Analysis of the Behavior of a Clay Soil Stabilized with Mineral Coal Fly Ash and Lime for Geotechnical Applications

Analyse comportementale d'un sol argileux stabilisé avec des cendres volantes de charbon et de chaux pour les applications géotechniques

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ABSTRACT: It´s reported the experimental study of the behavior of mixtures of a clay soil with varying amounts of coal fly ash. The clay soil was collected in the experimental field of PUC-Rio, at an approximate depth of 2 m. Tests of physical characterization (particle size analysis, specific weight of grain, limits) and mechanical characterization (compaction tests and direct shear tests) were performed. Direct shear tests were performed on clay soil samples compacted at the optimum moisture content and the corresponding maximum dry specific gravity, with fly ash contents of 15 and 30 %, related to the dry weight of soil. For soil-ash-lime mixtures, it was added 3 % of lime to replace the dry weight of ash. It was studied the influence of ash contents and of lime addition in the mechanical behavior of the soil. It was observed an increase in shear strength of the mixtures, which is reflected in the increase of its parameters cohesion and internal friction angle, when compared to the pure soil. Thus, the results were satisfactory for application of these mixtures in layers of landfills, for example, giving a great purpose to this material.

RESUMÉ: C´est rapporté l'étude expérimentale du comportement des mélanges d'un sol argileux avec des quantités variables de cendres volantes de charbon. Le sol argileux a été recueilli dans le champ expérimental de la PUC-Rio, à une profondeur approximative de 2 m. Les essais de caractérisation physique et caractérisation mécanique (essais de compactage et essais de cisaillement direct) ont été effectués. Les essais de cisaillement direct ont été effectués sur des échantillons de sols argileux compactés à la teneur d´humidité optimal et à la densité correspondante, avec des teneurs en cendres volantes de 15 et 30%. Pour les mélanges avec chaux, on a ajouté 3% de chaux pour remplacer le poids sec de cendres. On a étudié l 'influence des teneurs en cendres et de l' addition de chaux dans le comportement mécanique du sol. On a observé une augmentation de la résistance au cisaillement des mélanges, ce qui se traduit par l'augmentation de ses paramètres de cohésion et d'angle de frottement interne, par rapport au sol pur. Donc, les résultats ont été satisfaisants pour l'application de ces mélanges dans des décharge, par exemple, ce qui donne une destination trés noble à ce matériau.

KEYWORDS: direct shear tests, clay soil, fly ash, lime, geotechnical applications

1 INTRODUCTION

The attempt of the diverse use of industrial wastes has been a constant concern in many countries, which has motivated the development of new techniques for use of this type of material. Coal ashes are in the group of industrial wastes and are usually applied as soil stabilizers. They are added to the soil when it doesn´t have appropriate parameters of resistance for use in geotechnical applications, or when the main objective is to improve them significantly, adding products with cimentitious features, like lime or cement (Nardi, 1975).

This study aims to analyse the influence of the addition of fly ash and lime to a clay soil. This fly ash is a fine waste from burning coal process in Thermoelectric Complex Jorge Lacerda, located in the city of Low Capivari in the state of Rio Grande do Sul. The reuse of this waste for various purposes is important, reducing environmental impacts and costs of disposal in sedimentation basins.

2 METHODOLOGY

The experimental program of this study consists of two steps: at first, the contents of ash and lime were chosen, based on previous works. Afterwards, tests of physical characterization of materials (clay soil, fly ash, mixtures with lime) were performed in order to know their particle size and their values of bulk density of the grains.

In the second stage, mechanical characterization tests (compaction tests and direct shear tests) were performed. A sequence of direct shear test was performed for the soil-ash and soil-ash-lime mixtures.

2.1 Materials

The soil used in this study is a clayey soil (Figure 1) collected in the Experimental Field, located in PUC-Rio, at a depth of approximately 2 m. This material has already been used in many previous works.

Mixtures with 15% and 30% of fly ash (Figure 2) were tested in order to determine the "optimal content" of this material It is worth mentioning that these contents were defined based on the analysis of previous works which used the same ash.

The lime content used was arbitrated at 3%, replacing the dry weight of the ash. Table 1 shows the contents of each material used in this research.

Figure 1: Clayey soil used in this research.

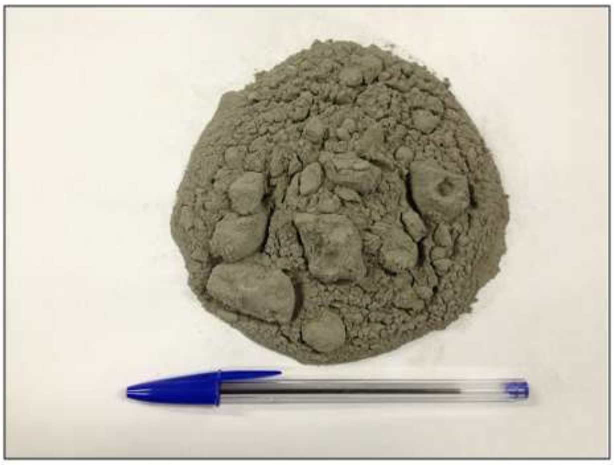

Figure 2: Fly ash used in this research.

Table 1. Contents and symbols for materials.

Material	*Soil (%)*	*Fly ash (%)*	*Lime (3%)*	*Symbol*
Clay soil	100	-	-	CS
Fly ash	-	100	-	FA
Mixture 1	70	30	-	CS70FA30
Mixture 2	85	15	-	CS85FA15
Mixture 3	70	27	3	CS70FA27L3
Mixture 4	85	12	3	CS85FA12L3

2.2 Methods and test procedures

2.2.1 Physical characterization tests

Physical characterization tests were performed in order to determine the properties of the soil and the mixtures, and involved particle size analysis, determination of bulk density of grains and of limits. All these tests were performed at the Laboratory of Geotechnics and Environment at PUC-Rio, and followed the methodologies prescribed in the rules below:

- NBR 6457/1986 - Samples of Soils - Preparation for compaction tests and characterization;
- NBR 7181/1984 - Particle size analysis;
- NBR 6508/1984 - Determination of bulk density of the grains;
-NBR 6459 (1984) – Soil – Determination of the liquid limit;
-NBR 7180 (1984) – Soil – Determination of the plasticity limit.

2.2.2 Mechanical characterization tests

Compaction tests and direct shear tests were performed. Compaction tests were performed on samples with the pure soil and the mixtures containing 12%, 15%, 27% and 30% of fly ash, in order to determine the compaction optimum moisture and the corresponding maximum dry specific weight of each one. These tests followed the methodologies of NBR 7182 (1986), using the Proctor Normal compaction energy and with material reuse.

Direct shear tests were performed for the pure soil and the corresponding mixtures, in order to determine the shear strength by obtaining the cohesion and friction angle parameters, and the procedures for its execution are described in ASTM D 3080 (2004).

For the preparation of samples, a cylindrical specimen was compacted into the Normal Proctor energy with optimum moisture and maximum dry specific weight obtained by compaction tests. Then, 3 specimens were prepared for the direct shear test.

Tests were carried out under controlled deformation and normal stresses of 50, 200 and 300 kPa. Through the maximum shear stress x horizontal displacement graphic, the failure envelopes and the shear strength parameters were determined. Figure 3 illustrates the direct shear equipment used in this research.

Figure 3: Equipment used for the tests.

3 RESULTS

3.1 Physical characterization tests

3.1.1 Bulk density of grains

Results are shown in Table 2, where it can be noticed a reduction of values with the increase of the ash contents.

Lopes (2011) used the same ash in her research, finding for this parameter a value of 2,105. According to Ubaldo (2005), he obtained a value of 2,090 for the same material, collected in the same place. Although the values obtained by these two authors are very similar, the slight difference between them can have occurred because of factors as the chemical composition of the coal.

Table 2. Bulk density of grains for the pure soil and mixtures.

Material/mixture	*G*
CS	2,720
CS85/FA12/L3	2,665
CS70/FA27/L3	2,587
CS85/FA15	2,651
CS70/FA30	2,566
FA	2,147

3.1.2 Grain size analysis

The grain size curves of the clayey soil and their mixtures with fly ash were obtained (Figure 4). It can be observed that the fly ash has an expressive content of thin material, corresponding to the silt. According to the SUCS System, it is classified as a low plasticity silt (ML). Rohde et al (2006) found the same classification for this ash, which is the typical classification of fly ashes from thermoelectric power plants in south of Brazil.

Besides, the mixtures have a grain size, which is intermediate between the pure materials. For the mixture with a higher ash content, the silt fraction tend to increase, while the clay content tends to reduce.

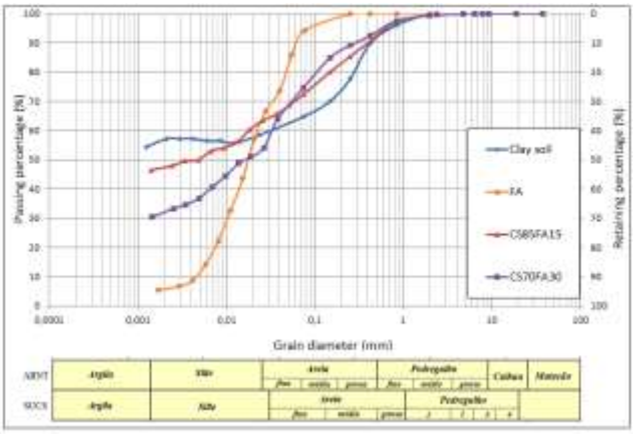

Figure 4: Grain size curves of the clayey soil, the fly ash and their mixtures.

3.1.3 Atterberg limits

The results of limits tests were 53% and 39% for the liquid and plastic limits, respectively. According to the Unified Soil Classification System (USCS), standardized by ASTM D 2487 (1983), the clayey soil is classified as CH, corresponding to a medium plasticity sandy clay.

3.2 Mechanical characterization tests

3.2.1 Compaction tests

Table 3 presents the results of the compaction tests. It can be observed a reduction of the dry specific mass and the optimum moisture content as the ash content rises.

Table 3. Results of standard compaction tests.

Material/Mixture	Water content (%)	Specific dried weight (g/cm³)
CS	26,3	1,55
CS85/FA15	24	1,55
CS70/FA30	23,5	1,5
CS85/FA12/L3	24	1,55
CS70/FA27/L3	25,5	1,49
FA	22,8	1,925

3.2.2 Direct shear tests

The behavior of shear stress versus horizontal displacement for the clayey soil and their mixtures with 15% and 30% of fly ash is shown in Figure 5. The same behavior for the mixtures with lime is shown in Figure 6.

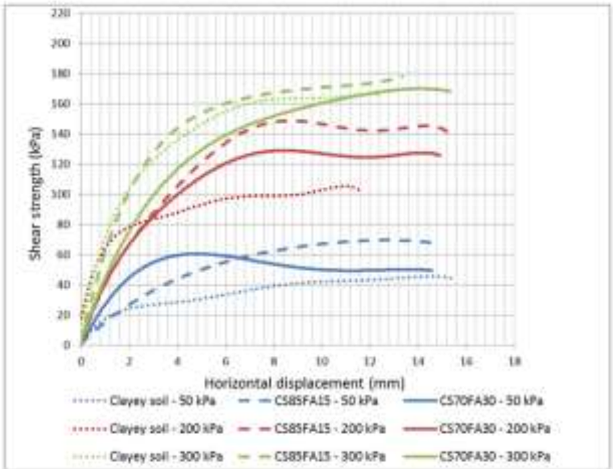

Figure 5: Shear stress x horizontal displacement curves of the clayey soil and their mixtures with fly ash.

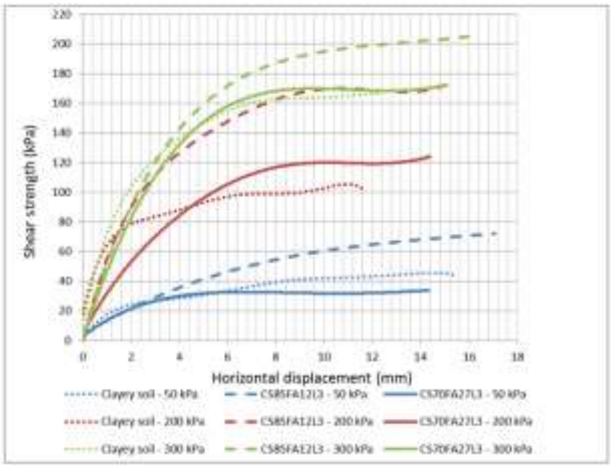

Figure 6: Shear stress x horizontal displacement curves of the clayey soil and their mixtures with fly ash and lime.

In general, the mixture with 15% of ash and the corresponding mixture with lime (CS70FA12L3) presented a better behavior under low and high stress values, which can be explained for a higher cohesion between the particles of these mixtures.

The failure envelopes were obtained considering a displacement of 12 mm, when it is observed that the shear stress becomes constant. Figures 7 and 8 present the strength envelopes for the mixtures without and with lime, respectively. The influence of lime addition on the mixtures can be observed through the Figures 9 and 10.

Concerning the influence of the ash content on these mixtures, it can be noticed that under lime absence conditions, mixtures present a better behavior than the pure soil, mainly the mixture CS85FA15, which presents a considerable increase on cohesion, due to the development of pozolanic reactions. In the lime presence, the mixture CS85FA12L3 obtained the best shear strength parameters, indicating that 12% of ash is supposed to be the "optimum content" to be used in mixtures with this soil, even though it presents the lowest ash content.

Regarding the influence of lime addition on the mixtures with fly ash and clayey soil, even if the mixture CS85FA15 has presented the biggest cohesion, the mixture with lime presents a better behavior, which can be explained by the reactions between ash, lime and the soil. Table 4 summarizes the shear strength parameters of the pure soil and their mixtures with ash and lime.

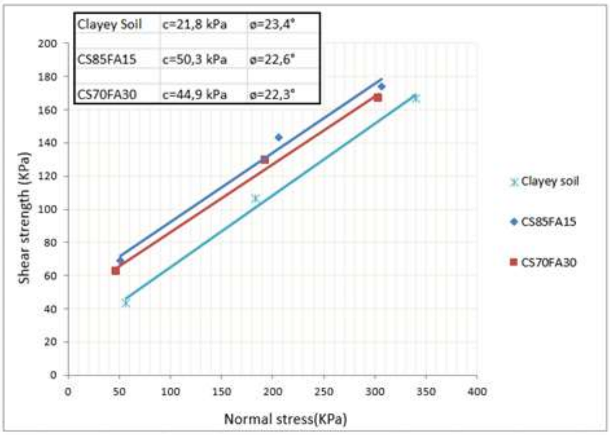

Figure 7: Influence of the fly ash content for the mixtures CS85FA15 and CS70FA30.

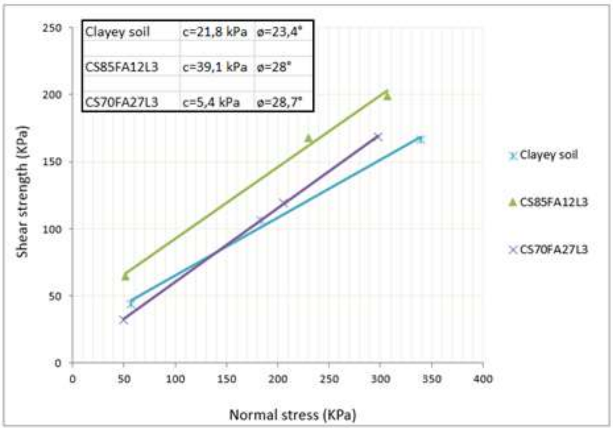

Figure 8: Influence of the fly ash content for the mixtures CS85FA12L3 and CS70FA27L3.

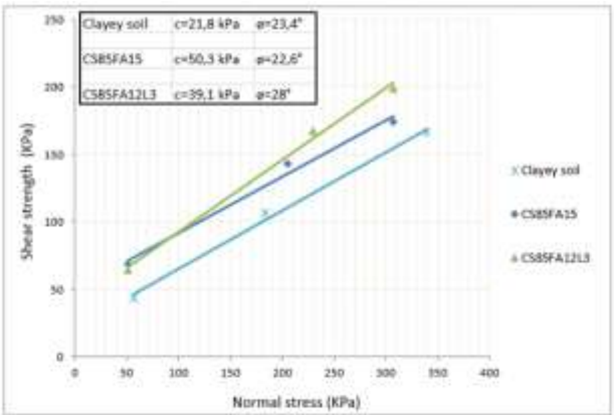

Figure 9: Lime influence for the mixtures CS85FA15 and CS70FA12L3.

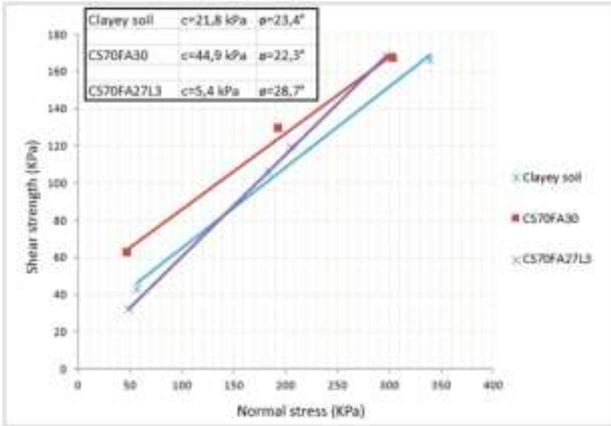

Figure 10: Lime influence for the mixtures CS70FA30 and CS70FA27L3.

Table 4: Shear strength parameters of the materials.

Material/Parameters	c (kPa)	ø (degrees)
CS	21,8	23,4
CS85/FA15	50,3	22,6
CS70/FA30	44,9	22,3
CS85/FA12/L3	39,1	28
CS70/FA27/L3	5,4	28,7

3 CONCLUSIONS

In general, the behavior of the mixtures was superior to the pure soil one, mainly the mixture with 12 % of ash, which provided to the soil an increase of both the strength parameters, that is, cohesion and friction angle. Despite the mixtures without lime also presented good strength parameters, the mixture CS85FA12L3 was the one that obtained the best results, what can be explained by the cementitious reactions between the lime and the other components of the mixture.

However, it is worth noting that even in the presence of lime, this increase of reactions was not observed in the mixture CS70FA27L3, which may have occurred because of the low lime content added to the mixture, in comparison with large ash contents. Thus, it can be concluded that it is not necessary to add large amounts of ash to this soil in order to obtain better failure envelopes.

Through the results obtained in this research, it is possible to enable the use of this fly ash for application in geotechnical works, as landfills, providing an environmentally correct disposal of this waste and giving it a noblest destination.

4 ACKNOWLEDGEMENTS

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