degree, and the fibers or strips especifications (length, thickness, roughness, elasticity modulus, elongation capacity, etc). According to Johnston (1994), fibers in a cemented matrix can generally have two important effects. Firstly, they tend to reinforce the composite over all loading modes that induce tensile stresses, like indirect tensile, flexural and shear, and second, they improve the ductility and toughness of a matrix with fragile characteristics. Fibers do not prevent the formation of cracks in the material butare able to increase tensile strength by controlling crack propagation (Taylor, 1994). According to Hannant (1994), fibers keep the cracks together, which increases ductility and post-cracking state improvement. Fibers that "cross" the cracks act as a "soil-cement-fiber micro-anchorage", contributing to the increase of strength, rupture deformation and toughness of composites. When included in sandy soils, fibers cause the creation of a cohesion intercept as well as an increased friction angle. In the case of cemented soil, fibers have a greater influence on ultimate cohesion and ultimate friction angle (Vendruscolo, 2003).According to Casagrande (2005), fibers inhibit the amplitude of cracks associated to the composite rupture, which leads to an increase in the areas under the stress- strain curves. This property is commonly referred as toughness and represents the fracture work or energy absorbing capacity of the composite".

Nonetheless, with the great advance of the chemical industry, synthetic materials have been widely used as reinforcement in civil engineering constructions, which are advantageous due to the great ease of large-scale productions and resistance to external agents. The main polymers used are polypropylene (PP), polyethylene (PE), polyester (PET) and polyamide (PA). However, in terms of fibers, the most frequent used is PP fiber.

Despite the amount of fiber researches, there is a gap about the use of plastic fibers as soil reinforcement, especially when it comes to using strips. The main difference between the two types of inclusion is in the shape of the materials. While polymeric fibers are very thin and elongated materials, such as filaments, strips are materials of greater width and thickness, usually cut from existing plastic structures. Consoli et al. (2002) carried out one of the first experiments on the utilization of PET fibers derived from plastic wastes in the reinforcement of natural and artificially cemented sand, showing that the plastic waste improved soil mechanical response. Some other research has conducted studies using polymeric fibers in soils (Chebet and Kalumba, 2014; Luwalaga, 2015 and Peddaiah et al., 2018), but not with cement addition. Thus, this study seeks to contribute to the understanding of the mechanical behavior of lateritic fine-grained soil treated with cement and PET strips, in order to establish a correlation between soil-cement properties and soil-cement-PET strips properties, besides the mechanical behavior of the fibrous composites as a whole.

2. MATERIALS AND METHODS

For the development of this research, a lateritic fine-grained soil was used. The soil was collected the region of Bauru, in the state of Sao Paulo, Brazil. For soil characterization, particle size distribution tests (ABNT NBR 7181), soil specific gravity (ABNT NBR 6508) and compaction tests (ABNT NBR 7182) were conducted. All tests were performed at the Laboratory of Soil Mechanics at School of Engineering at Bauru. Standard Proctor tests were conducted with natural soil, and at soil-mixtures corresponding to cement percentages of the extreme contents(2% and 10%) in order to evaluate the influence of cement addition to the soil compaction parameters. PET strips were cut from bottles that would be discarded without any reuse. Direct shear tests were conducted according to ASTM D3080.

Tests were performed with the addition of cement to the soil in percentages of 2, 6 and 10%, in order to analyze the behavior of this composite in relation to shear strength properties. Then, the direct shear tests of the soil-cement-strip composite were conducted with the lowest cement content (2%) in order to evaluate the influence of the strips and analyze its viability. The strips were added in percentages of 0.75; 1.0; 1.5 and 2.0% in the lengths of 10, 15, 20 and 30 mm.

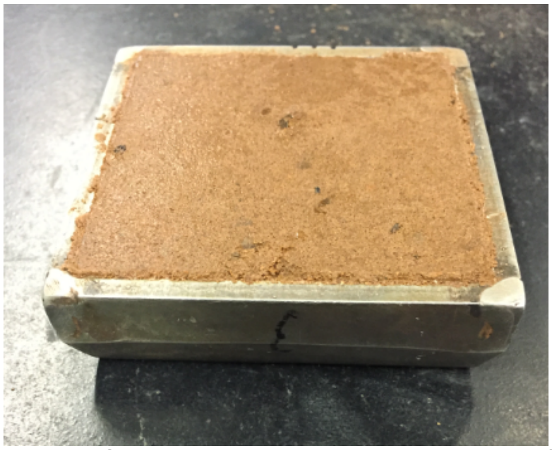


Figure 1. Specimen molded only with the addition of cement.

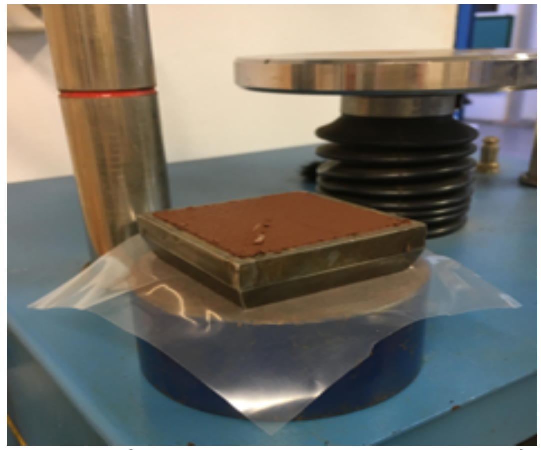


Figure 2. Specimen molded with the addition of cement and fibers.

3. RESULTS AND ANALYSIS

In Table 1, particle size distribution results show soil composition. The soil is classified as a medium to fine, reddish brown, clayey sand, according to the classification adopted by ABNT NBR 6502/1995. Figure 3 illustrates the particle size distribution obtained in tests with and without the addition of deflocculant. Figure 4 represents the compaction curve for the natural soil (maximum dry mass of 1.950 g / cm³ and optimum moisture content of 10.8%).Figures 5 show the compaction curves of soil-cement mixtures, with the addition of 2% and 10% of cement.

Table 1 – Properties of the lateritic soil. (FAGUNDES, 2014).

Properties	Unity	Characteristic Value
Sand	%	80,2
Silt	%	5,8
Clay	%	14,0
Liquid Limit	%	15,5
Plastic Limit	%	NP
Maximum dry density	g/cm³	1,950
Optimum moisture content	%	10,6
Specific Gravity Of Solids.	-	2,649

NP = Non Plastic

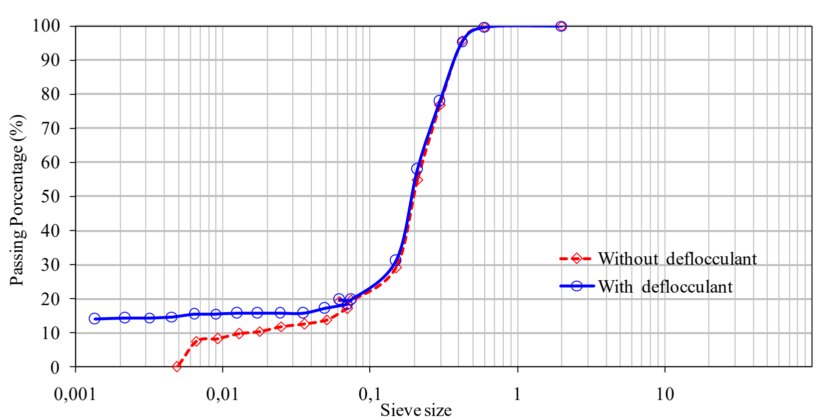


Figure 3 – Particle size distribution curve.

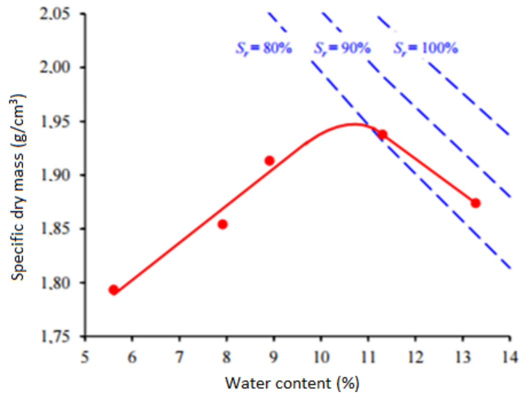
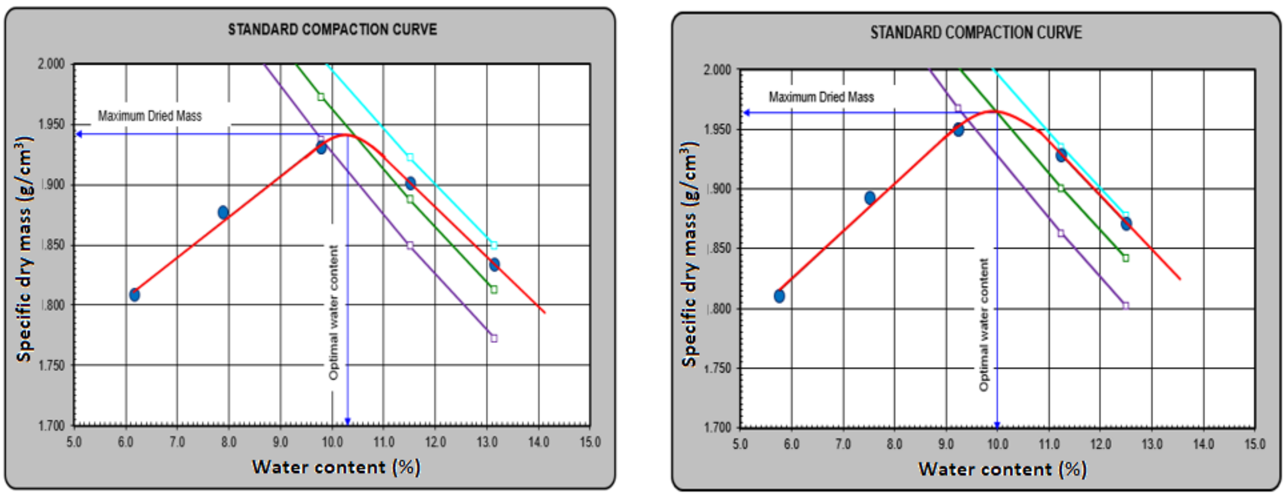


Figure 4. Natural sandy soil compaction curve.



(a) Addition of 2% of cement.
(b) Addition of 10% of cement.

Figure 5. Compaction curves of the soil with cement addition.

At first, Standard Proctor tests were conducted with specimens with 2% and 10% cement percentage (the lowest and the highest percentage, respectively) in relation to the dry mass to analyze the difference in the optimal parameters. According to Figure 5, the optimal parameters found were: 10.3% of optimum moisture content (OMC) and 1.940 g/cm³ of maximum dry mass (2% cement) and 10.0% of OMC and 1.965 g/cm³ of maximum dry mass (10% cement). As the difference in OMC between the two tests is less than 1%, the results are very similar to those obtained without cement inclusion and is compatible with the deviations that may occur in the field. Then, it can be stated that the OMC and the maximum dry specific mass are not significantly influenced by the addition of cement. These results are consistent with what is reported by Kézdi (1979) and Ulbrich (1997). Afterwards, the soil-cement specimens were molded for the direct shear tests at the OMC of natural soil moisture(10.8%), which in all cases is consistent with the acceptable optimum moisture deviation of 1%, compatible with the deviations that may occur in the field.

Table 2. Material properties.

Material	Maximum water content (%)	Maximum dry mass (g/cm³)
Natural sandy soil	10.8	1.950
Addition of 2% of cement	10.3	1.940
Addition of 10% of cement	10.0	1.965

Direct shear tests were specimens were molded in natural soil OMC, with 95% compaction degree. At first, three trials were performed (using normal stresses of 30, 60 and 125 kPa) with natural soil and with the addition of each percentage of cement applied in relation to the dry mass of the soil in percentages of 2, 6 and 10%. Four shear strength envelopes were obtained. Figure 6 shows shear strength envelopes of the tests performed with natural soil.

The shear strength parameters found for the natural soil of the Bauru region is cohesion of 5.48 kPa and friction angle of 33.53º. Figure 7 illustrates the shear strength envelopes with addition of 2, 6 and 10% of cement. Table 3 shows the parameters of shear strength of the soils, where is possible to verify the influence of cement on soil shear strength.

The Figure 8 shows the stress-strain curves regarding the soil with cement in the optimum percentage (2.0%).

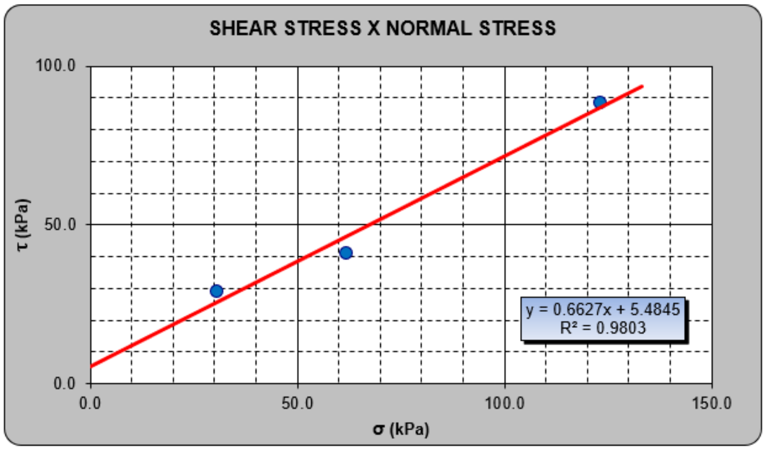


Figure 6.Shear strength envelope of natural soil.

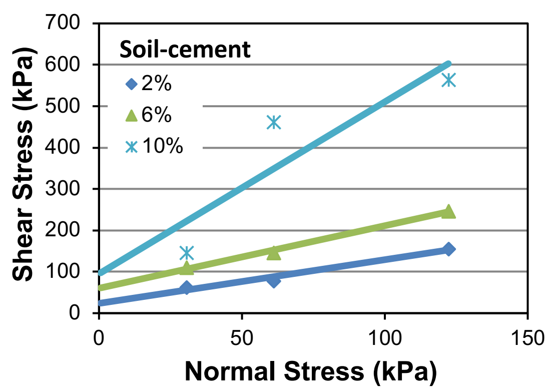


Figure 7. Shear strength Envelopes with different percentages of cement addition.

Table 3. Parameters of shear strength of the soils.

Percentage (%)	Cohesion (kPa)	Frictionangle (º)
0.0	5.49	33.53
2.0	22.50	46.84
6.0	116.59	48.10
10.0	157.67	74.34

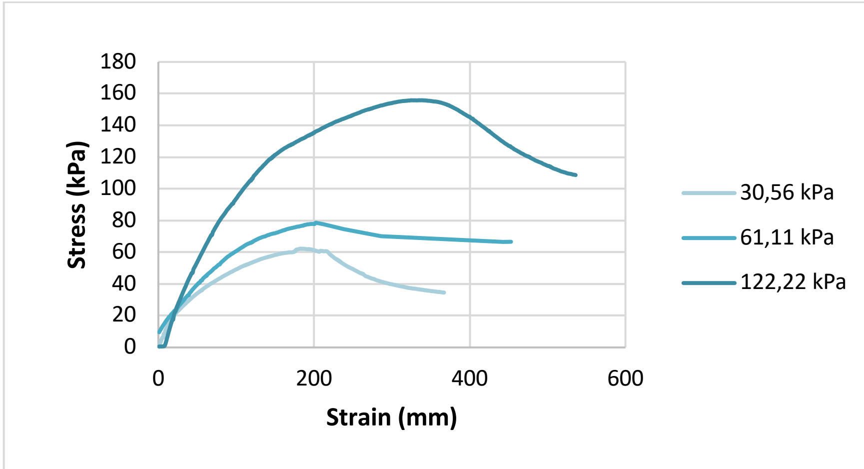


Figure 8. Stress-strain curve of the sandy soil with addition of 2.0% of cement.

For tests with inclusion of PET strips, the choice of cement percentage was considered based on the high cost of cement and its polluting potential. Then, in order to study the addition of cement for various purposes and for the reasons mentioned above, subsequent tests were performed with a cement percentage of 2% and PET strips. Figure 9 shows a comparison of shear strength envelopes of soil-cement and soil with 2% cement and optimum strip content (found by testing the inclusion of fibers in the soil-cement composite).

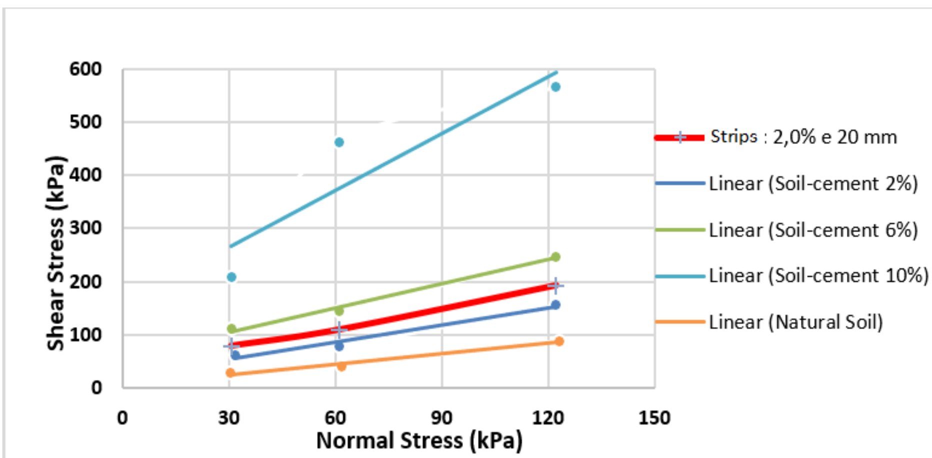


Figure 9 .Shear strength Envelopes of soil-cement and soil-cement-strip.

Table 4 presents the results obtained for the inclusion of strips in the cement-treated soil. It is noted that the combination of strips with a length of 20 mm and a 2.0 percentage presented the best results. In practical terms, the inclusion of this length and strip content leads to results similar to the addition of 6% cement only. Thus, the influence of strips on soil behavior became more evident and this research shows a solution with a lower cost (adding a minimum amount of cement and strips waste addition, which have a lower comparative cost). Analyzing the shear stress x shear displacement curves shown in figure 10, it is possible to notice that the rupture of the specimens with the addition of cement occurs after a greater displacement than that of the sandy soil, however, there is a tendency of high loss of strength after the peak. Thus, it is possible to conclude that the addition of cement alters the rupture of the material, making the rupture fragile, so that the strength of the material drops sharply when the deformation increases. Regarding the inclusion of strips, it is possible to notice that there is an increase in the ductility of the material, presenting greater deformations and lower stress peaks, in comparison with the data obtained in tests carried out with the addition of 2% cement to the sandy soil. This behavior was more accentuated for inclusions of larger strips, of 30 mm in length, and in larger quantities.

Table4. Soil-cement shear strength parameters with different strips percentages and lengths.

Length (mm)	Percentage (%)	Cohesion (kPa)	Frictionangle(º)
10	0.75	15.7	48.4
	1.00	29.5	51.3
	1.50	55.3	28.9
	2.00	38.4	51.3
15	0.75	73.9	39.0
	1.00	38.2	51.4
	1.50	34.4	49.4
	2.00	38.1	46.2
20	0.75	73.8	29.2
	1.00	15.2	46.7
	1.50	28.6	46.7
	2.00	78.8	17.2
30	0.75	6.1	51.1
	1.00	29.4	45.5
	1.50	34.2	43.2
	2.00	71.8	38.6

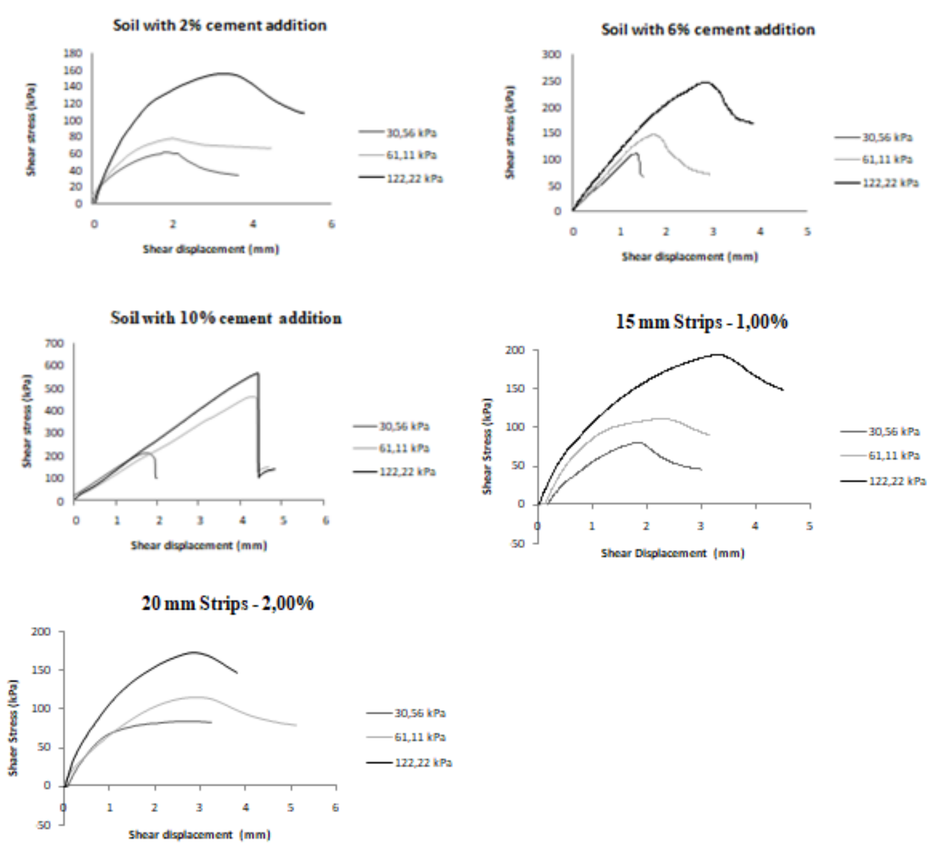


Figure 10. Stress x strain curves obtained in soil-cement and soil-cement-strips direct shear tests.

4. CONCLUSIONS

This research evaluated the influence of cement and Polyethylene Terephthalate (PET) strips in the shear strength of a lateritic fine-grained soil using direct shear tests. The inclusion of cement influenced the shear strength of the soil and the content of this material is directly proportional to this increase in strength.
Moreover, it can be concluded that the soil-cement-fiber composites resulted, in all cases, in higher direct shear strengths when compared to natural soil, increasing both cohesion and friction angle values.
Soil shear strength increased in all cases where cement and strips were included, but the cohesion and friction angle parameters showed a specific behavior. Therefore, the cohesion parameter suffers an improvement with the addition of this material; and, the friction angle varies, because this parameter is affected by the improvement of cohesion and the way the grain of soil and cement rearrange themselves in the mixture with the strips. So tensile strenght and the rupture depend on the distribution of the strips in the specimen, the amount of strips requested during the rupture and how the effort will be distributed.
In all mixture cases, cohesion was greater than in natural soil. The strip addition to soil-cement (2%) resulted in the highest cohesion when using 20 mm and 2.0% (in relation to the dry mass) and the fibers that led to a higher friction angle were the 15 mm strips and an inclusion of 1.0%.
In general, the addition of PET strips and cement to the clayey-sand soil proved to be an excellent option for increasing soil shear, presenting high potential application, being important to highlight that the use of this or other combination must be analyzed in relation to the desired purpose.

5. ACKNOWLEDGEMENTS

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